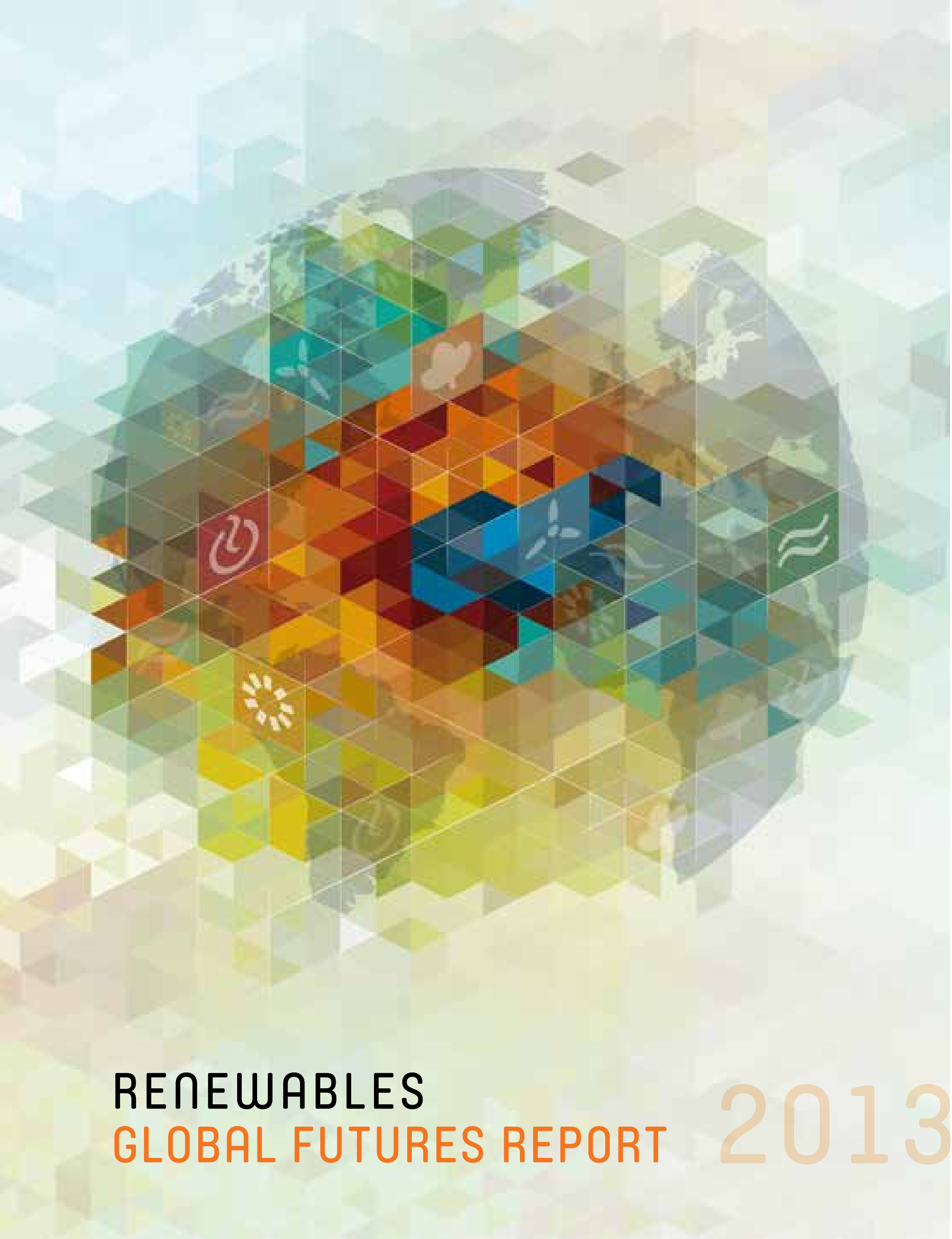
REN21 Renewable Energy Policy Network for the 21st Century



RENEWABLES
GLOBAL FUTURES REPORT 2013

REN21 – Renewable Energy Policy Network for the 21st Century

REN21 is a global multi-stakeholder network that connects a wide range of key actors from governments, international organizations, industry associations, science and academia as well as civil society to facilitate knowledge exchange, policy development, and joint action towards a rapid global transition to renewable energy. REN21 promotes renewable energy to meet the needs of both industrialized and developing countries that are driven by climate change, energy security, economic development, and poverty alleviation.

REN21 is committed to providing policy-relevant information and research-based analysis on renewable energy to decision makers from both public and private sectors to catalyze policy change. REN21 also provides a platform for interconnection between multi-stakeholder actors working in the renewable energy field, and works to bridge existing gaps to increase the deployment of renewable energy worldwide.

REN21 was launched in June 2005 as a result of discussion held the previous year at the International Conference for Renewable Energies in Bonn, Germany, and has evolved since then into an inclusive multi-stakeholder network with the mission to advance renewable energy worldwide. REN21 is guided by a distinguished Steering Committee of experts engaged in policy, business, advocacy, research, and economic development. For more information, see http://www.ren21.net.

ISEP – Institute for Sustainable Energy Policies

The Institute for Sustainable Energy Policies (ISEP) is an independent, non-profit research organization located in Tokyo, Japan. ISEP was founded in 2000, and since then has become a strong voice and source of innovative research in Japan and worldwide. At its core, ISEP aims to provide the resources and services necessary for policymaking towards a sustainable energy future. Three focal areas are promotion of renewable energy, improvement of energy efficiency, and restructuring energy markets.

In Japan, ISEP engages in a wide range of programs and activities, including policy recommendations on renewable energy and energy efficiency to the Japanese government, guidance and advice to local municipalities, and public events, conferences, and symposia. In addition, ISEP facilitates community-level renewable energy projects through a "Citizens' Fund" and through a cooperating program with the Japanese Ministry of Environment.

Internationally, ISEP has worked with many organizations in Europe, the United States, and Asia to promote knowledge exchange and foster international collaboration related to sustainable energy policies. ISEP has played an active and contributing role with REN21 since its inception in 2005, and co-produced this *Renewables Global Futures Report* in a unique partnership with REN21 during 2011–2012.

FOREWORD

When REN21 was founded in 2004, the future of renewable energy looked very different than it does today. No one imagined then that 70% of new power capacity added in Europe would be renewable, which is what happened in 2011. No one imagined that tens of millions of homes and businesses in several countries would add solar power on their rooftops so rapidly. No one imagined that China would go from minor player to global leader in just six years, or that developing countries as a group would become home to more than one-third of global wind power capacity. And many scenario projections made in the years prior to 2004 showed levels of renewables by 2020 that were already exceeded by 2010.

The evolution of policies and markets for renewable energy has been absolutely remarkable over the past decade. The annual REN21 *Renewables Global Status Report* provides evidence of this rapid development. In 2011, over $260 billion was invested in new renewable energy capacity, more than for fossil fuel and nuclear power combined. This is up from just $40 billion in 2004. In 2011, some 120 countries around the world had policies to support renewable energy; most are now developing countries. In 2004, countries with support policies numbered about 50, then mostly developed countries. In 2011, the annual solar photovoltaic (PV) market was 30-fold greater than in 2004. And in many other respects, policies combined with technology cost reductions have driven markets in unprecedented ways.

With the trends of the past 10 years behind us, and with the dynamic nature of renewable energy markets, technologies, and cost reductions continuing, we can look to the future with a very different perspective than in 2004.

The purpose of this report is to show the range of credible possibilities for the future of renewable energy. It does not present just one vision of the future, but rather a full and objective range of visions, based on the collective and contemporary thinking of many.

This report combines a unique array of interviews with 170 experts from around the world, along with over 50 recently published scenarios. These interviews and scenarios are blended into a "mosaic" of thinking about the future. Persons interviewed included industry and finance experts, CEOs and business managers, researchers and academics, policymakers and parliamentarians, and public advocates and visionaries, among many others. Views of existing energy companies are also included.

Of course, the economic difficulties reaching around the globe at the end of 2012 will profoundly affect the future as well, in ways that we cannot foresee. Yet in focusing on the long term, 2020 through 2050, this report encourages us to look at the possibilities that lie well beyond these difficulties.

The REN21 *Renewables Global Futures Report* is a sister publication to the annual REN21 *Renewables Global Status Report*. By design, the *Status Report* covers only the present situation worldwide, not projections about the future. So the two reports are very complementary. *Futures Report* author Eric Martinot served as lead author for the *Status Report* from 2005 to 2010, and is well grounded in the present situation. He uses present status as a starting point for visions of the future, creating an innovative blend of present and future.

REN21 intends to use this report to facilitate dialogues and discussions about the future of renewable energy among a wide range of stakeholders, and especially with a view to future policymaking. Although the report is careful not to provide policy recommendations, as that was not its purpose, it offers much insight to those formulating such recommendations. A series of "Great Debates" located throughout the report are a special element, and frame contemporary issues for discussion and understanding.

This report was made possible through a two-year collaboration with the Institute for Sustainable Energy Policies (ISEP) and the enterprising efforts of ISEP executive director Tetsunari Iida. On behalf of the REN21 Steering Committee, I would like to thank both ISEP and the German government for major financial support, along with the support of project co-sponsors. And a heartfelt thanks to report author Eric Martinot for his hard work over the past two years to provide such a remarkable synthesis of the world's thinking on the future of renewables.

The dedicated staff of the REN21 Secretariat, under the leadership of Christine Lins, supported the project, especially policy advisor Lily Riahi, who assisted in all aspects from initial concepts to final research. And finally, my sincere appreciation goes to all the interviewees, contributors, and reviewers for giving of their time and expertise.

Anyone who reads this report cannot help but have her/his own thinking affected by the multitude of viewpoints presented here. And they will likely discover new, imaginative, and forward-looking ways to think about the future. I encourage everyone to share those views and to engage with others in forging a sustainable and renewable energy future.

Mohamed El-Ashry

REN21 Chairman
January 2013

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(*) These items are available online at http://www.ren21.net/gfr

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Report Author and Research Director

Eric Martinot (Institute for Sustainable Energy Policies)

Assistant to the Research Director

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REN21 Research

Fabiani Appavou and Kanika Chawla (REN21 Secretariat)

ISEP Research

Romain Zissler (ISEP and Paris-Dauphine University); Fuyuko Ujiie, Noriaki Yamashita, and Shota Furuya (ISEP); Mark Morrison and Lauryn May (Columbia University); Silvia Tanga (Tufts University)

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Editing, Design and Layout

Lisa Mastny, editor
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Original Inspiration

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Consulting Reviewers

Morgan Bazilian, Gonzalo Bravo, Dolf Gielen, Rainer Hinrichs-Rahlwes, Hans-Jörgen Koch, Thomas Johansson, Christine Lins, Amory Lovins, Hironao Matsubara, Miquel Muñoz, Wilson Rickerson, Janet Sawin, Martin Schöpe, and Sven Teske.

Reviewers

Adnan Amin, Mohit Anand, Doug Arent, Alan AtKisson, Roger Ballentine, Pedro Ballesteros Torres, Ron Benioff, Ralph Chapman, Mike Cleary, Suani Teixeira Coelho, Luis Crespo, David de Jager, Mike Eckhart, Jose Etcheverry, Paolo Frankl, Lisa Frantzis, Herbert Girardet, Chris Greacen, Renata Grisoli, Marie-Christine Gröne, Stefan Gsänger, Alexander Haack, Karin Haara, Winfried Hoffman, Peter Jørgensen, Vinod Kala, Tarun Kapoor, Ansgar Kiene, Christian Kjaer, Tracy Lane, Li Junfeng, Franz Marré, Angus McCrone, Pradeep Monga, Fred Morse, Kevin Nassiep, Wolfgang Palz, Walt Patterson, Terry Penny, Emiliano Perezagua Gil, Brian Perusse, Klause-Peter Pischke, Michaela Pulkert, Mark Radka, Anjan Ray, Keywan Riahi, Dima Rifai, Steve Sawyer, Annette Schou, Stefan Schurig, Henriette Schweizerhof, Ralph Sims, Gauri Singh, Scott Sklar, Pil-Bae Song and colleagues, Virginia Sonntag-O'Brien, Leena Srivastava, V Subramanian, Wim Turkenburg, Maryke van Staden, and Carl Weinberg.

PREFACE

What is our current thinking about the future of renewable energy? What is the range of credible possibilities for that future? As suggested by the cover, this report is a "mosaic" of insight into these questions. Most significantly, the report does not provide one preferred vision or position, but rather portrays a range of possibilities and thinking on the subject—compiled into a simple overview. The report is intended as a tool for education and discussion, and as an objective framework for thinking about the future.

To answer these questions, the report author and researchers compiled information from a wide variety of sources. These included: (1) interviews with some 170 industry experts, technology experts, executives, researchers, visionaries, policymakers, finance experts, and utility managers in 15 countries; (2) interviews with local city officials and stakeholders in more than 20 cities; (3) discussion workshops in three developing countries; (4) more than 50 recently published scenarios by credible international organizations, energy companies, and research institutes, covering global, regional, and national long-term futures to 2020–2050; (5) all existing government policy targets for future shares or amounts of renewable energy to 2020–2050, including regional, national, state, provincial, and municipal targets; (6) long-term action plans by local/city governments; (7) corporate annual reports and other publications and communications by major energy companies; and (8) a variety of published articles and references, including the REN21 *Renewables 2012 Global Status Report.*

This report is not intended to be scientific. It does not convey objective surveys or statistical samples. And it does not offer recommendations. It also is not intended as journalism, although it does make extensive use of interviews. Rather, the report is intended to provide an overall mosaic of the range of contemporary thinking.

For those unfamiliar with some of the energy terminology and concepts found in this report, an online supplement is available, "Glossary and Basic Energy Concepts." Full references for published sources used, along with a list of selected readings on renewable energy technologies, economics, and policy, are available in the online supplement, "Bibliography and Topical Readings."

Brevity was a key consideration in writing the report. Therefore, the complexities and details of many subjects cannot be covered. Many explanatory notes and references to other publications are contained in the endnotes. Many other excellent publications cover renewable energy; of particular note are four recent works, together comprising more than 4,000 pages of information: IPCC *Special Report on Renewable Energy* (2011), GEA *Global Energy Assessment* (2012), and IEA *Energy Technology Perspectives* (2012) and *World Energy Outlook* (2012).

This report presents data in four main ways:

1. Opinions from people interviewed are presented as coming from "industry experts," "finance experts," "visionaries," and other such generic titles. All interviewees were granted confidentiality to allow a frank exchange of views. The point of the interviews was not to ascribe credibility to the specific opinions offered, which would require attribution, but rather to collect as comprehensive a picture as possible, and as varied as possible, into one overall description. As such, the sources of the individual inputs are less important than the overall mosaic of information conveyed. Responsibility for the credibility and content of the report rests solely with the author. *(See Annex 1 for details and a complete list of interviewee names and affiliations.)*

2. Scenario results are presented with reference to the organization authoring the scenario. A full list of scenarios referenced, along with 2–4 page "profile" summaries of each scenario, are provided in the online supplemental report, "Scenario Profiles Report." *(See Annex 2 for a list of all scenarios used in this report. See Annex 3 for more discussion of scenarios and variables influencing renewables futures.)*

3. Additional views of utility companies, oil and gas companies, and automakers are included with quotes from specific companies based on public sources such as corporate reports. (Interviews with a large number of these companies were not possible.)

4. Views of developing country experts and companies are sometimes provided in generic form with reference just to country name, reflecting input from discussion workshops and other published materials. Interviews were conducted in only a limited number of developing countries: China, India, Morocco, and South Africa.

Source information was compiled into a series of 30 "discussion topics" that break down renewable energy futures into specific areas of subject matter. These topics are cross-referenced in endnotes throughout the report, and provide additional information, discussion/debate points, and references for the interested reader. These topics are available in the online supplement, "Topical Discussion Report." *(See further links to topics in Annex 4.)*

This report portrays a number of "Great Debates" throughout the text. Such "debates" emerged from expert interviews and published material, when opinions diverged significantly and pointed to areas of controversy. In addition to text boxes, 30 such debates are summarized in Annex 4 and are cross-referenced with topics in the online supplement, "Topical Discussion Report."

All information presented in this report is attributable to sources other than the author himself, although of course the personal views of the author, and especially his optimism for the future of renewable energy, will inevitably color the results. However, the author took care to be objective, and to separate his own views, which are presented uniquely in the "Epilogue: Speaking Personally" at the end of this report.

Eric Martinot

Report Author
Tokyo, Japan
January 2013

EXECUTIVE SUMMARY

The future of renewable energy is fundamentally a choice, not a foregone conclusion given technology and economic trends. The context for that choice includes the present situation—high levels of current investment and more than a decade of dramatic market growth, proliferation of support policies, and cost reductions for renewable energy. The context also involves a growing diversity of motivations, such as energy security, climate and environment, industrial and economic development, financial risk mitigation, flexibility, and resilience.

Cost comparisons between renewables, fossil fuels, and nuclear, and the role of future policy for all technologies are of course key elements of the context for future energy choices. However, choices also depend on how cost comparisons are made, and on changing paradigms for energy systems and services, mobility, and buildings.

This report paints a mosaic of the possibilities ahead, grounded in the opinions of 170 leading experts and the projections of 50 recently published scenarios.

Many existing energy companies, especially those with a vested interest in the status quo, project conservative future shares of renewable energy and emphasize cost hurdles and variability challenges. These companies continue to believe that the future will be dominated by fossil fuels. Such "conservative" outlooks project the share of renewable energy in global energy supply remaining below 20% in the future, not much higher than today.

"Moderate" outlooks by experts and scenarios project renewable energy shares of 30–45% by 2050, including electricity, heating/cooling, and transport. In such outlooks, renewable electricity is integrated into power grids at high shares (i.e., 50–80%) using a variety of options such as demand-response, balancing with natural gas, new market structures for balancing services, and some energy storage. Transport employs modest but growing amounts of biofuels, along with electric vehicles and plug-in hybrids, partly charged from renewable electricity, and some modal shifts of freight to more-electric options.

"High renewables" outlooks project 50–95% energy shares by 2050. Such shares were cited by many experts, and are projected in several scenarios, typically those of public advocacy organizations, but also in recent scenarios of the International Energy Agency (IEA), which has traditionally published more conservative projections. High-renewables projections typically show some combination of significant and continued renewable energy cost reductions, along with aggressive and long-term support policies for renewable energy, and major transformations in energy markets and infrastructure.

"High renewables" projections show up to 100% shares of just renewable electricity alone (not counting heating or transport). These high shares come from a portfolio of renewable technologies, along with balancing and grid-strengthening measures, energy storage, and evolved electricity market rules. In transport, large shares of biofuels and electric vehicles are projected, even for freight transport, such as biodiesel and electric trucks and electric rail. The use of electric vehicles for grid balancing purposes is enhanced through smart-grid interactions and "vehicle-to-grid" (V2G) and "vehicle-to-home" (V2H) concepts. Buildings are designed, constructed, and heated/cooled in a different paradigm. The use of renewables-integrated building materials becomes ubiquitous, "low energy" or "passive" buildings with high energy efficiency and low heating requirements become the standard, and many forms of renewable heating and cooling are used, including solar thermal, geothermal, and biomass.

One common attribute of many high-renewables scenarios is a future carbon emissions constraint. Such high-renewables carbon-constrained scenarios typically model aggressive energy efficiency improvements, sometimes model carbon capture and storage for fossil fuels, and typically model little or no nuclear power. Such scenarios may also include some type of carbon price incorporated into energy markets.

According to some views, the challenges of integrating renewable energy into utility power grids, buildings, transport, and industry are not fundamentally a technical issue—although a variety of technical issues certainly need to be worked out. Rather, the challenges relate to practices, policies, institutions, business models, finance, aggregation, and cross-sectoral linkages, along with changes in professional practices, education and training.

The finance challenge is key. Many new sources of finance are possible in the future, such as insurance funds, pension funds, and sovereign wealth funds, along with new mechanisms for financial risk mitigation. And many new business models are possible for local energy services, utility services, transport, community and cooperative ownership, and rural energy services.

Some projections of annual investment in renewables by 2020 are US$400–500 billion, up from $260 billion in 2011. Projections of average annual investment in the coming decades range between $300 billion and $1 trillion. Public support for renewables, in both direct and indirect forms, estimated by the IEA at about $90 billion in 2011, is also projected to increase through the 2020s in a growing number of countries, although it is also projected to remain much lower than public support for fossil fuels.

Strong visions for the future of renewable energy are proliferating at the local/city level. Many regions, cities, and towns around the world are planning renewable energy futures. In addition to a variety of planning approaches, specific support policies for renewable energy can be found in hundreds of cities. Such policies can include targets, subsidies, public investment, innovative financing, bulk procurement, green power purchasing, building codes, transport fuel mandates, municipal utility regulation, and many others.

Local governments and stakeholders are creating new approaches to urban planning that incorporate renewables, including low-energy buildings, heating and cooling infrastructure, district heating networks, "smart" approaches to both electricity and heat, and innovations in urban mobility that integrate renewables. Growing numbers of regions, cities, towns, and communities are envisioning "100%" renewable energy futures for themselves in the long term.

At the national level, at least 30 countries around the world already have shares of renewable energy above 20%. Some 120 countries have various types of policy targets for long-term shares of renewable energy, including a binding 20% target for the European Union by 2020. Some countries have long-term policy targets that will put them squarely in the "high renewables" domain by 2030 or 2050, such as Denmark (100%) and Germany (60%). Outside of Europe, a diverse group of at least 20 other countries target energy shares in the 2020–2030 time frame that range from 10% to 50%, including Algeria, China, Indonesia, Jamaica, Jordan, Madagascar, Mali, Mauritius, Samoa, Senegal, South Africa, Thailand, Turkey, Ukraine, and Vietnam.

National renewable energy markets are projected to grow strongly in the coming decade and beyond, as shown by current policies and targets, and by scenario and expert projections. Snapshots of markets and policies in Europe, the United States, Japan, China, and India show many emerging and possible developments. For example, Europe's policy targets, national policies, and EU-level directives are projected to accelerate heating and transport from renewables through 2020, as well as continued growth in renewable electricity. In the United States, state-level policies imply continued markets even with national policy uncertainty. China's wind power market has become a world leader, and projections show the continuation of trends, along with growing markets for solar hot water and solar photovoltaic (PV). India has ambitious targets for solar power, both grid-tied and off-grid, along with aggressive projections for wind power and rural use of biomass.

Projected markets in a much greater number of developing countries on a bigger scale will create a diverse geographic base for renewables. Beyond existing "BRICS" leaders Brazil, China, and India, experts believed that expansion will accelerate through 2020, particularly in leading developing countries such as Argentina, Chile, Colombia, Egypt, Ghana, Indonesia, Jordan, Kenya, Mexico, Nigeria, the Philippines, South Africa, and Thailand. Beyond 2020, renewables markets will become even broader-based in a larger number of countries, as developing countries take increasing leadership. Unique opportunities for renewable energy exist in future development, including new electric power infrastructure, diesel generator replacement, new settlements, new power-market rules, regional cooperation frameworks, local manufacturing, and rural (off-grid) energy services.

With the dramatic growth of renewable energy markets over the past decade, along with manufacturing economies of scale, have come dramatic technology improvements and cost reductions. Recent growth rates reflect a "take-off" phase that has seen many renewable energy technologies become mainstream investments and undergo dramatic advances in performance, cost, and scale. Hydropower, geothermal, and biomass power and heat are the most mature, and most projections show continued growth that reflects their mature status.

Among other renewables, onshore wind power is closest to commercial maturity, with many examples of unsubsidized wind power already competitive with conventional energy (in specific locations), and many projections of further technology and cost evolution. Offshore wind power is more expensive than onshore, but has large (although uncertain) potential for cost reductions, not just for turbines, but also for logistics and long-term operations and maintenance costs.

Solar PV has seen dramatic cost reductions in recent years. Projections show continued cost reductions, many possible technology advances, and full competitiveness with retail electricity prices without subsidies—so-called "grid parity"—occurring in many jurisdictions soon (and already, according to some), and in many more places around the world by 2020. Solar thermal power (CSP) still has a large cost-reduction potential, with future opportunities for bulk power supply, for dedicated applications such as industrial heat supply and desalination, and for power grid balancing using multi-hour and multi-day embedded heat storage.

While debates about the sustainability of so-called "first generation" biofuels continue, many projections show large future markets for "advanced" biofuels from agricultural and forestry wastes, and from crops grown on marginal or otherwise-unproductive lands. A wide variety of new approaches to using biomass is also projected, such as growing international commodity markets for wood pellets and bio-heating oil, greater use of biogas in a variety of applications, new types of "biorefineries" in agriculture and forestry, and greater use of biomass in heat supply.

This report suggests that future policies will evolve over time and will remain an essential part of renewable energy futures. Experts pointed to a range of future policies to support renewable heating and cooling in buildings. They also pointed to new policies for electric power systems integration, including market rules for balancing services, demand response, net metering, consolidation of grid balancing regions, transmission planning and access, and others. Experts also pointed to many other policies for transport, industry, and rural energy that will be key to future integration of renewables. And finance experts pointed to policies that adopt risk-return perspectives in supporting energy investments, rather than traditional cost-benefit perspectives.

"Transformational change" is implied by many of the scenarios and expert opinions presented in this report. Experts made clear that such change is not just about technology and infrastructure, but about models of social, institutional, business, and policy change. Transformational change is implied by future needs for technical and institutional restructuring of power systems, by much-less-homogeneous transport systems with a multitude of fuel types and vehicle types powered by renewables, and by new building design and construction practices and renewables-integrated building materials. Ultimately, transformation means more than just renewables fitting into existing energy systems, but rather all energy technologies evolving together, with different roles, into transformed energy systems.

INTRODUCTION

Renewable energy has been in a multi-decade process of becoming "mainstreamed" among businesses, governments, consumers, and utilities. In interviews, industry experts, CEOs, policymakers, and many others consistently pointed to this ongoing process, some proclaiming that "mainstreaming" was now achieved, especially considering that the majority of annual global investment in power generation was now flowing to renewable energy instead of fossil fuels and nuclear.[1]

The growth of renewable energy worldwide began in the 1990s and accelerated greatly in the 2000s. By 2011, the renewable energy industry was investing $260 billion annually. Many of those interviewed credited this growth to the proliferation of supportive government policies, to rising costs of conventional energy, and to dramatic reductions in renewable energy technology costs and economies of scale in manufacturing. These experts emphasized that policies at the national, state, provincial, and local levels have played a major role in driving renewable energy markets, investments, and industry growth over the past two decades.[2]

Given the dynamic nature of this growth over the past decade, many past projections of renewable energy have already fallen short. For example, the International Energy Agency (IEA) in 2000 projected 34 gigawatts (GW) of wind power globally by 2010, while the actual level reached was 200 GW. The World Bank in 1996 projected 9 GW of wind power and 0.5 GW of solar PV in China by 2020, while the actual levels reached in 2011, nine years early, were 62 GW of wind power and 3 GW of solar PV. The history of energy scenarios is full of similar projections for renewable energy that proved too low by a factor of 10, or were achieved a decade earlier than expected.[3]

Many of those interviewed pointed to the increasingly diverse nature of motivations for renewables as part of the mainstreaming process. Cited motivations that will continue to drive renewable energy development in the future included security of energy supply, autonomy, resilience, jobs, industrial development, financial profit, portfolio risk mitigation, price risks of fossil fuels, rural energy access, climate change, environmental sustainability, and nuclear accidents and wastes.[4]

When thinking about the future of renewable energy, experts spoke of the broader context and debates about the future of energy systems overall. This meant thinking about cost comparisons, technology choices, financial risks and returns, future fuel prices, total energy demand, levels of energy efficiency achievable, environmental costs, social acceptance, and the overall shape and characteristics of future energy systems.[5]

Many experts argued that some forms of renewable energy are competitive today with conventional energy (fossil fuels and nuclear) in many places, even in the absence of policy support. Or, that renewables would already be competitive if "costs" were defined and counted properly, at both technology and system levels.[6] *(For more on these issues, see "Great Debate 1" on page 12, Box 2 on page 16, costs discussions in Chapter 6, and Annexes 3 and 4.)*

Experts also made clear that support policies and continued cost reductions remain central. Many of the "high-renewables" scenarios presented in this report model strong levels of policy support in the future together with continued cost reductions. Experts asserted that policymakers will confront a wide range of choices and considerations in the future, in terms of continuing, updating, and retiring existing renewable energy policies, and creating new ones.[7]

As renewables become more integrated with existing infrastructure and markets, policymakers will confront the need for new policies to achieve these various forms of integration, as noted throughout this report. Said one industry expert, "the long-term trajectory of renewables certainly depends on what happens with policies during the next ten years, and policy continuity beyond that."[8] *(See also "Great Debate 2" on page 13.)*

Yet many experts also believed that technology and cost are no longer the fundamental issue. Many scenarios referenced in this report portray high-renewables futures using only currently existing technologies. Some scenarios also show total energy system cost to be roughly equal for renewables-centric and fossil fuel-centric cases. Thus, experts made clear that renewable energy futures also depend on finance, risk-return profiles, business models, investment lifetimes, infrastructure integration, social and environmental factors, and a fundamental rethinking of how energy systems are designed, operated, and financed.[9]

In particular, the theme of "integration" was raised consistently during interviews. "Integration is in our face over the next five to ten years," said one expert, referring to integration of renewables in utility power grids, buildings, transport, and industry. "Integration is not just about hardware, but also about how power markets function," said another.[10] *(See Chapters 2 and 3.)*

Some experts emphasized the "paradigm-changing" nature of the energy systems transition ahead (actually a "transformation" in the words of some; see also the report's Conclusion). "Technically speaking, we are moving from landlines to cell phones," offered one expert as an analogy. And along with this transition, "We will see a lot of new players coming in, with unknown dynamics and unknown relationships." Another said: "We can be almost sure that the future will not be a linear growth line from today."

One senior electric utility manager put it this way: "What's happening is that society is changing the design criteria for energy systems." This manager noted that, according to the old criteria, conventional technologies fit centralized, inflexible, and commodity-like systems. But according to new criteria, system designers will think in terms of flexibility, modularity, multiple levels of service and reliability, and a balance of centralized and decentralized, with energy becoming more service-like and less commodity-like.[11]

Experts also emphasized the long time frames associated with energy system infrastructure and investment. For example, a typical coal power plant might last for 40 years. So high shares of renewables in the longer term imply less fossil fuel construction even in the shorter term. Some developing country experts were concerned that the coming years will see large amounts of conventional generation such as coal power added to utility grids in developing countries. Such "lock-in" of conventional generation could pre-empt larger future shares of renewables, some said. In achieving high-renewables futures, some scenarios model an immediate slowdown in construction of conventional power plants before 2020, particularly in developing countries.[12]

This report brings together industry and expert opinions with published scenarios to map out the range of possibilities for renewable energy futures, blended into a unique "mosaic" of viewpoints. The following chapters explain and explore those possibilities, from the conventional-rooted to the highest projections of renewable energy and transformational change.

The report follows two main lines of thought. Firstly, according to a credible range of contemporary thinking, *how much renewable energy will exist in the future?* This question is addressed in Chapter 1 and throughout the report.

Secondly, according to contemporary thinking, including interviews with 170 experts, *what do renewable energy futures look like?* In the following chapters, experts and scenarios paint views of the future that reflect the following possibilities, choices, and actions:

- The challenges of integrating renewables into electric power grids, buildings, transport, and industry are met by a variety of stakeholders such as utilities, builders, planners, manufacturers, energy-service businesses, and many others. *(See Chapter 2.)*
- Profitable ways to invest in renewable energy from an expanding range of sources using a wide variety of business models are pursued by energy consumers, energy companies, investors, banks, funds, intermediaries, and other types of businesses. *(See Chapter 3.)*
- At the local level, possibilities for urban planning, built infrastructure, and transport systems that incorporate renewable energy are acted upon by local governments, community groups, residents, businesses, and many other types of local stakeholders. *(See Chapter 4.)*
- At the national (and EU) level, renewable energy markets grow in a diversifying and greater number of countries around the world—driven by supportive renewable energy policies, influenced by policy targets, and supplied by local renewable energy industries. *(See Chapter 5.)*
- Globally, technology performance and capabilities evolve, costs decline, and aggregate global markets grow, through the ongoing work of manufacturers, researchers, project developers, energy companies, and other market players. *(See Chapter 6.)*

Box 1 | Detractors of Renewable Energy and Future Outlooks

Renewable energy has historically had many detractors. "Renewable energy is too expensive," many have said over the years. "Increasing amounts of public subsidies will be required for a long time," many have also said, or its variation, "renewable energy is only developing because there is policy support." And many have considered renewable energy technologies relatively immature and requiring further research.

Such views persist today in the energy industry. For example, ExxonMobil, in its 2012 *Outlook for Energy* to 2040, said, "advances in technology will be necessary to make [renewable] fuels more practical and economic … geothermal and solar will remain relatively expensive." ENI noted, "the technologies presently available only allow for limited production of energy at high prices." And Chevron said, "because of major technical hurdles—such as scalability, performance, and costs—as well as market-based barriers, broader adoption [of renewables] can't happen overnight."

Renewables advocates reply that conventional cost comparisons are unfair for a host of reasons, including existing public subsidies for fossil fuels and nuclear, the failure to properly incorporate future fuel-price risks in comparisons, and the failure to adequately count environmental costs. (See "Great Debate 1" on next page.) They also say that some renewable technologies are already fully competitive, and that for others, policy support will not be necessary in the long run, as rapid evolution in markets, technologies, and costs, driven by past policies, are making more renewable technologies fully competitive more quickly. Most scenario projections of renewable energy show lower renewables costs in the coming decade and beyond. (Some do not, however. ExxonMobil (2012) forecasts that the price of electricity generated from renewables will be higher than the price of conventional electricity even in 2030, with the exception of onshore wind power.) *(See Chapter 6.)*

Another major detraction has been the variability of renewables. Detractors have said that this variability means high costs because of the need for energy storage. "Until better technologies become available for the storage of electricity, wind farms usually require back-up from conventional forms of base-load power generation," said CLP Hong Kong Power. However, many utility experts pointed to a wide range of options to manage the variability of renewable energy that do not require storage. Scenarios also exist that show high shares of renewables using mostly other balancing options. *(See utility power grid integration in Chapter 2.)*

Detractors have also called renewables "too diffuse" to meet the needs of highly concentrated energy uses in modern industrial society. Some have also believed that, "It's only applicable in some countries with good renewable resources or lacking in conventional energy resources." *(See Chapters 1 and 5.)*

The range of contemporary thinking by experts, industry players, published scenarios, and many energy companies themselves, as portrayed throughout this report, is mostly at odds with the above thinking of detractors. Although it was not the purpose of this report to directly refute such viewpoints, one cannot help but see, after reading the entire report, that such viewpoints face diminishing validity in the future.

Source: See Endnote 13 of the report's Introduction.

Great Debate 1 | Is Renewable Energy More Expensive Than Conventional Energy?

In energy scenarios, energy systems are mixes of fossil fuels, renewable energy, and nuclear power, combined with models of future infrastructure (e.g., power grids, buildings, cars, and factories) and levels of future energy demand (accounting for population, economic growth and structure, and energy efficiency). Many other factors enter the picture, such as future fossil fuel prices, interest rates, policies, and carbon prices. Scenarios typically model least-cost energy mixes, some with constraints like future carbon emissions. *(See also Annex 3 and Box 2 on page 16.)*

In scenarios and professional debates alike, renewable energy is often portrayed as "competing" with conventional energy (fossil fuels and nuclear). And historically, debates about renewable energy versus conventional energy have revolved around cost comparisons between individual technologies, or "cost competitiveness." However, experts debated how to make proper cost comparisons. Many noted that it depends on what is counted as "costs." They pointed to three fundamentally different types of comparisons, and posed the question, "What is the right way to make economic decisions and comparisons between competing technology alternatives, such as between renewables and fossil fuels?"

Levelized cost comparisons

Conventional economic comparisons are typically made on the basis of levelized cost (i.e., cents/kilowatt-hour), accounting for direct investment costs, fuel costs, and operating and maintenance costs, as well as the cost of capital (interest rates). However, experts pointed out key deficiencies of the conventional approach, which does not account for some factors, in particular:

- **Fuel and technology subsidies.** Fossil fuel subsidies, direct and indirect, "tilt the playing field" toward fossil fuels and amount to large public expenditures. The IEA WEO (2012) estimates that global subsidies to fossil fuels exceeded US$520 billion in 2011, compared to roughly US$90 billion in policy support for renewable energy. (See Chapter 3.) Some experts called for elimination of fossil fuel subsidies, or justified equivalent subsidies to renewable energy. Experts also pointed to existing public subsidies to nuclear power, both direct and indirect (i.e., accident liability).
- **Environmental costs.** Experts were quick to point out that most environmental costs associated with fossil fuels and nuclear are not included ("internalized") in conventional economic comparisons. Some experts also pointed out that many emissions regulations targeting conventional power plants are an attempt to partly internalize environmental costs, but they questioned whether existing regulations go far enough.
- **Fossil fuel price risk.** Experts voiced arguments about the manner in which the risks of future fossil fuel price swings is calculated and incorporated into economic comparisons (and who bears those risks). Analyses have been done on the "hedging premium" necessary to account for natural gas price volatility and uncertainty; for example, one U.S. expert claimed that between 1 and 3 U.S. cents/kWh should be added to the cost of power from natural gas to account for a hedging premium.

Summing up, one European wind industry expert said, "By 2020, we should see real competition in energy markets for wind power in Europe; by then, investors will be fully exposed to fuel price risk and carbon costs, and existing subsidies for coal, gas, and nuclear will be greatly reduced."

Financial risk-return comparisons

Finance experts pointed to "risk-adjusted spread" as the measure they use to compare alternative investments. This involves the difference between a project's internal rate of return and the cost of capital (interest rates), adjusted for the risks of that specific technology, market, segment, and supplier. Experts noted that this method can provide different results from levelized cost comparisons because of the inclusion of risk. They noted that the risk profiles of conventional fossil fuel plants in many markets have increased in recent years. And several experts spoke of "portfolio" approaches to energy investments that minimize the total risk across an entire portfolio of energy assets, similar to financial portfolio management.

Whole-energy-system comparisons

Some experts emphasized that cost comparisons should be made at the level of whole energy systems, not at the level of individual technologies. For example, they pointed out that "least cost" in an electric power system depends on configuration, market rules, types of generation, operation patterns, load profiles, and other factors. And in projecting costs of transport-sector scenarios, IEA ETP (2012) considers total costs—including vehicles, fuel, and fuel/road infrastructure.

As another example, Lovins/RMI (2011) models four alternative electric power systems: a fossil-fuel-centric system similar to what exists today, a nuclear and clean coal system, a highly distributed system with a high share of renewables, and a high-renewables and high-efficiency (low energy demand) system. At the system level, the scenario found that all four options cost about the same, when some technology innovations and many forms of typically uncounted cost-savings are taken into account. (And it found that a highly distributed system costs about the same as an all-centralized version, but provides better mitigation of outage risks and other economic and environmental shocks.)

Notes and discussion: See Annex 4. Source: See Endnote 14 of the report's Introduction.

Great Debate 2 | What Is the Future Role of Policy?

Only a few countries had renewable energy support policies in the 1980s and early 1990s, but many more countries, states, provinces, and cities began to adopt such policies during the period 1995–2005, and especially during the period 2005–2012. The number of countries with some type of support policy related to renewable energy more than doubled during this latter period, from an estimated 55 in early 2005 to some 120 by early 2012.

At the national, state, provincial, and local/city levels, policies have played a major role in driving renewable energy markets, investments, and industry growth. However, not all policies have been equally effective, and success has often rested on detailed design and implementation. Consequently, governments continue to update and revise policies in response to design and implementation challenges and in response to advances in technologies and market changes.

These targets and support policies will continue to exert a strong influence on national markets in the years and decades ahead. In the future, national policymakers will confront a wide range of choices and considerations in continuing, updating, and retiring existing policies, and creating new ones. As renewables become more integrated with existing infrastructure, policymakers will confront the need for new policies to achieve these various forms of integration.

In interviews, policy and industry experts offered a wide range of views about the role of policy. For example, some foresaw a cascade of new policies for renewable heating and cooling to match existing policies for electricity. And many foresaw the evolution of policies such as feed-in tariffs, but disagreed about when such evolution would need to take place. Scenarios incorporate a wide variety of policy mechanisms, taken in various combinations over various time frames. Indeed, policy is one of the main drivers in moderate and high-renewables scenarios.

Common policies that many experts and scenarios project for the future include:

- Legally binding targets for renewables
- Electricity market reforms for power generation and combined heat and power (CHP)
- Publicly supported research, development, and commercialization
- Feed-in tariffs, quotas, and/or other finance-attracting policy regimes
- Subsidies, tax credits and abatements, and other cost-reduction incentives
- Market aggregation policies
- Energy efficiency standards for equipment, vehicles, and materials
- Building codes and standards (both national codes and local policies)
- Emissions trading and cap-and-trade schemes for both power and heat supply
- Carbon taxes
- Industrial policies that target renewable energy for jobs and international competitiveness
- Social policies that target renewable energy for its social benefits
- Frameworks for energy prices that reflect the full cost of energy, including environmental and social costs
- Phase-outs of subsidies for fossil fuels and nuclear power

Experts questioned how strong such policies need to be in the future, or how much political will exists to enact new policies or maintain existing ones. Experts were also concerned about whether existing policies would continue in specific countries, and some wondered how Japan's Fukushima accident would affect policies in Japan and elsewhere. And developing country experts noted many energy and development issues for policymakers in the future. *(See Chapter 5.)*

Finance experts questioned how future energy policy could become more consistent with financial risk-return perspectives. They suggested that policymaking will move beyond traditional cost-benefit perspectives, such that in the future, policymakers will ask, "what are the highest-return and lowest-risk energy options and portfolios, and how do we support those?" rather than the historical question of, "what is the cost of renewables compared to the cost of other energy sources?"

Finance experts also wondered about future carbon policies and how such policies would affect renewable energy. Many high-renewables scenarios incorporate some type of carbon policy, such as carbon taxes and emissions trading schemes. ExxonMobil, in its 2012 *Outlook for Energy*, noted: "Because of emerging policies that will seek to curb emissions by imposing a cost on higher-carbon fuels, use of renewable energy … will grow significantly."

Many experts pointed to policies for power grid integration as a key area for policymaking in the future, as do most scenarios. For example, the IEA WEO (2010) says that: "policies to facilitate the integration of variable renewables (such as wind power) into networks are important. Such policies can range from better planning for transmission projects to the development of smart grids, the creation of demand response mechanisms and the promotion of storage technologies."

Notes and discussion: See Annex 4. Source: See Endnote 15 of the report's Introduction.

01

HOW MUCH RENEWABLES?

Future renewable energy shares are in the range of 15–20% in conservative scenarios, 30–45% in moderate scenarios, and 50–95% in high-renewables scenarios. Attaining high shares of electricity is considered easiest, high shares of heating/cooling most difficult, and high shares of transport energy most uncertain.

The world gets about 17–18% of its energy from renewables, including about 9% from "traditional biomass" and about 8% from "modern renewables."[a, b] The "traditional" share has been relatively stable for many years, while the "modern" share has grown rapidly since the late 1990s. During the 1990s, projections of renewable energy that were considered most credible, for example by the International Energy Agency (IEA), foresaw shares of modern renewables reaching no more than 5–10% into the far future, given the policies and technologies existing at the time. As a result of the market, policy, and technology developments of the past 15 years, those early projections have already been reached.[1]

In 2011, about 30 countries were getting 20% or more of their total energy from renewables, and some as high as 50%.[c] (The "total energy" metric counts electricity, heating/cooling, and transport.) Countries in this category include Austria, Brazil, Chile, Denmark, Finland, Iceland, New Zealand, Norway, Peru, the Philippines, Portugal, Romania, Sweden, Uganda, and Uruguay. The European Union (EU) as a whole and the United States both stood at 12%. France, Germany, Italy, Spain, and several other countries were above 10%, and Japan was at 6%. Furthermore, in 2011, about half of all new electric power capacity added worldwide was renewable—as much capacity as fossil and nuclear combined. In interviews, industry experts emphasized that historical thinking and projections about renewable energy remaining a "fringe" technology no longer make sense.[2]

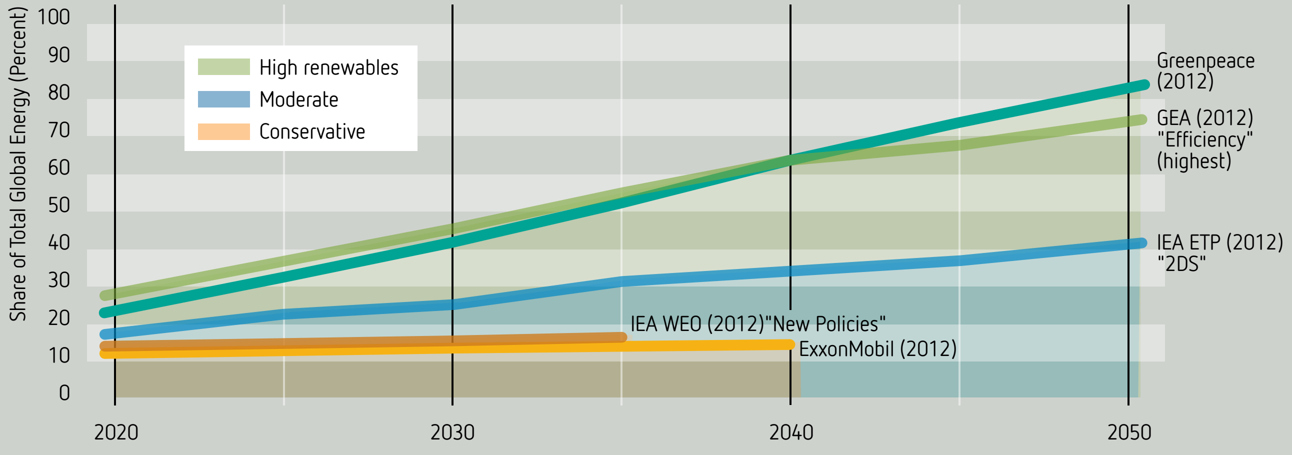
During the late 1990s and early 2000s, as renewable energy started to grow more rapidly than many had predicted, new scenarios emerged that showed much higher long-term shares of renewables. Notable among these was a "Sustained Growth" scenario by the Shell oil company that showed 50% of global energy from renewables by 2050, a figure that shocked many at the time. The IEA also released a report, *Energy to 2050: Scenarios for a Sustainable Future*, that outlined a "Sustainable Development" scenario with a 35% share from renewables.[3]

By the mid-2000s, a larger number of scenarios emerged showing 30–50% shares. Prominent among these was the first (2006) edition of the IEA *Energy Technology Perspectives* (ETP), which gave a set of "Accelerated Technology" scenarios for 2050. In these scenarios, an intermediate case showed a 24% share, and the highest case showed a 30% share. A few years earlier, the German Advisory Council on Global Change (2004) had published its "Exemplary Path" scenario that projected a 50% share by 2050. And in 2007, the first edition of the *Energy [R]evolution* scenario by Greenpeace and the European Renewable Energy Council (EREC) likewise projected a 50% share by 2050.[4]

The most recent scenarios, published in 2010–2012, could be viewed in three main groups: "conservative," "moderate," and "high renewables."[5] See Figure 1 for the wide variation between groups. *(See Annex 2 for a list of the recent global, regional, and national scenarios covered in this report, including full citations corresponding to scenario abbreviations used throughout the text, and see the online supplement, "Scenario Profiles Report," for summaries of these scenarios.)*

Conservative scenarios in the 15–20% range can be found published by oil companies, some industry groups, the IEA, and the U.S. Energy Information Administration (EIA). For example, BP's *Energy Outlook 2030* (2012) and ExxonMobil's *Outlook for Energy: A View*

Figure 1: Conservative, Moderate, and High-Renewables Scenarios to 2050



Source: See Annex 2 for full scenario names and citations.

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a) These figures are final energy shares; see Endnote 1 for full explanation of the differences between final and primary energy shares and sources of data. Energy shares in this report are primary energy unless noted. "Traditional biomass" is commonly defined as unprocessed solid biomass, including agricultural residues, animal dung, forest products, and gathered fuel wood, that is typically combusted in stoves, furnaces, or open fires for cooking, heating, and agricultural/industrial processing in rural areas. "Modern renewables" includes all other renewables such as hydro, biomass power and heat, wind, solar, and geothermal.

b) Many endnotes provide further explanations or clarifications not possible in the text. All data about the current status of renewable energy, typically statistics for 2011, come from the REN21 Renewables 2012 Global Status Report *unless noted.*

c) "Total energy" means either primary or final share depending on source; see Endnote 2. Throughout this report, "energy share" means total energy counting electricity, heating/cooling, and transport.

Box 2 | Renewable Energy in Global Energy and Climate Scenarios

All energy scenarios portray a mixture of energy supply technologies combined with energy demand growth and energy efficiency improvements. For example, ExxonMobil (2012) shows 77% fossil fuels, 15% renewables, and 8% nuclear by 2040. The IEA ETP (2012) "2DS" case shows 46% fossil fuels, 41% renewables, and 12% nuclear by 2050. And Greenpeace (2012) shows 18% fossil fuels, 82% renewables, and no nuclear by 2050. *(For elaboration of information in this box, see Annex 3 and its references.)*

Many scenarios that portray carbon mitigation objectives or results *(see below)* also split out fossil fuels into sub-shares for fossil fuels with carbon capture and storage (CCS). For example, in the GEA (2012) "Supply" case, all coal power plants and some natural gas plants have CCS by 2050.

The degree of energy efficiency improvements and energy-demand reductions deemed possible and projected into the future is a key determinant of the absolute amounts of renewables and the shares attained in scenarios. As many scenarios note, if total energy demand in the future is reduced substantially, relative to what it otherwise would be (i.e., a baseline or reference case), then it is easier to meet that reduced demand with higher shares of renewables. For example, the IEA WEO (2012) "450" case shows 21% less energy demand in 2035 than the reference case. Similarly, IEA ETP (2012) "2DS" shows 26% less energy demand in 2050 compared to a reference case, and the GEA (2012) "Efficiency" case shows 33% less energy demand by 2050 compared to a supply-intensive case.

For scenarios with high levels of energy efficiency, the absolute increase in renewable energy can be modest and still provide high future shares of renewables. For example, Greenpeace, in projecting 40% less energy demand in 2050 due to energy efficiency (relative to a 2050 reference case), shows that global energy demand in 2050 is just about the same as energy demand today. And according to Greenpeace, achieving an 82% share of renewables in that situation only means a 6-fold increase in the absolute amount of renewable energy between now and 2050.

In contrast, both IEA WEO (2012) "450" and BP (2012) scenarios show a roughly 2.3-fold increase in the absolute amount of renewables by 2030–2035, but they show much lower renewable energy shares—15% for BP and 27% for IEA—due to much lower levels of energy efficiency improvements. And some of the 160 scenarios surveyed by IPCC (2011) show more than a 6-fold increase in absolute renewables by 2050 but still a lower share than Greenpeace.

Carbon mitigation motivations are an explicit driver or goal of many published scenarios. Such scenarios are typically called "carbon-constrained" or "back-casts," which means they work backward from some defined future goal or constraint, such as stabilization of annual carbon emissions at a given level, or stabilization of atmospheric concentration of greenhouse gases. Scenarios then project what mix of energy technologies and what energy system characteristics will meet the chosen constraint, within the bounds of economic competitiveness and technological feasibility. Carbon-constrained scenarios typically show trade-offs between renewables, energy efficiency, nuclear power, and CCS technologies for fossil fuel plants in achieving carbon reduction goals.

The IPCC (2011) surveyed over 160 climate-mitigation scenarios with climate goals by 2100, organized into ranges based on the stabilized atmospheric concentration of CO_2: one range higher than 600 parts per million (ppm), three ranges 400–600 ppm, and one range below 400 ppm. Renewable shares were above 50% for a majority of scenarios around 450 ppm, and up to 77% for some lower concentrations.

Other examples of carbon goals or constraints in global scenarios include IEA RETD (2010), which is based on stabilization at 400 ppm by 2100 and shows a 56% share of renewables, and IEA WEO (2012), which is based on 450 ppm and shows a 27% share of renewables (along with nuclear and CCS). Other scenarios target emissions reductions rather than stabilization levels, such as Greenpeace (2012), which results in 85% lower energy-related CO_2 emissions by 2050 (relative to 1990 base year), and the range of GEA (2012) scenarios, which result in 30–70% lower emissions by 2050 (relative to 2000 base year).

For more on scenarios and variables that affect renewable energy futures, see Annex 3.

Source: See Endnote 7 for this chapter.

to 2040 (2012) both show an under-15% share by 2030–2040. The EIA (2011) shows 14% by 2035, and the IEA's *World Energy Outlook* (WEO, 2012), in its "New Policies" scenario, shows 18% by 2035. Conservative viewpoints by oil and gas companies mirror such conservative scenarios. These companies continue to make statements such as "fossil fuels will continue to provide the majority of the world's energy supplies for decades to come" (Chevron), and "oil's preeminence in the global energy mix will remain unchallenged in the foreseeable future" (Total).[6]

Moderate scenarios show long-term renewable energy shares in the 25–40% range. Two IEA examples are the IEA WEO (2012) "450" carbon-stabilization scenario, which shows a 27% renewable energy share by 2035, and the IEA ETP (2012) "2DS" scenario, which shows a 41% share by 2050. The IPCC *Special Report on Renewable Energy* (2011) synthesized the results of over 160 climate-mitigation scenarios (most from 2009–2010) and found that over half of them project shares above 27% by 2050—a large group in the "moderate" category.[7] (And many show very high absolute amounts of renewables, too, under high global energy demand scenarios; see Box 2.)

High-renewables scenarios project 50–95% energy shares of renewables by 2050. For example, the GEA *Global Energy Assessment* (2012) shows up to 75% in the highest of its "Efficiency" cases and a median share of 55%. The "ACES" scenario by the IEA multilateral program Renewable Energy Technology Deployment (2010) shows 55%. And among the group of 160 scenarios surveyed by the IPCC (2011), there are a number in the range of 50–80%. The biennial

Greenpeace *Energy [R]evolution* scenario, which has become the most widely recognized and thorough projection made by renewable energy advocates, shows 82%.[a] At the highest end, WWF (2011) shows a 95% share.[8]

The credibility of such high-renewables scenarios has increased over the years, following a long tradition of "100%" scenarios dating back to the 1970s by renewable energy advocates and visionaries. The difference is that now, given the scope of government policy targets and market growth in recent years, such high-renewables scenarios are grounded in growing present-day markets.[9] *(See Endnote 9 for further discussion of "credibility" in the context of scenarios.)*

In interviews, most industry experts believed that the world could reach at least 30–50% shares of renewables in the long term. (See also Box 3 for a recent global goal of 30–35%.) And some experts advocated for 100% or near-100% futures. European experts cited considerably higher shares just for Europe *(see following section)*, with many saying that Europe could attain 50–70% shares.[10] *(Also see following sections for more expert opinions based on individual sectors.)*

National and EU Shares

Many moderate and high-renewables scenarios, both for individual countries and for the EU, exist for energy share by 2050. For Europe, two high-renewables scenarios are the EREC (2010) *RE-thinking 2050* scenario, which shows almost 100%, and the European Commission (2011) "Energy Roadmap 2050," whose "High Renewables" scenario shows 75%. For India, Greenpeace (2012) shows 81%. For China, the Lawrence Berkeley National Laboratory (2011) shows 17–32% by 2050 (including nuclear).[11] *(For more on national and EU targets and market projections, see Chapter 5.)*

Conservative national and EU scenarios project 10–20% shares in the longer term. Examples include 11% by 2035 for the United States (U.S. Department of Energy, *Annual Energy Outlook*, 2012); 13% by 2030 for Japan (Ministry of Economics, Trade and Industry, "National Energy Plan," 2010; pre-Fukushima); 20% by 2030 for China (Xiliang et al., 2010); 13% by 2030 for Asia and the Pacific, excluding hydro (APEC/ADB, *Energy Outlook for Asia and the Pacific*, 2009); and 22% by 2030 for Europe (EC, 2009, reference case).[12]

Beyond such scenarios, national governments are projecting their energy supply mix into the future and enacting actual policy targets (goals) for future shares of renewable energy to 2020, 2030, and even 2050. At least 118 countries had policy targets for renewable energy by 2011, a dramatic increase from 49 countries in 2005. The EU as a whole targets 20% by 2020, and all EU members have individual targets for 2020 that collectively achieve the 20% target. Germany, long the renewable energy leader in Europe, and one of the earliest policy pioneers in the 1990s, has a comprehensive set of targets that provide for a step-wise progression every decade, from 18% in 2020 to 60% in 2050. Denmark, also an early policy pioneer, is the only EU country to target 100% renewables in the long term (2050), starting with 35% in 2020.[13]

Box 3 | UN "Sustainable Energy for All": Doubling the Global Renewables Share

In 2012, the United Nations launched a global goal for renewable energy—a doubling of global energy share from renewables by 2030. This goal is an interlinked part of the UN's "Sustainable Energy for All" initiative, which also aims to double the global rate of improvement in energy efficiency and to ensure universal access to modern energy services. Reaching these goals would mean achieving a roughly 30–35% share of renewables, and a tripling of modern renewables if the share of traditional biomass remains constant.

Source: See Endnote 10 for this chapter.

Outside of Europe, a diverse group of at least 20 other countries target energy shares in the 2020–2030 time frame that range from 10% to 50%, including Algeria, China, Indonesia, Jamaica, Jordan, Madagascar, Mali, Mauritius, Samoa, Senegal, South Korea, Thailand, Turkey, Ukraine, and Vietnam. To give a few specific examples, Algeria targets 37% from solar power (both solar PV and CSP[b]) and 3% from wind power by 2030; Indonesia targets individual renewable technologies that collectively add up to 18% by 2025; and Ukraine targets 19% by 2030 (compared to 1% in 2010). OECD countries Australia, Canada, Japan, and the United States do not have total energy share targets, but do have other types of national targets *(see the following sections)*.[14]

China targets 15% from renewables and nuclear combined by 2020. (For comparison, renewables were about 9% and nuclear was about 1% in 2010, and thus this target represents a roughly 50% increase in renewable energy over 2010 levels.) Chinese experts offered a range of views about long-term shares beyond 2020. Some envisioned that this share could reach as high as 50%, while others believed that the 15% reached in 2020 would be the limit, and renewables would then grow at the same rates as other technologies. Most experts believed that a 35% share by 2040–2050 was reasonable. Others cited uncertainty about nuclear and shale gas, and stressed that if shale gas were to materialize in large quantities, this would displace some of the drive and need for renewables.[15] *(See Annex 3 for further discussion of competing fuels.)*

Sectoral Shares: Electricity, Heating/Cooling, and Transport

The previous discussion was focused on shares of total energy. However, many targets and scenarios also exist that project renewables separately in individual sectors: electricity, heating/cooling, and transport. These sectoral shares provide greater insight into the future because the challenges, opportunities, and technologies are very different in each sector. In particular, there was strong expert agreement in interviews that high shares of electricity from renewables will be the easiest to attain. And

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a) *The Greenpeace scenario is a joint publication of Greenpeace International, the European Renewable Energy Council (EREC), and the Global Wind Energy Council (GWEC). GWEC became a co-author in 2012. Throughout this report, this scenario is cited as simply Greenpeace for brevity.*

b) *See online supplement "Glossary and Basic Energy Concepts" for all technical terminology. PV stands for photovoltaic and CSP stands for concentrating solar thermal power.*

many countries already have targets for shares of electricity.[16] *(See Chapter 5 for further country-specific information on electricity projections.)*

Heating and cooling from renewables will be much more difficult to attain in large shares, many experts said, and published scenarios support this view. Although heating and cooling technologies are fairly well understood and established, policies for heating are not as evolved or widespread as for electricity, and many challenges persist in terms of integration into the built environment. There are far fewer scenarios projecting heating and cooling shares relative to those projecting electricity shares, and only a handful of countries have policy targets or national-level policies for renewable heating and cooling.[17] *(See also buildings integration in Chapter 2 and heating and cooling at the city/local level in Chapter 4.)*

Long-term transport shares are the most challenging to project, and the most uncertain, because the range of possible vehicle technologies and fuel types in the future is very broad, future oil prices are uncertain, and technology progress for many elements, from vehicle batteries to advanced biofuels, remains unpredictable. These factors create uncertainty about what future transport systems look like. Fewer scenarios project shares of transport fuels, and in those that do, projections vary widely. However, quite a number of countries do have blending mandates and/or targets for future shares of biofuels in transport.[18] *(See also transport integration in Chapter 2 and biofuels in Chapter 6. For more details on current biofuels mandates, see annual editions of the REN21* Renewables Global Status Report.*)*

Table 1 shows global sectoral-share projections for the years 2030 to 2050 from several scenarios. These include two conservative scenarios by oil companies, two moderate scenarios by the IEA (WEO "New Policies" and "450"), and four high-renewables scenarios by IEA ETP, GEA, Greenpeace, and WWF. Beyond these global shares, examples of country-specific policy targets and projections are given in the following sections.[19]

■ *Electricity Shares*

The global share of electricity from renewables in 2011 was 20%. In the EU, the share was 21%. A number of countries already produce very high shares of electricity from renewables, mainly from hydropower in most countries. To illustrate the breadth of such countries, a list of countries with shares above 30% includes: Argentina (31%), Austria (68%), Brazil (85%), Cameroon (88%), Columbia (70%), Costa Rica (94%), Croatia (61%), Denmark (32%), El Salvador (65%), Ethiopia (89%), Finland (30%), Guatemala (63%), Iceland (100%), Latvia (55%), Madagascar (57%), New Zealand (73%), Norway (96%), Panama (59%), Paraguay (100%), Portugal (53%), Romania (34%), Slovenia (30%), Spain (34%), Sudan (81%), Sweden (55%), Switzerland (58%), Uganda (54%), and Venezuela (66%).[20]

At least 48 countries have targets for shares of electricity from renewables in the 2020–2030 time frame. Many of these targets represent a doubling or tripling of current shares. Examples of targets for 2020 include: Egypt (20%), Ireland (40%), Madagascar (75%), Philippines (40%), and Thailand (14%). A few targets extend to 2030, such as Kuwait (15%), South Africa (42%), and Tunisia (40%). And targets for three countries extend all the way to 2050: Denmark (100%), Germany (80%), and Malaysia (24%).[a] In late 2012, the Japanese government was expected to announce a target for a 30–35% share by 2030, as part of its new post-Fukushima energy strategy.[21]

Table 1: Sectoral Shares of Renewable Energy in Recent Global Scenarios

Scenario	By Year	Electricity	Heat	Transport
By 2030–2040				
ExxonMobil *Outlook for Energy: A View to 2040* (2012)	2040	16%	—	—
BP *Energy Outlook 2030* (2012)	2030	25%	—	7%
IEA *World Energy Outlook* (2012) "New Policies"	2035	31%	14%	6%
IEA *World Energy Outlook* (2012) "450"	2035	48%	19%	14%
Greenpeace (2012) *Energy [R]evolution*	2030	61%	51%	17%
By 2050				
IEA *Energy Technology Perspectives* (2012) "2DS"	2050	57%	—	39%
GEA *Global Energy Assessment* (2012)	2050	62%	—	30%
IEA *Energy Technology Perspectives* (2012) "2DS High Renewables"	2050	71%	—	—
Greenpeace (2012) *Energy [R]evolution*	2050	94%	91%	72%
WWF (2011) *Ecofys Energy Scenario*	2050	100%	85%	100%

Sources: See Endnote 19 for this chapter and Annex 2.

Notes: Transport shares for IEA WEO, IEA ETP, and BP are only for biofuels; transport share for Greenpeace includes electric vehicles; transport share for WWF is entirely biofuels. Heat share for WWF is only industry and buildings. Electricity share for BP is estimated from graphics. Electricity share for GEA is based on the central "Efficiency" case.

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[a] *Germany's 80% share is reached through step-wise targets for each decade starting with 35% in 2020, and is part of its* Energiewend *movement to completely eliminate fossil fuels and nuclear.*

Some countries have targets for amounts of annual electricity generation from renewables rather than shares. For example, by 2020 or 2030, Algeria targets 41 terawatt hours (TWh), Australia targets 45 TWh, and South Korea targets 40 TWh.[22] *(For power capacity targets in gigawatts (GW), for selected countries, see Chapter 5.)*[a]

Many states, provinces, and sub-national regions also have electricity-share targets. For example, Scotland targets 100% by 2020, Upper Austria 100% by 2030, South Australia 33% by 2020, and Abu Dhabi 7% by 2020. In the United States, 30 states have Renewable Portfolio Standard (RPS) policies that mandate future shares of electricity and thus represent a form of *de facto* target, typically in the 10–30% range, and 10 more states have other types of policy targets. In Canada, four provinces have RPS policies, and another five have other types of policy/planning. In India, at least 15 states have RPS policies and other states have policy targets.[23] *(See also Box 6 on page 42, and Chapter 4 for city and local targets.)*

Many experts during interviews thought that a 40–50% global electricity share by 2030 was feasible if national policies remain aggressive. Many European experts believed that Europe would reach even higher shares of electricity, up to 70–100% in the long term. Several experts were similarly optimistic about such levels on a global scale, and one asserted that, "we can achieve a global electricity share of 80% from renewables in the next 20–30 years."[24, b]

Table 2 shows electricity shares for Europe, the United States, Japan, China, India, other Asia, Latin America, and Africa from recent scenarios.[25] (See also Figure 2 for targets and projections for selected countries.)

Heating and Cooling Shares

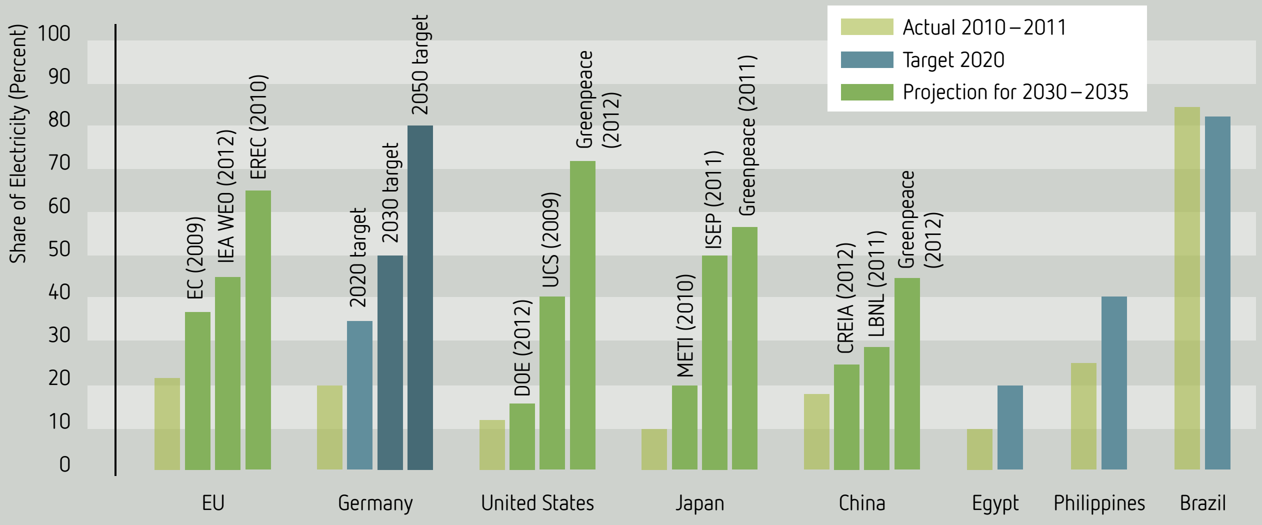
Very few countries outside of Europe have policy targets for shares of heating from renewables. For the EU, national renewable energy plans collectively imply about 20% of heating by 2020. Germany's Renewable Energies Heating Law, effective in 2009, requires all new residential buildings to obtain at least 20% of household heating and hot water energy from renewables, with an overall goal of 14% of total heating energy to come from renewables by 2020, including district heating systems.[26]

Other targets for share of heating (and cooling) from renewables by 2020 by EU members include Belgium (12%), Denmark (40%), France (33%), Greece (20%), Lithuania (39%), Romania (22%), Spain (19%), and the United Kingdom (12%). Beyond 2020, EU-wide scenarios for 2030 project 20–25% on the low end (EC 2009), and 45–55% on the high end (EREC 2010 and Greenpeace 2012). For 2050, some projections reach 60–100% (EREC 2010 and SEI 2009).[27] *(See also Chapter 4 for city and local targets for heating and cooling shares, and more on national heating policies and markets in Chapter 5.)*

Industry experts offered widely differing opinions about future heating/cooling shares, and some found it difficult to offer an opinion. Many believed that it would be difficult to go beyond 25–30% shares in many regions of the world without major transformations in the energy efficiency of new building designs, along with retrofits to existing buildings. *(See buildings integration in Chapter 2.)* Views on Europe were more optimistic than this level, partly because of advanced policies, building designs, and use of biomass, especially in northern Europe. The possibilities for higher shares also depend on climatic zone and renewable resource availability, said experts.[28]

Figure 2: National and EU Electricity Shares from Renewables, 2010–2030

(2010 Actual, 2020 Targets, and 2030–2035 Projections)



Source: See Endnote 25 for this chapter.

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a) TWh units are used for annual amounts of electricity generation; GW units are used for physically existing power capacity. See Table 4 on page 53, and see the online supplement "Glossary and Basic Energy Concepts" for more on energy units.

b) All quotations from experts interviewed for this report are anonymous; see Annex 1. Other quotations from published sources or energy companies are cited with the publication author and year or company name, and detailed citations are provided in endnotes.

Table 2: Electricity Shares of Renewable Energy in Recent National and Regional Scenarios

Country/Region and Current Share	Scenario	By Year	Electricity Share
Europe (21%)	EC (2009) "Energy Trends 2030"	2030	36%
	IEA WEO (2012) "New Policies"	2035	43%
	EREC (2010) *RE-thinking 2050*	2030	65%
	SEI (2009) *Europe's Share of the Climate Challenge*	2030	75%
	EC (2011) "Energy Roadmap 2050" "High Renewables"	2050	97%
	EREC (2010) *RE-thinking 2050*	2050	100%
United States (11%)	DOE EIA (2012) *Annual Energy Outlook*	2035	15%
	IEA WEO (2012) "New Policies"	2035	23%
	UCS (2009) *Clean Energy Blueprint*	2030	40%
	Greenpeace (2012) "Advanced Revolution"	2030	71%
	Lovins/RMI (2012) *Reinventing Fire* "Renew"	2050	80%
	NREL (2012) *Electricity Futures Study*	2050	30–90%
Japan (10%)	METI (2010) "National Energy Plan"	2030	20%
	ISEP (2011) "Energy Shift"	2030	50%
	Greenpeace Japan (2011) *Energy [R]evolution*	2030	57%
	Greenpeace Japan (2011) *Energy [R]evolution*	2050	85%
	ISEP (2011) "Energy Shift"	2050	100%
	WWF Japan (2011) "100%"	2050	100%
China (18%)	CREIA (2012) "Study of High-Share Renewable Energy"	2030	25%
	BNEF (2012) "Global Renewable Energy Market Outlook"	2030	28%
	LBNL (2011) "Accelerated"	2030	29%
	Greenpeace (2012) *Energy [R]evolution*	2030	43%
	IEA ETP (2012) "2DS"	2050	50%
	Greenpeace (2012) *Energy [R]evolution*	2050	92%
India (31%) **/Other Asia**	Greenpeace (2012) *Energy [R]evolution* (India)	2030	62%
	GEA (2012) *Global Energy Assessment* (South Asia)	2050	27–86%
	Greacen (2012) (Thailand)	2030	30%
	APEC and ADB (2009) "Energy Outlook for Asia and the Pacific"	2030	16%
Latin America	World Bank (2011) (Latin America/Caribbean)	2030	54%
	Greenpeace (2012) *Energy [R]evolution*	2030	86%
	GEA (2012) *Global Energy Assessment*	2050	60–100%
Africa	Greenpeace (2011) *Energy [R]evolution* (South Africa only)	2030	50%
	IRENA (2012) "Renewables" (all Africa)	2030	50%
	IRENA (2012) "Renewables" (all Africa)	2050	73%
	Greenpeace (2012) *Energy [R]evolution* (all Africa)	2050	92%
	GEA (2012) *Global Energy Assessment* (sub-Saharan Africa)	2050	34–92%

Sources: See Annex 2 for full scenario names and citations, and online supplement "Scenario Profiles Report" for scenario summaries. IEA ETP figure for China is given as "almost 50%." Current shares and other notes from Endnote 25 for this chapter.

Globally, the IEA WEO (2012) "New Policies" scenario projects that heat from modern renewables almost doubles from 2010 to 2035. The IEA says: "production of heat from modern renewables continues to be dominated by bioenergy throughout the projection period … This heat is used mainly by industry (where biomass is used to produce steam, in co-generation and in steel production) but also by households (primarily for space and water heating)." The IEA projects that, by 2035, bioenergy use for heating grows by more than 60%, geothermal heat increases 6-fold, and solar heating increases more than 3-fold. Greenpeace (2012) shows a 50% share of global heating from renewables by 2030 and a 90% share by 2050. Greenpeace projects that through 2020, biomass will represent a large share of renewables heating growth, while beyond 2020, the continued growth of solar collectors, and growing shares of geothermal heating and heat pumps, will occur.[29]

Transport Shares

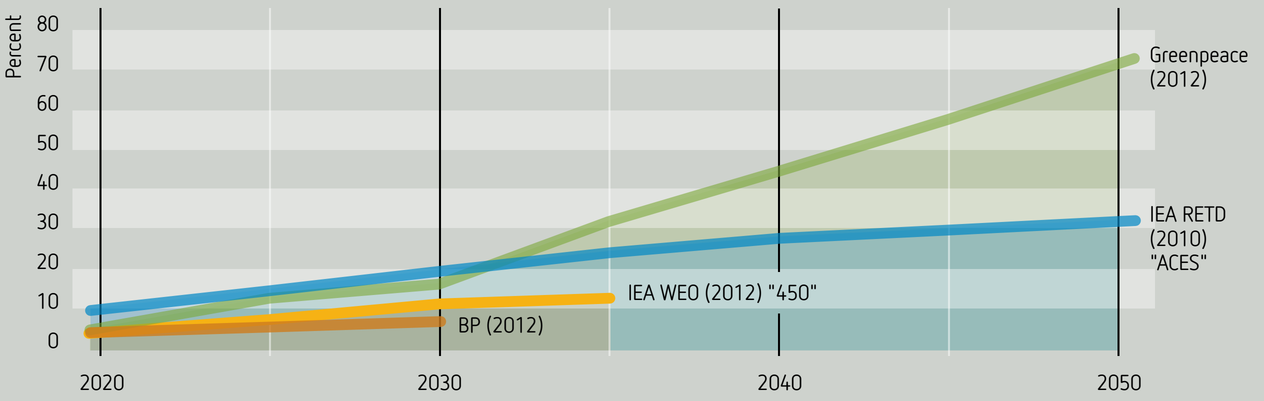
About 107 billion liters of biofuels were produced globally in 2011, representing about 3% of global road transport fuel demand. A handful of national and regional policy targets exist for future transport shares from renewables. An EU-wide target of 10% by 2020 includes both sustainable biofuels and electric vehicles. A few individual EU member countries also have their own transport fuel targets for 2020. Most notable is Sweden, which targets a complete phase-out of fossil fuels in transport by 2030. The United States has a Renewable Fuels Standard, which requires 36 billion gallons (135 billion liters) of biofuels to be blended annually with other transport fuels by 2022. In addition, in 2011, at least 24 countries and 26 states/provinces around the world had mandates for blending biofuels in gasoline and/or diesel, typically at 5–10% blends, with some biodiesel blends up to 20%.[30]

Virtually all scenarios project an increase in biofuels, but most projections are quite modest relative to the large gains in electricity shares in the same scenarios. (See Figure 3.) The IEA WEO (2012) "New Policies" and "450" scenarios are an exception, and project that biofuels grow by a factor of 3–6 between 2010 and 2035, which would mean consumption of roughly 350–700 billion liters of biofuels in 2035. This represents a 6–14% share of transport energy by 2035. The IEA sees the increases driven by advanced biofuels in the longer term (which the IEA assumes will become commercially available by 2020, although not yet competitive with conventional fuels). More conservatively, BP (2012) projects a 7% share by 2030.[31] *(See also biofuels in Chapter 6.[a])*

For 2050, IEA RETD (2010) projects that advanced biofuels make up one-third of global transport fuel by 2050. The GEA (2012) "Supply" case shows about 20% of energy from biofuels, and the "Efficiency" case shows about 16% from biofuels plus 21% from electricity, for a 37% total share. WWF (2011) projects that the transport sector will become 100% powered from renewables by 2050, including a combination of electricity, biofuels, and hydrogen. For Europe alone, EREC (2010) projects over 80% by 2050, from high shares of both renewable electricity and biofuels. SEI (2009) also projects a transition to electric vehicles, such that virtually all passenger vehicles are electric in Europe by 2050, along with half of all freight vehicles.[32] *(See also transport integration in Chapter 2.)*

Industry expert opinions on the future of liquid biofuels for transportation were wide-ranging. Some thought that as much as half of all transportation fuel by 2050 could come from biofuels, while others projected much less.[33]

Figure 3: Global Share of Transport Fuel to 2050



Source: See Annex 2 for full scenario names and citations.

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[a] *See biofuels in Chapter 6 for endnotes relating to food security, sustainability, and resources, issues that experts mentioned in connection with biofuels for transport.*

02 INTEGRATED FUTURES:

CHALLENGES AND POSSIBILITIES

Many policymakers, utilities, builders, automakers, and industries recognize that stronger integration of renewable energy is the next "frontier." This means new and flexible ways to manage variability on power grids, to think about building design and construction, to fuel industry, and to provide mobility with renewable energy.

Industry and utility experts consistently pointed to "integration" as a critical part of reaching the higher levels of renewable energy portrayed in Chapter 1.[a] Experts stressed the need to think beyond renewable energy technologies themselves. Rather, the thinking about future energy systems needs to focus on how renewable technologies will be integrated into existing infrastructure: utility power grids, buildings, industry, and transport.[1]

Experts stressed that integration may often require new policies and planning approaches, as well as new power market rules *(see also Chapter 5)*. And they pointed to many local government actions and roles for integration at local levels, such as building codes and urban planning for renewables and electric vehicles *(see also Chapter 4)*. They also pointed to integration of renewable energy into new energy-service business models and investment mechanisms *(see Chapter 3)*. This chapter looks at future integration in four basic categories: utility power grids, buildings, industry, and transport.[2]

Utility Power Grids

Electricity generation from some renewable technologies has a well-known variable nature. This is particularly true for wind power and solar photovoltaics (PV), and to a lesser extent for solar thermal power (CSP).[b] As these sources are integrated into existing power grids in large quantities, this variable nature becomes one of the main technical challenges. As the share of renewables on power grids increases, electric utilities must respond to the challenge of balancing large shares of variable renewables, in order to maintain grid balance and stability according to technical and regulatory tolerances.[3, c]

Utility experts pointed out that managing variability is nothing new: utilities have contended with variability since the dawn of centralized power networks, although mostly in terms of demand variability rather than supply variability. Experts also noted that utilities in many jurisdictions are already managing variability for large shares of renewables, for example in California (USA), Denmark, Germany, Ireland, South Australia, and Spain.[4]

Many other jurisdictions are facing imminent scale-up of this integration challenge. Said one European expert: "European utilities in particular are facing trouble right now because they have to invest in the grids themselves and put increased attention on grid balancing, both at centralized and distributed levels, in order to accommodate renewable energy policy goals and targets to be fulfilled in the next 5–10 years. And this integration is not just about hardware, but also about how power markets function."[5]

Published sources and interviews show that more than a dozen different options are available to utilities to balance variable renewables. These options encompass technical, planning, and market-regulatory changes. Utility experts pointed out that some of these options are already widely used even without the presence of renewables. Experts also emphasized that each grid is unique, and solutions will be diverse.[6]

Sources point to a range of planning and market-regulatory changes that will be important in the future, such as: (1) new power market designs that support greater flexibility; (2) expanded diversity of resources within geographic grid "balancing areas"; (3) coordination or merging of balancing areas under central balancing authorities (grid operators); (4) faster balancing response times through market and operational mechanisms; and (5) new types of system optimizations. One operational change that some utilities are already implementing is to use power dispatch models that incorporate day-ahead weather forecasts for wind speeds and solar insolation.[7]

In conjunction with these options, utility experts pointed to six key technical-operational measures: controlled curtailment, demand-response, gas turbines, energy storage, strengthened transmission capacity and interconnection, and ramping and cycling of conventional power plants. These are described below.[8]

■ **Controlled curtailment of renewables.** "Curtailment" is the prevailing strategy today by many utilities to deal with surplus amounts of wind power during periods of insufficient demand or un-curtailable generation from conventional power plants. Spain is perhaps the most advanced in this measure, the result of a dedicated renewable energy power control center (CECRE) that it established in 2006. The power center allows the grid operator Red Eléctrica to monitor and control, in real time, renewable power generation around the country. "Necessity was the mother of invention," said one Spanish expert in explaining the basis for the center. In 2012, Spain averaged about 18% of its power generation from wind, with much higher peaks during some time periods, including an historic peak of 61% of total national power output on the morning of April 19, 2012.[9]

■ **Demand response.** "Demand response" is a phrase that covers a wide range of actions by utilities and their customers to reduce power demand at specific times. It includes contracted load curtailment that is controllable by the utility within pre-established parameters, and can also include time-of-use-based market prices to influence consumption decisions. Utility experts emphasized many possible forms of demand response in the future, particularly in industry. For example, demand-response in the chemical and metals industries could be integrated with process engineering, based on allowable ranges of process temperatures. Other examples are water pumping, air conditioning, and freezing, all of which can offer options for shifting demand when integrated with storage ranges and limits (i.e., water or thermal).[10]

Demand response can contribute to peak shaving, contingency reserves, and regulatory reserves. Indeed, the grid operator for most of the U.S. state of Texas, ERCOT, now supplies 50% of its regulatory reserves through demand response. Many experts considered demand-response to be one of the primary and most cost-effective mechanisms in the future to manage variability, beyond others discussed in this section, and some scenarios likewise model demand-response as the primary response to variability.[11]

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a) Some experts disliked the "integration" concept, and instead preferred to think of coming "transformations" of both local and national energy systems. See also the report's Conclusion.

b) The variability of CSP plants depends partly on the degree of embedded thermal storage. Some forms of ocean energy are also variable.

c) The term "electric utility" is used generically in this report to denote a variety of companies in the power sector. In many countries, power grid functions have been "unbundled" into various classes of power generators, distribution utilities, and transmission system (grid) operators.

- **Gas turbines (peaking and non-peaking).** Many scenarios call natural gas a "bridging" or "transitional" fuel toward high-renewables futures. Experts envisioned growing use of combined-cycle and simple-cycle gas turbines for balancing grids, particularly for complementing wind power. However, experts pointed out that most combined-cycle plants that exist today were not planned nor designed to operate on a variable regime. Constant ramping up and down creates excessive wear and tear, lowering lifetimes and increasing maintenance costs. Simple-cycle turbines make better peaking plants but are significantly less efficient. Spanish experts noted that Spain had planned to add simple-cycle turbines on to the grid for balancing high shares of wind power; however, these plans were shelved due to underutilization of already-existing combined-cycle gas plants.[12]

- **Strengthened transmission capacity and interconnection.** Utility experts pointed to stronger transmission capacity as an important means to balance power flows and variable sources within a region, as well as to deliver renewable generation from remote locations. The extreme end-point cited by some experts is a theoretical "copper plate" in which unlimited interconnection exists. However, experts questioned the degree to which networks can be expanded given environmental and social issues, as well as levels of investment required (particularly in developing countries). Many emphasized the difficulties in terms of transmission planning and social acceptance of new overhead transmission. Some countries may turn to buried underground transmission to achieve a stronger balancing capability while mitigating social issues, although underground transmission is more costly. Denmark has already mandated that all new transmission be buried underground.[13]

Experts also pointed to stronger cross-border interconnections to transfer renewable power generated in one country to neighboring countries. They envisioned future possibilities like Bhutan hydro and Sri Lanka wind power flowing to India; Mozambique hydro and Namibia wind power flowing to South Africa; and renewable power transferred among China, Mongolia, Japan, South Korea, and other Asian countries through an "Asian super grid." European experts envisioned "Desertec" transfers of renewable power from northern Africa to Europe, as well as a Europe-wide "super grid."[14]

- **Energy storage.** Hydropower has been a traditional form of large-scale energy storage on power grids, in the form of both conventional and pumped hydro. *(See hydropower in Chapter 6.)* In recent years, grid-tied battery storage has made inroads and shows much promise for the future, according to storage experts. Until more recently, grid-tied battery storage has been perceived as expensive and the province mainly of demonstration projects. However, an increasing number of commercial battery storage projects today are dispelling that perception, particularly in "niche" applications that are profitable under current conditions. Some of these are for centralized grid support and others are much more decentralized. Storage experts cited many examples of present-day commercial storage projects using batteries, as well as an increasing proliferation of distributed batteries at points of customer end-use.[15]

Beyond hydro and batteries, solar thermal power (CSP) plants also offer storage capabilities using embedded thermal storage. Many currently operating CSP plants typically have 4–8 hours of thermal storage that allows evening operation and can provide firm dispatchable power for spinning reserve, balancing, and ancillary services. CSP experts envisioned thermal storage capacity increasing to 24 hours in the longer term. Storage experts also cited other possible technologies for the future. From a grid stability perspective, different storage technologies are suited for different balancing time frames, ranging from minutes to hours, and even to days or weeks.[16]

- **Ramping and cycling of conventional plants.** Conventional hydropower plants (even without pumped storage) are routinely used to ramp and cycle. For other types of conventional power plants, however, ramping and cycling on a daily or hourly basis can be controversial, said experts, who noted that a major paradigm shift is implied. In particular, existing coal plants can be modified to allow ramping and cycling beyond original design parameters, and operated to provide more flexibility, although not without additional costs in terms of reduced equipment lifetime, higher maintenance costs, and stability of emissions equipment. Although ramping and cycling costs are not well known, and utilities resist such operation, some utilities have indeed converted coal plants to ramp and cycle.[17]

Nuclear plants can also ramp and cycle, and in some countries today, nuclear plant output is routinely cycled on a daily or weekly basis to handle grid conditions. A 2011 OECD study concluded that, "modern nuclear plants with light water reactors have strong maneuvering capabilities [to operate in load following mode]." The report notes that, "in Germany, load-following became important in recent years when a large share of intermittent sources of electricity generation (e.g. wind) was introduced to the national mix." The report also notes that ramping and cycling costs for most existing nuclear plants—beyond lost revenue from lower output—are confined to minor increases in maintenance costs.[18]

Beyond the six measures just described, other balancing options that are less commonly cited but still considered important by some experts include: (1) using biomass combined heat and power (CHP) plants with heat storage embedded in the CHP plants or locally with end-users, to allow variable operation of the power generation side of the CHP plant; (2) generating synthetic gas or hydrogen from surplus renewable electricity for injection into the natural gas grid as a means of absorbing excess generation on-demand; and (3) aggregating the charging/discharging of large numbers of electric vehicles through centralized "smart grid" mechanisms *(see also the following section on transport integration)*.[19]

Over the past decade, there has been much debate and controversy about the level of variability from renewables that power grids will be able to cost-effectively support and integrate. Much of this discussion has revolved around what percentage (share) is a technical "upper limit" to integration, with conservative numbers such as 10% or 20% often cited. A number of studies show difficulties above these levels without aggressive balancing measures. But other studies show the potential to reach higher shares with sufficient use of the balancing measures discussed earlier.[20]

For example, GEA (2012) concluded that up to 50% shares of variable renewables can be accommodated in most existing systems with investments in grid flexibility, gas turbines, energy storage, and demand management. NREL's (2012) *Electricity Futures Study* analyzes a range of U.S. cases from 30% to 90% shares by 2050, and concludes that it would be possible to attain a high share (80%) from technologies that are commercially available today,

Great Debate 3 | Is Energy Storage Necessary for High Levels of Renewables?

As noted in this chapter, the conventional view persists that high shares of renewable energy will require expensive storage technologies that must await further development. Many experts disputed this view, saying that the wide range of other options to manage variability mean that high shares are possible without storage. "We think little or no storage will be needed, at least in the United States," said one U.S. energy expert, who believed that in most cases, storage can be confined to distributed applications, notably in electric vehicles *(see following section on transport)*.

Many experts believed that storage will indeed be needed before 2030, but for now, "the immediate need is not that great; we can manage fine with pumped hydro and gas, even up to high levels," said one. Another utility expert noted: "storage has to come down to one-tenth the cost of generation for us to use it in a big way. We really don't need it as much as we think. It's cheaper just to add more generation to compensate for variability than it is to have lots of storage." And another said, "We don't need any storage breakthroughs over the next 15–20 years, so we have something of a '15-year reprieve' from needing storage because we can accomplish grid stability with other options, foremost among them demand-response."

Notes and discussion: See Annex 4.

in combination with a more flexible electricity system. In the 80% cases, variable renewables (solar PV, wind, and ocean) supply 40% of all U.S. electricity.[21]

The NREL study incorporates several forms of flexibility, including demand response, flexibility of conventional fossil fuel power plants, and energy storage (100–150 GW of storage in the 80% cases). Attaining higher flexibility would require new grid management practices, electricity market rules, business models, system planning, and more highly interconnected transmission infrastructure, according to the study. The Lovins/RMI (2011) "Renew" scenario shows 100 GW of storage. And Greenpeace (2012) projects a high (31%) share of variable renewables by 2030, based on smart grids, demand-response, and storage.[22]

The variability of renewables connected to a power grid has historically been a major reason why utilities have considered renewable energy "inferior" to conventional power generation and resisted its introduction. That is, the integration challenge is not just technical, but one of utility perception, willingness to change and innovate, and the institutional and regulatory frameworks that govern utility decisions. The IEA, in its 2011 book *Harnessing Variable Renewables,* puts it this way: "The extent of the challenge [of managing variability of renewables] is one of the most disputed aspects of sustainable-energy supply; detractors claim that variable renewable energy technologies, at high levels of deployment, introduce a level of uncertainty into the system that makes it just too difficult to meet the moment-by-moment challenge of balancing supply and demand for electricity across a power system."[23]

Utilities today still consider variability to be a major issue, but some have taken softer tones in recent years when discussing large renewables shares: "[Without] electricity storage breakthroughs … intermittent energy sources will be complementary and not competitors of traditional base load plants," said EDF. "To increase the proportion of wind and solar energy in our power generation mix as planned—and to ensure economic viability and supply security at the same time—we require energy storage and conventional power plants as a complement," said E.ON. "Until better technologies become available for the storage of electricity, wind farms usually require back-up from conventional forms of base-load power generation," said CLP Hong Kong Power. "[Variable renewables] mean that additional base load generation (traditional fuel sources) still must be built and interconnected to protect the system against unexpected generation swings" from renewables, said AEP.[24]

Oil companies as well use the variability issue to position renewables as merely an adjunct to fossil fuels. Said ExxonMobil, "intermittent sources such as wind and solar … must be integrated with other on-demand or "dispatchable" sources such as natural gas, coal, and nuclear."[25]

These traditional utility statements reflect historic views on the continued need for "base load" fossil and nuclear, and the perceived dependence of renewables on future energy storage technologies. Given many prevailing utility views that storage technologies are at least 20 years away, these utilities likewise see high levels of variable renewables 20 years in the future. In the shorter term,

Great Debate 4 | Is the Concept of "Base Load" Meaningful for Future Energy Systems?

Historically, as noted in this section, utilities have claimed that renewables are not "base load" and are thus inferior to conventional fossil fuels and nuclear. This claim was disputed by many experts, who pointed out that several different definitions of "base load" exist, some mutually inconsistent. Experts noted that meanings can be technical, economic, or institutional in nature, and that according to some meanings, renewables themselves would be defined as "base load." Thus, experts raised the question of whether the concept itself was meaningful in discussing future energy systems, or whether other concepts, many of them pointed to in this section, would better serve future thinking.

Notes and discussion: See Annex 4.

many utilities have focused on flexible use of natural gas. And indeed, gas companies themselves are projecting greater demand for natural gas in the future, driven by the need to balance variable renewables.[26]

Some utilities go further, to more controversial options: "Important research areas include … increasing the flexibility of lignite power plants," said Vattenfall. "When solar and wind [output declines], the base load is best balanced through flexible conventional power plants capable of ramping up and shutting down again quickly," said E.ON.[27]

Notwithstanding historic and current resistance by utilities to the integration challenge, it was clear to virtually all industry experts that utilities will eventually employ these options in increasingly creative, extensive, and broad-based ways to manage the variability of renewables and ensure stability. However, the manner, time frames, and extent of employing each of these options is still quite uncertain, said experts. Many expected to see these measures employed by utilities and grid operators to increasing degrees in the future, although perhaps over a relatively long span of 15–25 years. One utility manager from a Danish grid operator foresaw many flexibility measures implemented in the 2020–2030 time frame, including demand-response aggregation of many individual customers, competitive balancing-services markets, and addition of less-variable resources like CSP with embedded storage and offshore wind. Experts also expected to see new market rules and structures that recognize and place value on flexibility.[28]

Interconnection standards and net metering/billing for local distributed renewables (i.e., on customer rooftops) is another key element of utility-grid integration.[a] Net metering allows customers to benefit from retail electricity prices for any locally generated power that they supply back to the utility (rather than for self-consumption). In the absence of net metering, utility-set prices for reverse (customer-to-utility) power sales may be lower than retail electricity rates. An increasing number of utilities around the world are required by regulation to allow customer net metering for various sizes of installation.[29]

Integrating renewable energy at the power plant level with fossil fuels was another form of utility-grid integration pointed to by some experts.[30] (See Box 4.)

Finally, the broad range of technologies and practices implied by the term "smart grids" underlies the utility-grid integration challenge. *(See also Chapter 4 for more on smart grids at the local/city level.)* The concept of "smart grids" implies all of the necessary information and communication technology (ICT) infrastructure to implement the strategies noted in this section for balancing variable renewables on utility grids. The concept also implies the necessary ICT for much more efficient use of energy in buildings, transport, and industry that goes along with the integration of renewables into these sectors *(see following sections)*. And "smart grids" implies ICT for controlling local micro-grids and combining centralized generation, local generation, demand management, and energy storage at all levels.[31] *(See also "Great Debate 5" on page 27.)*

Box 4 | Hybrid Fossil Fuel/ Renewable Power Plants

Another way for renewables to integrate with utility power grids is through the hybrid combination of fossil fuel and renewable technologies at the power plant level. Some experts expressed optimism that such hybrid technologies would become a significant part of future energy systems, although few scenario models incorporate such hybrids. Said one power technology expert, "renewables advocates don't like to include fossil fuel technologies when talking about the future, but hybrid technologies need to be on the radar also."

Such hybrid technologies have been the subject of research and development for decades, much of it by the fossil fuel industry. And commercial applications have been growing, particularly for biomass co-firing with coal or gas in conventional power plants. There were some 100 co-fired plants operating in Europe, another 40 in the United States, and several in Australia and Japan.

Other hybrid technologies cited by experts include: (1) solar thermal power (CSP) plants integrated with combined-cycle natural gas turbines; (2) biomass and coal co-gasification systems to produce synthetic natural gas, with a typical mix of 20% biomass and 80% coal; (3) wind farms that are integrated with compressed-air energy storage and simple-cycle natural gas turbines to provide constant-output power from a remote location and thus maximize transmission capacity; and (4) CSP plants that preheat feed water for a coal power plant to increase its efficiency.

Source: See Endnote 30 for this chapter.

Buildings

Integration of renewable energy into buildings involves several technologies and forms of infrastructure, including solar heating and cooling, low-energy or "passive" buildings, district heating and cooling, small-scale combined heat and power (CHP) plants, biomass-fueled heaters and stoves, "building-integrated" solar PV, and thermal energy storage.[32]

Experts and scenarios underline that a transition to much higher efficiencies for buildings and heating and cooling equipment is fundamental to the integration of renewables. For example, GEA (2012) models a roughly 50% reduction in heating and cooling energy demand by 2050 through best practices in design, construction, and technology. This section presents many of the key technologies and infrastructure that experts and scenarios show will be part of future integration with buildings.[33] *(See also buildings and district heating in Chapter 4, and biomass technologies in Chapter 6.)*

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[a] *Net metering allows a two-way flow of electricity between the electricity distribution grid and customers with their own generation system. The customer pays only for the net electricity delivered from the utility (total consumption minus self-production). A variation that employs two meters with differing tariffs for purchasing electricity or exporting excess electricity off site is called "net billing."*

Great Debate 5 | Centralized or Decentralized Power Grids?

Industry experts, "decentralization advocates," utility managers, researchers, and other experts interviewed had widely divergent views on the question of distributed (decentralized) energy systems and the degree to which current centralized power systems will evolve into more decentralized and distributed versions.[a] Some believed that centrally managed grids would become relics, and envisioned networks of smaller, interlinked local grids with renewables and energy storage embedded throughout.

One expert said, "My intuition tells me we will head strongly to localized grids, with everything a distributed technology. Local semi-autonomous micro-grids will operate to minimize the balancing needs on the centralized systems, with sophisticated control systems, although the central grid remains available if needed." On the contrary, argued another expert, "I just don't see the case for the power system becoming like the Internet—the economic case still very much favors centralized power systems, as decentralized systems are more expensive."

Still others cited specific motivations and conditions that could herald distributed power systems. Constraints to building more transmission capacity were cited by several experts, who said that lack of transmission could force more distributed systems. For example, industrial companies that demand high reliability will increasingly find the desired reliability in local power systems rather than from centralized grids, claimed one expert. Another believed that "resilience" rather than "reliability" would drive the adoption of distributed systems—and called the resilience of distributed systems an "emergent property" that would counter shocks and disruptions.

Another expert thought that decentralized power systems would emerge strongly in rural parts of developing countries where centralized systems do not yet exist—and where adding new centralized systems will be expensive. "Rural electrification through mini grids will emerge as a major phenomenon … providing electrification at competitive cost to rural consumers," the expert said. *(See also developing countries in Chapter 5.)* And one expert pointed to the coming "logic of mini-grids" at the level of a small island, a remote rural community, an urban neighborhood, or an entire city. "Cities start to look like islands," the expert said.

On balance, many experts actually had little to say about distributed energy, simply believing that the future could be a balanced combination of both centralized and distributed, with renewables at all levels and scales. Centralized grids will still be needed to accommodate large-scale wind farms, including offshore wind, along with CSP and nuclear, they said. "The coming era of distributed generation will not necessarily seem like a revolution, but simply an evolution of current systems," one claimed.

Most scenarios do not address the issue of centralized vs. decentralized power systems. The Lovins/RMI (2011) "Transform" and NREL (2012) scenarios for the United States are two exceptions. Lovins/RMI models an electric power system in which fully half of renewable power capacity takes the form of distributed sources—700 GW of rooftop solar PV and 250 GW of distributed wind power by 2050—connected through interlinked micro-grids. Both scenarios show an 80% share of renewable electricity by 2050, but NREL only projects 85 GW of distributed solar PV.

Overall, a picture of power systems of the future emerged as a complex combination of on-site, mini-grid, and centralized grid levels, with renewables and natural gas generation and energy storage at all levels, and with all levels coordinated and interacting, according to a range of requirements for cost, reliability, flexibility, and service.

Notes and discussion: See Annex 4

■ *Solar Hot Water and Space Heating ("Solar Thermal")*

Solar thermal experts saw the integration of solar hot water and space heating into buildings as an extremely strong and continuing trend. In 2011, about 50 gigawatts-thermal (GWth) of new solar collectors were installed globally, enough new capacity to serve at least 25 million homes. China represents 60% of the global market, with about 120 GWth of capacity existing at the end of 2010. One Chinese solar thermal expert expected to see that capacity increase 5-fold by 2030, to at least 450 GWth. Other experts envisioned solar thermal collectors being integrated into building components in new and innovative ways. And they pointed to the growing use of solar "combi" systems, which provide both space heating and hot water, as an important future trend being led by Europe.[34]

Many experts believed that the highest-growth segment of solar thermal markets would become large systems for public and institutional buildings (i.e., hospitals, hotels, and schools), multi-family residences, and commercial buildings. Hundreds of such systems already exist in Europe and are appearing in other countries. One example is a recent solar thermal system in Riyadh, Saudi Arabia, for supplying hot water and heating to a university of 40,000 students. Installed in 2011, this system became the largest such installation in the world. Chinese experts envisioned large systems integrated with new commercial buildings. Solar for heating will also be used increasingly with district heating systems alongside biomass, noted one Danish expert, who said that, "in Denmark, solar-assisted district heating is booming because of the high price of gas."[35]

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[a] Some experts preferred the term "decentralized" rather than "distributed." One expert preferred to think in terms of "on-site" vs. "remote," because large-scale generation resources like wind turbines can also be "distributed" on local grids.

Solar Cooling

Experts pointed to solar cooling as a key future trend. Solar cooling involves the use of solar thermal systems to drive chillers for air conditioning and other cooling needs, often integrated with conventional cooling systems. However, experts claimed that solar cooling is most practical for new construction, as it is much easier to integrate with cooling systems when installing in new buildings, rather than when retrofitting existing buildings. Solar thermal-driven chillers have traditionally been used only in large buildings, but one expert suggested that much smaller solar chillers could be designed that would be competitive in residential homes, if designs could be fashioned with much lower costs and lower technical complexity.[36]

One of the key issues that solar thermal experts discussed was how to take integrated approaches to managing power, heating, and cooling together in buildings. They explained that in many climates, the electricity summer peak is driven by cooling, so renewable cooling can help shave electric peaks. And heating and cooling are connected because solar thermal systems that are sized for adequate heat supply in winter conditions are oversized for summer use, so excess capacity can be used for cooling in summer.[37]

District Heating

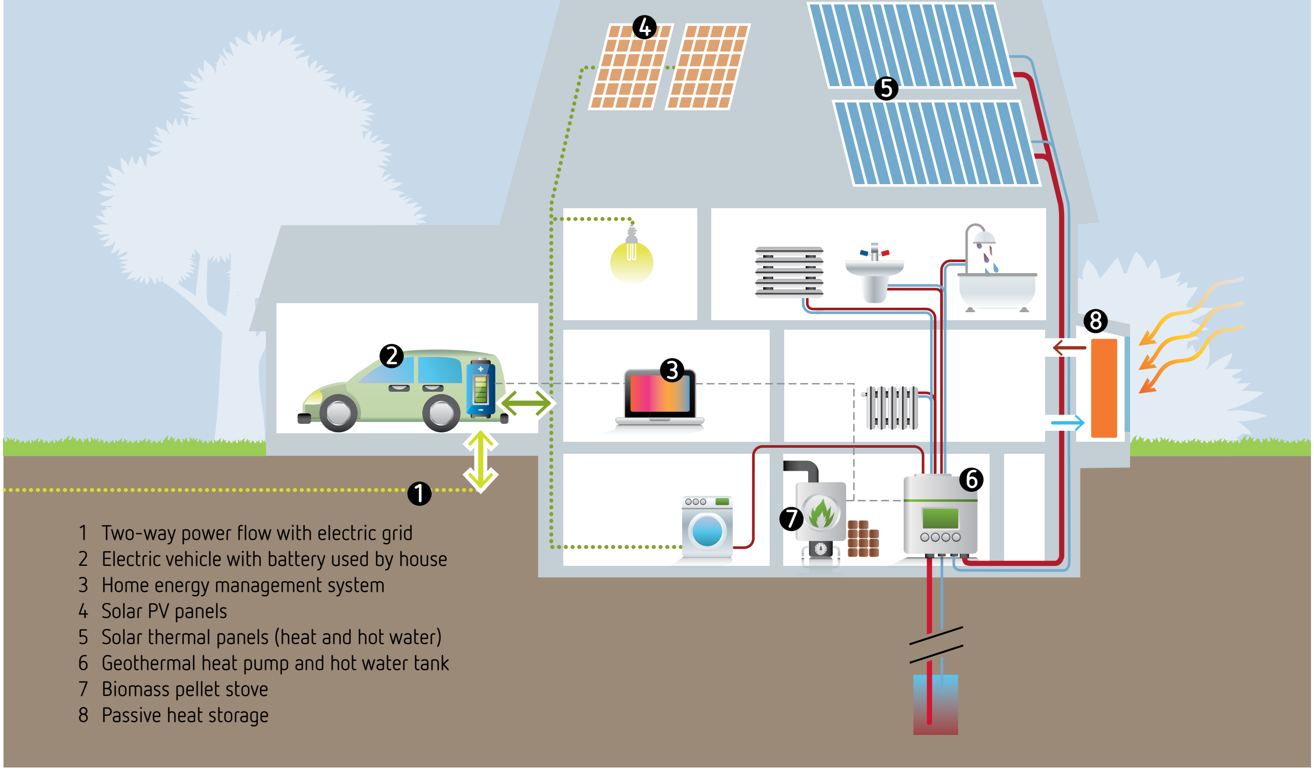
District heating using renewables is already widespread in many countries. In Northern Europe, many countries make extensive use of biomass in district heating systems. Many industry experts and scenarios project growing use of district heating to efficiently supply clusters of buildings and whole neighborhoods, fed from biomass (either heat-only or combined heat and power), geothermal, and to a growing extent, large-scale solar thermal systems. Greenpeace notes that, "the lack of district heating networks is a severe structural barrier to the large scale utilization of geothermal and solar thermal energy as well as the lack of specific renewable heating policy."[38] *(See also district heating in Chapter 4.)*

Low-Energy or "Passive" Buildings

Passive buildings are those with zero or minimal energy requirements for heating and cooling, due to highly insulated building envelopes with low thermal loss. The concept of a passive building also encompasses high-efficiency heating equipment, passive solar architecture for solar gains, solar day-lighting, and embedded thermal storage. European experts noted that passive buildings will be key to the 2010 EU directive for "nearly" carbon-neutral buildings by 2018–2020.[39]

With a passive house design, small amounts of renewable heating and cooling are sufficient to provide normal comfort levels in all seasons. A biomass pellet stove, and/or solar thermal system in suitable climates, can then provide most of the required heating energy for all-season comfort, perhaps with a gas boiler or electric heat pump as back-up. For groups of passive houses clustered close together, a shared solar thermal system or district heating system of relatively small size can be used as a community energy system because of the low heat demand. One passive building expert thought that such buildings would emerge as a strong trend by 2020—leading to a "passive house revolution"—due to a confluence of factors, including the EU directive, new building products, new thermal storage components, economies of scale in manufacturing, consumer awareness, and integration into architect/engineer training.[40]

Figure 4: Buildings: Integration Opportunities



Heat Storage

Heat storage integrated with solar heating and cooling was also seen as a coming trend, including both daily and seasonal storage. Coupled with low-energy buildings and passive solar gains, heat storage allows much higher shares of renewables for heating. Experts pointed to new storage technologies like phase-change materials and chemical storage. Said one expert: "phase-change materials have more potential but will take longer to develop, so we could see more chemical storage … The main advantage of phase-change is that it is more compact, and could also be used for seasonal storage." Thermal storage components can be integrated into new building designs or retrofitted in existing buildings.[41]

Building-Integrated Solar PV

A number of solar PV experts expressed the view that as solar PV reaches grid parity, building construction practices will make much greater use of so-called "building integrated" PV (BIPV). *(See solar PV in Chapter 6 for more discussion of grid parity.)* In 2010, an estimated 1.2 GW of the solar PV added was classified as building-integrated, or about 7% of the global solar PV market. The idea of BIPV encompasses several practices, first among them the use of solar PV-integrated building materials. Experts said that future BIPV roofing materials will evolve to higher efficiencies (to 14% from 8% today), increased reliability, and greater durability.[42]

One expert also pointed to the aesthetic issue of building-integrated PV, particularly for commercial buildings. "Solar PV will be seen as a cost of decoration, a cost of making buildings look good, like any other decorative façade material," said this expert.

Another expert envisioned that "solar glass" would become a common form of architectural glass, commonly available in architectural glass catalogs and routinely specified by architects. Since architectural glass shipping costs are relatively high, the integration of BIPV into architectural glass would become a local practice throughout the world. That is, local building materials companies would buy thin-film PV and integrate it on a roll-to-roll basis into building materials. Other common BIPV practices anticipated by experts include solar PV as a standard option integrated into prefabricated homes, and built-in solar PV connections and wiring when homes are first built to reduce "balance of system" costs.[43]

Industry

Integration of renewable energy into industry has been mostly limited to biomass heat and power in forest and food processing industries, using waste biomass residues. However, some industry experts claimed that industrial process heat applications were booming in other industries in some countries, citing Brazil and India. Experts in China also claimed that China was on the verge of a revolution in the use of renewable energy for industry.[44]

Much of industrial energy demand is for low-temperature heat, which can be supplied from renewable sources. Most low-temperature heat is today produced from medium-temperature heat, leading to losses. So substitution with renewables can save even more energy than the actual renewables input. Conventional solar thermal heating, biomass, and solar thermal power (CSP) will be three important sources of industrial process heat in the future, experts said. Solar thermal can supply low temperature heat, biomass can supply low- and medium-temperature heat, and CSP can supply heat at all levels but especially high-value, high-temperature heat.[45]

Many experts and scenarios note the potential for dedicated CSP plants coupled with industrial facilities, particularly water desalination plants. Said one expert of renewables integrated with industry: "… there is a long road to build trust in the technology through ensuring reliability. This will be a learning process. There are many new projects now, but most are still experimental. There is a lot of research, but much of it is confidential and not public."[46]

A report by UNIDO (2010), *Renewable Energy in Industrial Applications: An Assessment of the 2050 Potential,* was one of the first to comprehensively address the issue. The report notes that renewables play a relatively small role in industry today, but it finds that over 20% of all final energy use and feedstock in industry in 2050 could come from renewables. This includes contributions from biomass, solar thermal, and heat pumps by 2050 that together represent almost half of today's level of industrial energy use from all sources.[47]

The UNIDO report emphasizes future biomass use in energy-intensive industries such as pulp/paper, wood, cement, chemicals, and petrochemicals. The report projects that half of all solar thermal heat will be used in the food industry, with the remainder spread among other industries. The report also notes the potential for solar process cooling, primarily in the food and tobacco industries. The GEA (2012) "Efficiency" scenario echoes UNIDO's projection, and shows a similar long-term share of at least 45% of manufacturing energy from renewables. The IEA WEO (2010) concludes that, "overall, there is significant potential to increase the use of renewables in industry."[48]

The chemical industry also sees the potential to integrate solid biomass and liquid biofuels as industrial feedstocks. For example, Dow Chemical said, "while oil and natural gas will continue to be the predominant chemical feedstocks for the foreseeable future, much of the organic chemistry practiced today can be achieved using ethanol, seed oils and other biological sources such as algae." Huntsman noted: "the global push for renewable fuels is creating new sources of feedstocks for the chemical industry.… Increasingly, we believe our feedstocks for making differentiated chemicals will come from bio-based sources … [including] co-product glycerin from biodiesel manufacture, biodiesel itself, vegetable oils, and bio-ethanol. In addition, we are evaluating feedstocks from the agriculture industry to make new and novel bio-based products."[49]

Transport

Integration of renewable energy in road transport has so far involved the practice of blending 5–20% shares of ethanol and biodiesel with conventional vehicle fuels, and to a lesser extent, use of high-blend fuels with 75–100% biofuel shares. (High-blend ethanol requires specially designed or "flexible fuel" vehicles.) In total, biofuels supplied the equivalent of about 3% of global road transport energy in 2011, so the contribution of renewable energy to transport remains limited.[50]

In the future, there are several new vehicle technologies and fuel types possible that would greatly accelerate integration of renewable energy into transport. These include advanced biofuels, electric vehicles (including plug-in hybrids), hydrogen or methanol fuel-cell vehicles, natural gas vehicles, and compressed air vehicles. In the cases of these new vehicle technologies, renewable energy could supply a much greater share of transport energy by providing the electricity needed for electric vehicles, and by using renewables to manufacture hydrogen or synthetic natural gas fuels.[51, a] *(See also transport in Chapter 4 and biofuels in Chapter 6.)*

There are ongoing debates about the viability of all of these technologies. Debates about the future of electric vehicles involve battery cost, performance, and cycle life, and the prospects for continued battery technology improvement. Debates about hydrogen revolve around fuel-cell cost and performance, on-board hydrogen storage technology, and refueling infrastructure. Debates about natural gas vehicles revolve around refueling infrastructure and the efficiency of electrolyzer technology necessary for converting renewable electricity into synthetic natural gas.[52]

Experts offered many diverging views on how serious these issues were and over what time frames they could be resolved. However, many were of the firm opinion that renewable-powered electric vehicles would eventually dominate transport, some believing that this would begin to happen before 2020, and others seeing a "take off" in the period 2020–2030.[53]

Key to integration of renewables will be much more efficient, lightweight vehicles that can be powered by smaller amounts of biofuels or that utilize smaller, lighter batteries or fuel cells for electric vehicles, emphasized some experts. Amory Lovins and Rocky Mountain Institute, in their book *Reinventing Fire* (2011), make the case for super-efficient vehicles that require only one-quarter to one-tenth the energy of vehicles today, while still providing conventional size, performance, safety, and convenience. Key elements of their vision are lightweight materials, notably carbon fiber (as used today in the Boeing 787 and Airbus 380), and advanced manufacturing techniques and design that make the transition from metal to carbon fiber roughly cost-neutral.[54]

Another key will be electric "micro-vehicles," including small one-person or two-person commuter cars and two-wheeled cycles and scooters. In developing countries today, particularly India and China, markets for these micro-vehicles are already growing rapidly, noted several experts, who thought that developing country markets for such vehicles could become orders of magnitude larger than in developed countries. In general, many experts pointed to a growing diversity of vehicle types, sizes, and purposes, with more differentiated service niches, coupled with a wider array of ownership and mobility-service business models.[55] *(See business models in Chapter 3.)*

Conservative scenarios, particularly those by oil companies, generally project the continued dominance of fossil fuels in transport, with modest increases in biofuels use, and electric vehicles possibly making inroads by 2030–2040. For example, Shell says: "… biofuels are expected to play an increasing role in helping to meet demand for transport fuel. Shell predicts that their share of the global transport fuel mix will increase from 3% today to 9% by 2030." BP says, "Electric vehicles and plug-in hybrids, and the use of compressed natural gas in transport is likely to grow, but without making a material contribution to total transport before 2030." And ExxonMobil "expects to see growth in plug-in hybrids and electric vehicles, along with compressed natural gas and liquefied petroleum gas powered vehicles. However, these will account for only about 5 percent of the global fleet in 2040, their growth limited by cost and functionality considerations."[56] *(See also transport shares in Chapter 1.)*

Moderate scenarios project significant use of electric vehicles after 2025–2030 and much greater use of advanced biofuels. For example, the IEA WEO (2010) says, "electricity used in electric vehicles or in plug-in hybrids plays an important role in meeting transport energy demand in all three scenarios, especially in the "450" scenario." The WEO "450" scenario, the highest-renewable case, projects a 20 TWh aggregate battery capacity of electric vehicles and plug-in hybrids by 2035, representing hundreds of millions of vehicles. But the IEA notes that even in this case, only 45% of the electricity supplied to these vehicles would come from renewables, given the projected share of electricity from renewables in 2035. Thus, its "450" scenario puts greater emphasis on advanced biofuels.[57]

High-renewables scenarios project up to 50–80% of transport energy from renewables by 2050 from a mixture of electric vehicles (including plug-in hybrids), hydrogen fuel-cell vehicles, and advanced biofuels. A 70% renewables share is projected in the

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a) Of course, electric vehicles charging from centralized grids use power from all sources, not just renewables, and the proportion of power from renewables depends on several technical and operational factors; see Endnote 51 for this chapter.

Greenpeace (2012) scenario, which also shows electricity providing 44% of transport energy by 2050. This shift is accompanied by reductions in transport energy demand (60% less compared to the reference case), through shifts to smaller vehicles, reductions in distances traveled, shifts from road to rail, changes in behavior, and greater use of public transit. The GEA (2012) "Advanced Transportation" cases project some combination of electricity and hydrogen fuels delivering 20–60% of transport energy by 2050, depending on levels of overall transport demand by then.[58]

Automakers also offer many future visions. Almost all of the top-25 global automakers are developing plug-in hybrids and/or electric vehicles, and many appeared set to bring them to market in 2013–2014, following early leaders such as Mitsubishi, Nissan, BYD, Kia, and GM, which already introduced commercial products in 2009–2012. Mitsubishi envisions that 15–20% of its annual vehicle sales by 2020 will be electric and plug-in hybrid vehicles (following the commercial introduction of its iMiEV electric car in 2009).[59]

Automakers see the growth of electric vehicles tied to the development of local vehicle charging infrastructure. *(See Chapter 4.)* For example, Mitsubishi notes that worldwide sales of its iMiEV are doing best in Norway, where public parking facilities have been adapted to re-charge electric vehicles. BMW projects that 5–15% of its new vehicle sales will be fully or partially electric by 2020. Daimler and BMW both are also developing hydrogen fuel-cell vehicles, and part of their vision is the production of hydrogen vehicle fuels from renewables. Audi is developing natural gas vehicles, and part of its vision is the production of synthetic natural gas from renewables. Tata is developing an ultra-light fiberglass compressed-air car charged by electricity with a range of 300 kilometers. Many automakers are also introducing flex-fuel vehicles that run on high-share blends of biofuels.[60]

Visionaries thinking in the long term pointed to the integration of transport with electric power and renewables as a future "game changer." Such views, dating back to the 1990s, are gaining more widespread acceptance, they said. These experts envisioned millions of grid-connected electric vehicles providing grid balancing for variable renewables and controlled through smart grids—the so-called "vehicle-to-grid" (V2G) concept. Some named this aggregation of potentially millions of vehicles a "virtual power plant" that could be controlled by a utility subject to vehicle-owner-set parameters through "smart grid" technology. Automakers themselves have increasingly recognized this potential, and several now incorporate the notion of V2G into their own future visions, including Mitsubishi and Toyota.[61]

As part of the V2G paradigm, experts also pointed to electric vehicles integrated with near-zero-energy building technologies, micro-grids, and solar PV, in which the electric vehicle becomes part of the building's energy system and can supply power to the building (i.e., homes and offices) when parked. This has been called the "double use" concept. "It needs systems thinking," said one energy storage expert, referring to the need for automakers, equipment vendors, architects, and building developers to work together.[62]

Some auto companies seem to be pursuing this vision: for example, Toyota has introduced its "Smart Center" concept for homes that integrates home energy management, electric vehicles, local renewables, energy storage, and smart-grid control into a single system. In this concept, electric vehicle batteries would be "used as a household power source in emergencies," said Toyota, which implies less than full V2G integration. However, in 2012, Toyota also announced actual testing in Japan of "vehicle-to-home" systems (V2H) that allow routine power-sharing between home and vehicle. Nissan has a similar program for "smart houses" and development of local energy storage solutions.[63]

Beyond road transport, many scenarios show a transition to greater use of electric rail transport for freight in particular, and also for passengers. For shipping and aviation, experts believed that these transport modes would be much more difficult to integrate with renewables, and would require the longest time frame. Several airlines have demonstrated biofuel use in aircraft test flights in recent years, but experts noted that alternative aviation fuels are not available in sufficient quantities for use beyond small shares. Some scenarios ponder a major role for hydrogen in both shipping and aviation in the long term, but few model such by 2050. Most scenarios show some role for biofuels in shipping and aviation by 2050, but typically much less than for road transport. The IEA (2009) found that projections for biofuels in aviation ranged from a few percent to 30% by 2050.[64]

03

INVESTMENT FUTURES:

FLOWS, INVESTORS, AND BUSINESS MODELS

Annual investment in renewable energy reached US$ 260–290 billion in 2011 and is projected to increase annually through 2020 and well beyond. Innovative new forms of investment and finance are projected from new sources, such as pension funds along with new business models for energy services for households and businesses and for mobility services.

Finance experts interviewed in 2011 were quite optimistic about the clean energy sector in general. A typical expression was, "there is barely any renewable energy market that isn't getting raised in discussions for investment." One expert noted, "investors will reach the point—and this is happening already—where they perceive renewable energy as no more risky than 'standard industrial risk' for investments, equivalent to other standard forms of infrastructure investment." Another said that, "by 2020, renewables will be the leading energy class for investment."[1] *(Although global economic uncertainties in 2012 were clouding short-term business and investment prospects in many countries, such expert sentiments should be interpreted in a long-term context.)*

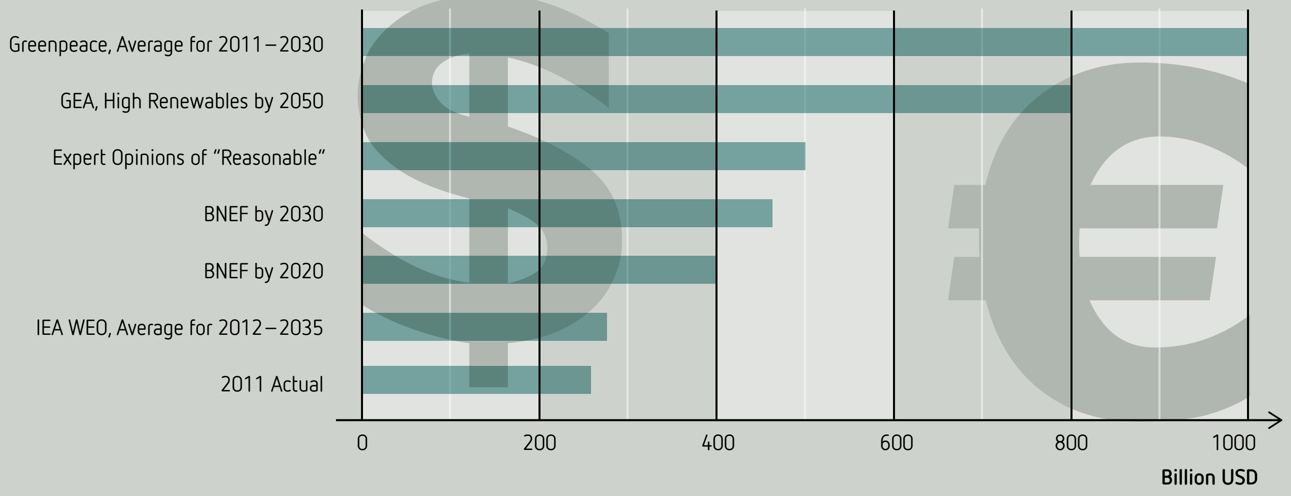
Global investment in renewable energy reached $260–290 billion in 2011, up from just $40 billion in 2004.[a] Solar PV received the largest share of annual investment, at $127 billion, followed by wind power at $84 billion. The year 2011 also saw record investment in solar thermal power (CSP) ($20 billion) and offshore wind power ($13 billion), offset by modest year-on-year declines in investment for biomass (to $11 billion in 2011) and biofuels (to $7 billion). Asset finance for utility-scale projects, biofuel refineries, and distributed projects together exceeded $160 billion. Globally, in 2011, net investment in renewable power capacity exceeded investment in all fossil fuel and nuclear power capacity combined. Since 2010, in fact, renewable energy has received more than half of new power-generation investment.[2]

Many finance experts interviewed in 2011 believed that annual private investment in renewables could exceed $500 billion annually by 2020. A few experts cited figures as high as $1 trillion by 2020. However, while most experts were generally optimistic about the opportunities for scaling up and extending many existing investment sources and mechanisms, some also cautioned that there will be a clear need in the future to go beyond current financing sources. These experts asserted that utility balance-sheet finance, bank lending, private equity, and venture capital are only scalable to a certain point, and would not support $500 billion-plus annual investment levels; to reach these levels would require the involvement of other institutional investors and new equity sources at both small and large scales.[3]

Scenarios also show large investment volumes in the future, although estimates vary over a wide range. At the low end, the International Energy Agency (IEA) *World Energy Outlook* (2012) projects a $6.4 trillion total investment in renewable energy during the 23-year period 2012–2035, or an average of $280 billion per year. This is roughly equivalent to the actual investment volume in 2011, so the IEA's projection does not show major growth in investment. Technology shares of this $6.4 trillion are led by wind power (33%), followed by hydro (24%), solar PV (20%), biomass and geothermal (12% together), and biofuels (6%). Investment in non-OECD countries accounts for fully half of the global total over the period 2012–2035, with larger investment shares for hydro relative to OECD countries, which in turn show larger shares for solar PV.[4]

Higher scenario projections for future investment better mirror the expert opinions noted previously. Bloomberg New Energy Finance (2011) projects $400 billion annual investment in renewable energy capacity by 2020, and $460 billion by 2030, three-quarters of which will be for wind and solar power. BNEF shows solar PV investment rising to $150 billion by 2020 and then remaining constant through 2030. It also shows wind power investment rising to $140 billion by 2020 and then $200 billion by 2030. And BNEF shows investment in biofuels, biomass, and waste-to-energy reaching $80 billion by 2020 and then declining slightly to $70 billion by 2030.[5]

Figure 5: Annual Investment Flows to Renewable Energy in Scenarios



Source: See Endnote 6 for this chapter. See Annex 2 for full scenario names and citations.

Notes: All scenarios are 2012 except BNEF is 2011; figures are for renewable energy capacity additions, although accounting methods and counted investments vary across sources, see endnote.

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a) *All dollar amounts in this chapter are in U.S. dollars. Investment data from Bloomberg New Energy Finance and Frankfurt School UNEP Collaborating Center, 2012,* Global Trends in Renewable Energy Investment 2012. *The numeric range shown here is approximated and reflects different reporting methods that include or exclude $10 billion for solar hot water and $25 billion for hydro projects larger than 50 MW. (Commonly reported BNEF figures exclude these items.)*

GEA (2012) projects up to $800 billion per year by 2050 in its highest-renewables case, but as low as $160 billion per year for some cases with low energy demand and high shares of nuclear power and carbon capture and storage. At the highest end of the projections, Greenpeace (2012) shows a $20 trillion investment in renewable energy during the 20-year period 2011–2030, or an average of $1 trillion per year. Greenpeace notes that "a major driving force for investment in new generation capacity will be the replacement of the ageing fleet of power plants in OECD countries and the build up of new power plants in developing countries."[6] (See Figure 5 for comparisons of annual investment flows across scenarios.)

Virtually all finance experts believed that investment and ownership in renewable energy will come from a broadening array of sources. In interviews, experts elaborated a wide range of investment sources, mechanisms, and models. These include insurance companies and pension funds, utilities, oil companies, retail investors, sovereign wealth funds, banks, public equity, and multilateral finance.[7]

Several experts pointed to the "unlocking" of pension funds and large institutional investors looking for stable, safe, long-term investments that could be guaranteed on 20-year time frames. Such "unlocking" could occur by creating ratings for renewable energy projects (asset finance), by lengthening feed-in tariff validity periods, by extending project design lifetimes, by reducing construction performance risk, and/or by insuring against wind-resource variability risk. Another mechanism for unlocking pension funds is utility-pension fund joint-ownership models, where a utility finances and builds a project with short-term funds and then sells a share of the project to pension funds. Dong Energy is one utility that has piloted this approach with 49% pension-fund ownership. Beyond pension funds, some experts pointed to sovereign wealth funds, particularly from oil-exporting countries, as a significant new source of finance.[8]

Utility companies themselves do not necessarily share the degree of optimism suggested by experts and scenarios. Nevertheless, over the past 20 years, utilities around the world have increasingly embraced renewable energy investments, either on their balance sheets, through the establishment of subsidiaries, or as investment partners. Hydro has been the preferred renewable investment by utilities for many decades, but since the 1990s, utilities have increasingly invested in wind power, and to a much lesser extent in other renewables. Industry experts pointed to progressive utilities as bellwethers of future industry-wide investment.[9]

Several utilities have announced multi-billion dollar investments in renewables over the next five years, including EDF, E.ON, RWE, and Vattenfall, and at least three of these are also targeting 20% or more shares of renewables by 2020. Some utilities have reached the point where over half of their generation assets are already renewable, including Iberdrola and Next Era Energy Resources. And some utilities have set climate-related targets: for example, Dong Energy targets a 50% carbon dioxide (CO_2) emissions reduction by 2020 and an 85% reduction by 2040 (relative to 2006). Notwithstanding these examples, many other utilities around the world see renewables as minor parts of their corporate strategies, or have yet to include renewables at all.[10]

Oil and gas companies do not necessarily envision large investments in renewables either. Many are investing in renewables, but still at relatively low levels, and indications are few that these companies plan large investments in the long term. French Total's announcement in 2009 that it would invest $2 billion in renewables during 2010–2020 was a large leap from the few millions it had been investing prior to that, but this still represents a very small share of the company's investment in oil and gas upstream activities. BP launched its Alternative Energy business in 2005 and committed to invest $8 billion over 10 years (and had reached almost $7 billion by 2011).[11]

Oil companies with recent investments and plans in the renewables arena include BP (wind), Chevron (geothermal, solar, wind), ENI (solar), Petrobras (solar, wind, hydro), Repsol (geothermal, wind), Sonatrach (solar), Statoil (geothermal, wind), and Total (solar).

Great Debate 6 | Will Utilities Lead, Follow, Push Back, or Perish?

With increasing levels of renewables, the business models and revenue streams of many existing utility and energy companies are coming under threat or stress. Some companies will lose market share, revenue, and even sufficient profit to continue to exist, many experts believed. How existing companies (called "incumbents" by some) decide to respond to that stress will shape how renewable energy develops in the future.

Experts believed that change is under way, and many were confident that utilities would rise to the challenge. One said, "utilities are already reevaluating their strategies, and this will certainly start to happen in the next 3–5 years, and then we'll see overall changes in business models and market structures in the 5–10 year time frame." Another commented that "utility resistance is declining with new business models, guided by new policy frameworks," and believed that, "the mindset of established utilities is changing—they are recognizing that if they do not change, they can't continue with business-as-usual."

However, not all experts were as certain that utilities would lead. Said one, "utility system transformation will emerge within five years, but led by external stakeholders, not by the utilities themselves." Another saw the utility leadership question as generational: "To transform the utility systems in the ways required, we are going to have to retire many existing power engineers."

One finance expert believed that some utilities will come under pressure to lead or perish quite soon, and predicted the "coming imminent collapse in financing of conventional centralized power generation assets in OECD countries." This expert explained that "solar PV will destroy the financing, economics, and operations of the traditional centralized networks much faster and with much larger negative consequences than anyone is discussing."

Notes and discussion: See Annex 4.

Great Debate 7 | What Roles Will Oil and Gas Companies Play?

Oil companies are a dominant part of our existing energy systems. Will they remain that way in the future? Clearly, oil companies are positioning themselves as biofuels suppliers in addition to many agriculture-based biofuels producers. Over the past decade, some oil companies have sought to position themselves as future suppliers of hydrogen from renewables, or have tried to get involved in small-scale solar or biomass projects, but with limited success. Some experts believed that offshore logistics capabilities will ultimately mean a major role for oil companies in offshore wind power given comparative advantages, but so far few oil companies have gone beyond expressing interest.

Notes and discussion: See Annex 4.

(Many oil companies are also investing in biofuels; *see Chapter 2*.) Some companies recognize in particular the comparative advantage they have for geothermal and offshore wind development. With environmental goals in mind, oil and gas companies are also investing in carbon capture and storage, natural gas generation, energy efficiency, and nuclear power—with renewables just one strategy among many and not necessarily the most important, company statements suggest.[12]

Beyond traditional energy companies, recent investment trends by private companies in a wide variety of other industries also suggest future investors. As just one example, Google has invested close to $1 billion in renewable energy projects in recent years.[13]

Finance experts suggested a variety of other new investment models and mechanisms that could take hold in the future, and cited examples of such models in use today. General categories include community ownership (co-ops and community-based utilities), direct ownership by business and retail power customers, ownership/leasing by equipment vendors themselves, ownership by large institutional investors such as pension funds, and ownership by national and local governments.[14]

Other investment mechanisms cited by experts include default insurance for utility power-purchase agreements, securitization of potentially thousands of rooftop solar PV loans (initiated through banks) into securities for long-term investors, and new ways to involve aggregates of many small investors in larger renewable energy projects. One such aggregation model cited is the U.S. model of master limited partnerships used in the oil and gas industry.[15]

Most experts foresaw continued markets for the "environmental attributes" of renewables, such as present-day green certificates and carbon trading. But experts also foresaw markets for these attributes expanding and diversifying in ways that are difficult to imagine today. Overall, a common sentiment was that "renewables will continue to be paid for their environmental attributes."[16]

In developing countries, finance experts saw a continued need for multilateral finance. Said one, "There are still political and geopolitical risks around the world … We'll see the multilaterals continuing to fill the gap and provide capital for renewable projects in addition to banks and institutional funds." But beyond multilateral finance, a number of finance experts also pointed to a "broadening and deepening" of finance sources in developing countries. A broader base of institutions, sources, and types of finance will emerge, including institutional investors, manufacturers, project developers, and other forms of foreign direct investment. And more finance will go to countries beyond the current major recipients (i.e., Brazil, India, and China), to include those countries currently considered "second-tier" and "third-tier."[17]

The often-cited risk of utility power-purchase agreements not being honored (also called "power off-take risk) will continue to be a major concern, said one expert. But policy learning, and finding new ways to reduce investment risks, including new types of structured investment funds and guarantee schemes, will be crucial to this deepening. Experts foresaw guarantee funds for power-purchase agreements, construction risk mitigation, and higher levels of equity from local investors. One expert projected that developing-country governments themselves would provide public equity in renewable energy projects, to share risks and leverage private finance.[18]

As noted in this report's introduction, some 120 countries around the world have some type of policy and/or target to promote renewable energy, and the number of policies keeps growing year by year. The IEA estimates that government support for investments in renewables will continue to increase in the coming decades through a variety of policy mechanisms. IEA WEO (2012) estimates that government support for renewables amounted to almost $90 billion worldwide in 2011.[a] This support grows to $240 billion annually by 2035 in the "New Policies" scenario.[19]

The IEA estimates that EU support for renewables will peak in the 2020s at around $70 billion annually and remain above $30 billion through 2035. U.S. government support will peak somewhat later, at about $60 billion before 2030 (compared to $15 billion in 2009). Chinese government support will exceed $30 billion during the late 2020s (compared to $3 billion in 2009), and government support in India will similarly reach almost $30 billion (although later—by 2035).[20]

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[a] "Government support" from policies is both direct and indirect, meaning that it goes beyond direct payments from government budgets. The IEA uses the term "subsidies" in a broader sense to mean "government support," where costs are met "either through government budgets (for example, tax credits) or by end-users collectively." The IEA defines direct subsidies as "tax credits for production and investment, price premiums and preferential buy-back rates (or feed-in tariffs)." Indirect subsidies "arise from mandates, quotas and portfolio standards, which support the uptake of renewables at higher costs to the economy or the consumer." (IEA WEO, 2012, p. 233)

Business Model Possibilities

Interviews revealed many interesting possibilities for business models in the future that could channel the future investment flows suggested in the previous section. Of course, private companies have been developing new models for renewable energy business and investment for many years already. In the coming years and decades, companies will continue to be successful with these models, while many new models will also emerge. It is difficult, of course, to say which models will succeed in the long term. In developing countries, experts pointed to demographics as an important factor, and cited innovative social and economic ideas by the younger generation as a setting within which renewable energy would grow. Across all countries, a selection of interesting possibilities follows, some of which are already being tested or used in commercial practice today.[21] *(See endnotes for specific examples of some of these models.)*

- **Third-Party Energy Services.** Third parties and utility companies will install, own, and operate solar PV on behalf of residents or building owners. A variety of companies will offer leasing and vendor-finance options. Third parties will bundle renewables investments with energy efficiency improvements, high-efficiency end-use equipment, and/or local energy storage for a true "energy services" business. Some companies will specialize in micro-grids that serve multiple buildings with electricity and/or heat, and offer a variety of models such as like energy-service, leasing, or co-op ownership. And as energy supply becomes more capital-equipment based at a local level, rather than commodity-based at a centralized level, companies will begin to offer households per-kilowatt capacity-based pricing plans (perhaps with kilowatt-hour (kWh) caps or time-of-day restrictions), beyond traditional per-kWh pricing—akin to the transition of mobile phone plans from per-minute billing to fixed billing plans with limits.[22]

- **Mobility Services.** Electric vehicle leasing companies will offer pricing plans based on the distance driven, including energy and battery costs. Fleet rental companies will provide short-term vehicle use in concentrated urban areas through smart-cards and membership, with vehicles charged through company-owned distributed renewable generation. Electric vehicles will become integrated with household-based renewable energy systems and packaged together with such systems. Electric vehicle "power integrator" companies will sell large blocks of energy storage and controllable charging (demand-response) to utilities, and contract with thousands of vehicle owners for intermediated charging control. Automakers will integrate renewable energy into their business by becoming producers of renewables-derived fuels, for example synthetic natural gas for use in natural gas vehicles. Automakers will also partner with local governments and property developers to build electric-vehicle charging infrastructure.[23]

- **Property-Assessed Clean Energy Loans.** Cities will borrow funds from investors and lend these funds directly to local property owners for additions of renewable energy and for energy efficiency improvements. Owners will repay the loans over long time frames, for example 20 years, through added amounts on local property tax assessments. A number of cities in the United States are already piloting this model (called "PACE") for both residential and commercial properties. One unique feature is that loans can be transferred to new owners if properties are sold, unlike conventional mortgage finance.[24]

- **Utility Business Models.** Utilities will offer on-the-bill financing for end-user investments. Utilities will use smart metering to create new consumer power-pricing models that offer rates based on time of use, capacity, reliability, and degree of curtailment allowed, among other characteristics. Utilities will tailor pricing models to the kinds of local-power infrastructure present on the consumer side. Local-scale utility companies, some based on the co-op model, will provide electricity and/or heating on the scale of a community, district, or small city, with most of their generation coming from local renewable sources. Emerging grid-based energy storage providers will sell energy storage services to utilities, end-users, or renewable generators, either through existing ancillary services markets or through bilateral contracts.[25]

- **Community and Cooperative Ownership.** Local communities and cooperatives will invest in renewable energy systems under joint-ownership models that also reflect new social models for energy services. This has started already in some parts of Europe, Japan, and the United States, and experts foresaw much wider use of community and cooperative models in the future. One "local power" expert cited examples of communities that have invested in local wind turbines, and have come to view wind power "as a normal part of life, not alien … especially if local inhabitants are part owners and see benefits from turbines locally." Cooperative models for multi-family or multi-building residential heat supply will also proliferate in the future, said experts.[26]

- **Industry and Retailer Involvement.** Industrial firms and retailers whose businesses depend on high levels of reliability will sign long-term power-purchase agreements with renewable energy generation companies for guaranteed availability and stable long-term pricing. These firms will also continue to purchase increasing quantities of green power products offered by a growing array of competing providers (in those jurisdictions where retail power competition is allowed). In retail products, a range of consumer labels and certifications will indicate the origin of embedded energy in products, such as the "WindMade" label indicating renewable energy content.[27]

- **Rural Energy Services.** In rural areas of developing countries, many new business models will emerge for provision of energy services, building on existing models and business activity. One expert noted that, "renewable energy companies [operating in rural areas] will more and more see themselves in the role of 'energy service' companies," rather than seeing themselves merely as technology providers. African experts foresaw a host of new business models bringing lower costs in the future that would spur rural use of renewable energy. For example, consumer-oriented organizations will increasingly train households how to build household biogas plants using the households' own labor and materials, and purchasing only technical components. These experts saw such "anti-turnkey" models proliferating in the future.[28] *(See also developing countries in Chapter 5.)*

Box 5 | Utility Business Models for Solar PV

In the United States, electric utilities are moving to employ innovative new business models for solar PV. Over the past several years, utilities have typically purchased solar power from third-party-owned facilities (through power purchase agreements), either larger ground-mounted systems connected directly to transmission grids, or smaller (less than 2 MW) systems on distribution grids. In fewer cases, utilities have directly owned or financed such facilities.

Many new business models are emerging that go beyond such historical patterns. Under one model—tax equity financing of third parties—a utility acts as a tax equity investor, often through an unregulated subsidiary. (One example is the Pacific Venture Capital subsidiary of Pacific Gas and Electric in California.) A second model is on-bill financing, in which a utility provides loans to its customers for investments in solar that are repaid on monthly utility bills. (Maui Electric in Hawaii is an example.) Equipment leasing is another model, in which a utility leases solar PV systems to its customers. (New Jersey Natural Gas is an example.)

Under a "community solar" model, a utility owns and operates a solar PV system serving multiple customers, located either at the point of end-use or on the distribution system, and sells the power from that system at a fixed long-term (i.e., 20-year) "solar rate" to those customers. One variation involves a utility selling power via fixed proportional shares of solar system output. (Examples include the Sacramento Municipal Utility District in California, Salt River Project and Tucson Electric Power in Arizona, and other municipal utilities.)

Source: See Endnote 29 for this chapter.

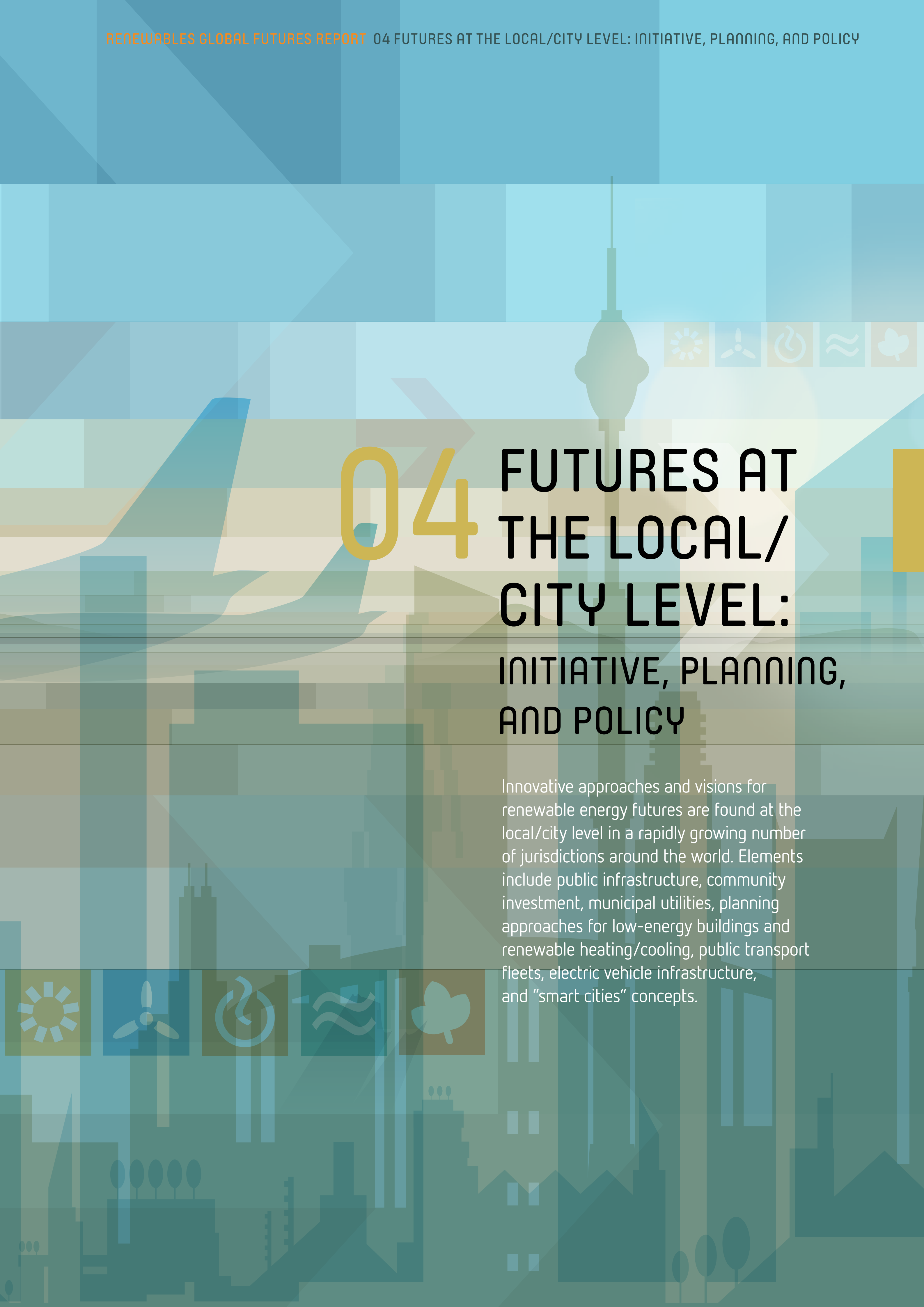
Great Debate 8 | Will Green Power Purchasing Scale Up Like Organic Food Has?

In many countries, consumers have a variety of options for purchasing "green" renewable energy—generally in the form of electricity, although in some countries voluntary purchases of "green" biogas, heat, and transport biofuels are also possible.
In 2011, green power sales continued to expand in a number of countries as price premiums for green power over conventional energy continued to decline. In the United States, regulations in several states require utilities or electricity suppliers to offer green power products; as a result, more than 850 utilities offer green pricing programs.

Experts noted that although green power sales are setting new records, green power is still a tiny fraction of total power sales. Some experts compared the situation to the early years of organic foods, and wondered whether households and companies would dramatically scale up their purchases from green power suppliers. (Experts noted that it also depends on the existence of policies that allow consumer choice of electricity supplier at the retail level, or that mandate utilities to offer green power options.)

Experts pointed to corporate purchases of green power as an encouraging trend, noting green power purchases among many leaders in corporate sustainability. "Corporate governance is heading toward climate and sustainability goals," said one corporate watcher, who believed that green power would increasingly fit those goals. However, some questioned whether other types of corporate models for renewable energy investment would become more significant than green power.

Notes and discussion: See Annex 4.



04

FUTURES AT THE LOCAL/CITY LEVEL:

INITIATIVE, PLANNING, AND POLICY

Innovative approaches and visions for renewable energy futures are found at the local/city level in a rapidly growing number of jurisdictions around the world. Elements include public infrastructure, community investment, municipal utilities, planning approaches for low-energy buildings and renewable heating/cooling, public transport fleets, electric vehicle infrastructure, and "smart cities" concepts.

Many regions, cities, and towns around the world are planning or envisioning their renewable energy futures.[a] In many respects, cities and local governments are at the forefront of meeting the integration challenges noted in Chapter 2 for buildings, transport, and even electric grids. And many of the business models noted in Chapter 3 are evolving through local initiative. In addition to a variety of planning approaches, specific policies for renewable energy can be found in hundreds of cities around the world. Such policies can include targets, subsidies, public investment, innovative financing, bulk procurement, green power purchasing, building codes, transport fuel mandates, municipal utility regulation, and many others. And local policies for renewable energy often complement, and in many cases go beyond, national-level policies.[1, b]

Interviews with local government officials and stakeholders, together with a range of local planning documents and published literature, suggest that in the coming decades, many cities and local communities around the world will have transformed their energy systems into much more localized and sustainable systems that integrate renewable energy in many possible ways.[2]

In the interviews, local experts envisioned greater use of local renewable resources of all forms, mixed with smarter, interconnected energy flows from neighboring or distant regions. They foresaw renewable energy integrated with intelligent energy management systems at a local scale, and with practices and technologies that maximize the use of local resources. And they foresaw this integration across all sectors: electricity, heating, cooling, and transport.[3]

The number of city and local governments engaged with their long-term energy futures is in the thousands. The most prominent collection of local approaches is the EU Covenant of Mayors, which has brought together more than 4,500 local governments from Europe and around the world to adopt future targets and plans for climate mitigation, energy efficiency, and renewable energy. Over half of the world's largest cities have adopted action plans for climate change, many of which explicitly target renewable energy for reducing greenhouse gas emissions.[4]

Many local emissions-reduction targets extend to 2020 and beyond, typically for 20–50% reductions from baseline levels, although some are higher. For example, Tokyo (Japan) targets a 25% reduction by 2020, Oslo (Norway) targets a 50% reduction by 2030, and both Chicago (USA) and Hamburg (Germany) target an 80% reduction by 2050. Stockholm (Sweden) has a unique emissions target: reduction of per-capita emissions to 3 tonnes of CO_2 by 2015. And cities in India such as Rajkot and Bhubaneswar target specific reductions in fossil fuel use. In addition, a number of cities and local communities around the world plan to use 100% renewable energy or aspire to become "carbon neutral" or "fossil fuel free."[5] *(See following "100%" section.)*

Hundreds of cities have established targets specifically for renewable energy, most to 2020 and beyond. There are several common types of target. One is the share of total electricity consumption within the local jurisdiction from renewable energy. Such electricity-share targets typically range from 10% to 30%. For example, Sydney (Australia) targets 25% by 2020 and Cape Town (South Africa) targets 15% by 2020. Some cities target the share of electricity consumed only by the local government itself, for its own buildings, vehicle fleets, and operations. Such "own-use" targets can range from 15% to 100%. For example, Austin (Texas) and Portland (Oregon) in the United States target 100%.[6]

Another type of target is the share of total energy from renewables, including transport and heating. For example, Calgary (Canada) targets 30% by 2036, and Seoul (South Korea) targets 20% by 2030. Some targets apply to biofuels use in public transport or vehicle fleets. For example, Stockholm (Sweden) targets 100% of public transit buses running on biogas or ethanol by 2025. And some targets are for total amounts of installed renewable energy capacity or number of installed units. For example, Los Angeles (USA) targets 1.3 GW of solar PV by 2020, Kunming and Dezhou (China) both target 50% of homes with solar hot water, and Iida City (Japan) targets 30% of homes with solar PV.[7]

The following sections present visions of future city and local government roles and infrastructure development, in terms of integration of renewables into urban planning and built infrastructure; urban mobility; emerging "smart cities" paradigms; and 100% renewable districts, cities, and regions. These visions emerged from interviews with city officials and stakeholders, along with documents accumulated from over 60 cities in Europe and in Brazil, China, India, Japan, Morocco, South Africa, and the United States.[8]

Integration Into Urban Planning and Built Infrastructure

A wide range of urban planning approaches and goals emerged from the interviews and documents. Experts envisioned investments in local infrastructure and urban landscapes that integrate distributed renewable energy across all sectors. To achieve this integration, they said that cities and local communities are increasingly focused on understanding, mapping, maximizing, and managing renewable resources—using tools like "smart grids" for electricity, heating, and cooling. Experts noted that urban planning approaches in particular include the integration of renewable energy into low-energy buildings and heating and cooling infrastructure. Urban planning can also include local control of municipal utilities and local power grid infrastructure.[9] *(See also buildings in Chapter 2 and "Great Debate 5" on page 27.)*

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a) Thanks to Lily Riahi for conducting research and interviews that formed the basis for this chapter, and for co-authoring the text.

b) For a full set of local policy examples beyond those in this chapter, see annual editions of the REN21 Renewables Global Status Report.

Low-Energy Buildings

Cities and local governments are shifting their focus from traditional "percentage savings" goals for efficient buildings to new goals of "near-zero" or "net-zero" energy use that includes on-site renewable energy. This approach utilizes a variety of planning approaches, new building codes, and building demonstrations. In Europe, the "Energy Performance of Buildings" directive took effect in 2011, requiring all new and retrofitted buildings to be near-zero energy use by 2020. The directive is driving many local communities in Europe to establish renewable energy targets for buildings, to revise building codes, and to alter permitting and land-use policies so that renewable energy is required or favored.[10]

Globally, hundreds of cities have demonstrated carbon-neutral and net-zero-energy buildings, using practices suited to local renewable resources. Experts envisioned that by 2050, most new and renovated residential and commercial buildings worldwide will be highly energy efficient and rely on renewable energy systems to ensure zero or near-zero energy use—that is, to produce at least as much energy as they consume. Experts saw net-zero-energy and/or carbon-neutral buildings becoming a key aspect of local infrastructure and planning. Such buildings have already begun to populate urban landscapes and are proving cost-effective compared to traditionally constructed buildings, experts said.[11]

Examples of Low-Energy Building Plans

Amsterdam has directed that all new developments be "energy neutral" starting in 2015. Portland (Oregon, USA) aims to achieve zero-net greenhouse gas emissions in all new buildings and homes by 2030. Hamburg (Germany) in 2009 enacted a Renewable Heating Act and Energy Efficiency Ordinance that will require new buildings to use renewable energy for a share of heating in real estate contracts. Other cities with low-energy building planning and codes include Adelaide (Australia), Albuquerque (USA), Austin (Texas, USA), Cape Town (South Africa), Chicago (USA), Edinburgh (Scotland, U.K.), Freiburg (Germany), Gothenburg (Sweden), Kyoto (Japan), Malmö (Sweden), Miami (USA), Munich (Germany), Sacramento (California, USA), Seoul (South Korea), Sydney (Australia), Vancouver (Canada), Växjö (Sweden), and Wellington (New Zealand).[12]

Heating and Cooling Infrastructure

Cities and local experts increasingly envision a future where urban district heating and cooling systems meet a large share of heating and cooling needs. Such systems incorporate a variety of renewable resources in heat-only and combined heat and power (CHP) configurations and can supply clusters of buildings or entire neighborhoods. Many contemporary examples exist of local district heating with renewables, particularly using biomass in CHP plants. Other sources of heat include deep geothermal steam or hot water, waste incineration, and waste industrial process heat.[13]

Experts also foresaw a larger role for CHP systems at the building level—so-called "micro-generation" using a variety of renewable fuels such as biomass and biogas, along with natural gas and landfill gas. In the absence of district heating or on-site CHP (or complementing them), renewable heating and cooling on a building level can come from solar-thermal collectors and ground-source (geothermal) or air-source heat pumps. One expert coined phrases for two [complementary] heating and cooling approaches: the "electricity building" that uses electric heat pumps and the "co-generation building" that uses CHP either on-site or through district systems.[14]

District cooling and on-site cooling can similarly make use of all types of renewable heat sources and configurations to provide space cooling with chillers, including geothermal heat pumps using ground, ocean, or lake sources. District cooling can also draw upon existing sources of heat like combined-heat-and-power plants. Indeed, district heating and cooling systems can be made to complement each other when there is a demand for both, and can also incorporate thermal energy storage. Some experts foresaw intelligent and integrated district heating and cooling systems using a variety of heat and cold sources and meeting a variety of customer needs. And experts emphasized that on-site renewable heating and cooling systems can integrate with or supplement conventional (HVAC) heating and cooling systems.[15]

Examples of Heating and Cooling Infrastructure

Solar hot water and/or heating in new building construction is mandated in Barcelona (Spain), Lianyangang (China), Rajkot (India), Rio de Janeiro (Brazil), and San Francisco (USA). Rosario (Argentina) is adding solar water heaters to public buildings. Xianying (China) plans to expand geothermal space heating six-fold. Copenhagen (Denmark) plans to supply heat to virtually all homes by 2025 with district heating and biomass CHP plants. Hamburg (Germany) allows individually owned solar thermal collectors to supply heat to the local district heating network. Hong Kong (China) plans a district cooling system using an ocean-source geothermal heat pump. Paris (France) is expanding a district cooling system using geothermal. Many cities have already reached high levels of heat supply from renewables: for example, Reykjavik (Iceland) meets 95% of its heating needs from geothermal, and Växjö (Sweden) supplies 90% of heat demand from renewables, primarily biomass.[16]

Local Power Grids and Municipal Utilities

Cities and experts noted that much can be done at the local level, including promotion policies and infrastructure planning, to develop local power grids that incorporate local renewable resources. (See also Box 6 on "Smart Cities.") However, experts also noted that such opportunities are limited by the degree to which local governments own or control their local grids, as most local distribution networks are owned and operated by regional or national entities. In this regard, experts noted trends toward municipal ownership or control of local power distribution and generation infrastructure.[17]

Municipally owned or controlled utilities allow local governments and citizens to play a much greater role in the planning and development of local power infrastructure. Several experts suggested models for how the presence of municipal utilities might accelerate local renewables development. For example, local governments could directly mandate utility investments, targets, or promotion policies that encourage private investment. Or a municipal utility could see renewables as a branding opportunity to differentiate itself from national and international utilities (which may also seek only larger-scale projects). Or, local governments could participate in profit-sharing schemes with utilities. Experts also noted trends toward municipalization or re-municipalization of local utilities (especially as existing concession/franchise agreements start to expire). For example, a number of cities in the United States and Europe are considering re-municipalization.[19]

Examples of Municipal Utilities

San Francisco (USA) established a new utility with the goal of providing the city with 100% renewable electricity by 2020. Austin (Texas, USA) mandated that its municipal utility reach a 30% electricity share from renewables by 2020, and actually reached that goal eight years early, in 2012. Boulder (Colorado) residents, unsatisfied with the existing regional utility's progress with renewables, voted in municipalization in 2012. Other cities with existing municipal utilities are quickly moving toward high shares of renewables, including Amsterdam (the Netherlands), Copenhagen (Denmark), Munich (Germany), Sacramento (California, USA), and Växjö (Sweden). In Germany, hundreds of municipal utilities are aiming at more renewables.[18]

Integration Into Local and Urban Mobility

Over the past two decades, cities and local communities have increasingly grappled with how to "green" local transport and incorporate renewable energy along with the full range of low-emissions and energy-efficient vehicles and strategies. Among many lessons, cities have been finding that rebuilding urban transport systems to incorporate greater shares of renewable energy requires a host of complementary measures. Cities around the world as diverse as Yokohama (Japan), Hamburg (Germany), and São Paulo (Brazil) have articulated visions and initiated specific projects and plans to make their transport sectors more efficient and to integrate renewable energy.[20] *(See also transport in Chapter 2.)*

In the future, cities and local communities will strive increasingly to integrate renewables into transport through the use of renewable electricity for both private vehicles and public transport (trains, trams, and buses). Hamburg (Germany), for instance, aims to convert its urban rail transit to be 100% renewable by 2050. Calgary (Canada) plans to run its entire urban transit system with wind energy. Freiburg (Germany) already runs its electric tram system on 100% renewables. Cities like Genoa (Italy), Hong Kong (China), Mexico City, and Sydney (Australia) are making large investments in the extension and electrification of their urban transport systems.[21]

Many cities are adding or converting to electric trolley buses and envisioning future fleets of battery-electric or fuel-cell buses, recognizing that electric mobility increases opportunities for integrating renewable energy. And a number of cities around the world are introducing charging stations for private electric vehicles, including Hong Kong (China), Yokohama (Japan), Amsterdam (the Netherlands), and Munich (Germany), while at the same time working to integrate renewables into local electricity supply and as direct power for such charging stations.[22]

Thus, cities clearly envision that the shift to electric vehicles will be accompanied by a shift toward renewable sources for vehicle charging. Many examples exist today that point to the future integration of renewables with electric vehicles at the local level. (Renewable supply can come either through direct renewable energy installations or through green-power purchases or certificates.) Austin (Texas, USA), for example, already powers its 50 electric-vehicle charging stations with green electricity. New York City and Chicago (USA) and Mexico City have all built solar-powered charging stations. Hamburg (Germany) plans that its current stock of 100 electric-vehicle charging points will be supplied from 100% renewable electricity. And the utility company in the Australian Capital Territory plans to power electric-vehicle charging stations in the city of Canberra with wind, hydro, and solar power.[23]

In parallel, most cities are investing in various ways to promote modal shifts from private vehicles to public transport that will also enable larger shares of renewables in transport. Cities envision a future with declining shares of private gasoline and diesel vehicles (and more use of hybrid vehicles), and with increasing shares of electric vehicles and bicycles that complement public transit and become a core part of a city's energy infrastructure. Taxis can be part of such strategies as well: Mexico City inaugurated a zero-emission taxi program to put 100 electric taxis on the streets by 2012.[24]

Cities are also increasingly using ethanol, biodiesel, and biogas to fuel public transit systems and public vehicle fleets, as well as promoting these fuels for private vehicles. Cities and experts envisioned

Box 6 | Emerging "Smart Cities" Paradigms

The idea of "smart cities" is an emerging local paradigm that many experts expected to see extended globally in the coming decades. Already, there are more than 100 announced "smart cities" projects around the world. As cities move toward sustainable and low-carbon infrastructure, they will increasingly use information and communication technologies (ICT) to develop "smart" energy systems that enhance energy efficiency and energy management, that maximize the integration of local renewables in buildings and local power grids, and that integrate electric vehicles in effective ways.

Cities and experts alike viewed ICT and "smart" systems as playing a distinctive role in the future process of "greening" urban infrastructure. They envisioned "smart" systems at the local level that handle increasing amounts of variable renewable energy from local sources, incorporate local energy storage, and provide greater flexibility, efficiency, and transparency in the power distribution grid. *(See also Chapter 2 for discussion of renewables integration into utility grids, buildings, and transport.)*

Smart buildings. As buildings and homes become low-energy, "passive," or zero-emission, intelligent energy management will play a greater role. Transition to these types of buildings will employ greater efficiency, on-site energy generation, and real-time information on energy use for both the consumer and the energy network. A major step toward these goals will be widespread deployment of smart meters mandated by local authorities or national governments. Connected to an energy management system, these meters will allow owners to have real-time information about the energy consumption of their homes and buildings in terms of heat and power systems. Such "intelligent building information systems" are paving the way for greater integration of renewables into building infrastructure and the grid.

Smart grids. "Smart grids" refers to a wide variety of innovations for future electric grids. *(See Chapter 2.)* At the local level, "smart grids" can mean many things, such as local energy consumption management ("demand response"), integration and balancing of distributed and variable renewable sources, grid balancing with energy storage, enabling of so-called electric vehicle-to-grid (V2G) and vehicle-to-home (V2H) applications, and optimum control of renewable-linked heat supply and combined heat and power (CHP) systems. Some cities even envision smart-grid control of so-called "virtual power plants" that combine citywide distributed renewables into flexible aggregated power at the city level. Cities and local governments envision many benefits from smart grids, foremost a stable, efficient, and resilient energy system, as well as the ability to incorporate higher levels of local renewables.

Smart transport. Under "smart" paradigms, cities will promote electric vehicles not only to reduce emissions and improve air quality, but also to enable "smart" charging to smooth energy demand and store energy to balance variable local renewables. Experts emphasized that such coordination will be important to ensure that electric vehicles do not place stress on local power grids and cause overloads. Yokohama, Japan, for instance, aims to introduce electric vehicle charging stations that also provide embedded energy storage. And electric vehicle charging and discharging will provide energy storage capacity for balancing variable renewable energy at lower cost. *(See Chapter 2 on power grid and transport integration for more discussion.)*

Hundreds of cities and local governments around the world are working actively toward ICT-rich smart buildings, smart grids, and smart transport. As one example, Boulder, Colorado (USA) plans to invest more than $100 million in creating a smart grid for the city. Many other active examples can be found, such as Amsterdam, Beijing, Buenos Aires, London, Moscow, Paris, São Paulo, Singapore, Seoul, Stockholm, and Sydney. A number of cities in developing countries are also following suit by more incrementally introducing ICT technologies, such as Delhi, Dhaka, Johannesburg, Karachi, Lagos, and Manila. Although the level of ICT integration varies from city to city, and local technological capabilities and skills are key to progress, many cities acknowledge the important role that ICT and "smart" paradigms will play in their future transformation.

Source: See Endnote 17 for this chapter.

this trend continuing for decades into the future, and foresaw many transit systems becoming 100% renewable fueled. For example, Johannesburg (South Africa) is introducing a fleet of ethanol-fueled buses. In Brazil, São Paulo and Rio de Janeiro collaborated on a pilot project to fuel city buses with a biodiesel blend, and Curitiba is expanding its bus fleet to 140 pure-biodiesel buses. São Paulo is also promoting "flexible fuel" vehicles that run on a much wider range of gasoline-ethanol blends.[25]

In India, New Delhi plans to fuel its bus fleet with biogas produced at local sewage treatment plants. In Japan, Kyoto will fuel public buses with biodiesel from waste cooking oil. Portland, Oregon, in the United States requires all vehicle fuels sold within city limits to be biofuel blends. And both Hong Kong (China) and Wellington (New Zealand) plan to add biofuels to their transport fleets. In Denmark, Frederikshavn fuels local transit from biogas and bio-methanol derived from waste, straw, and manure, along with growing numbers of electric and fuel-cell vehicles.[26]

Finally, cities are employing urban-density strategies, such as pedestrian zones and bike-sharing systems, to encourage greater use of human-powered transport. Barcelona, Berlin, London, Melbourne, Mexico City, Montreal, and Paris, among others, already have bike-sharing systems, while Sochi (Russia) and Genoa (Italy) are among those planning investments. Experts believed that these trends will lead to further integration of renewable energy, as most of these cities also aim to deploy electric bikes, which can then be powered from renewables.[27]

Local Visions and Actions for 100% Renewable Communities

Growing numbers of regions, cities, towns, and communities are envisioning "100%" renewable energy futures for themselves in the long term. Already, a number of small towns meet 100% or close to 100% of their electricity and heating needs from local renewable energy sources. Examples include Güssing (Austria), Samsø and Thisted (Denmark), Dardesheim and Schönau (Germany), Varese (Italy), and Kuzumaki (Japan). Some of these communities also produce "surplus" renewables that they use to offset fossil fuel transportation, and thus can declare themselves "100% total energy."[28]

Many medium-size cities aim to transition to various forms of "100%" in the coming decades, such as Fredrickshavn (Denmark), Moura (Portugal), Malmö (Sweden), and San Francisco (USA). Larger cities, with populations over 1 million, are also working toward various "100%" or "near-100%" goals in time frames ranging from 2025 to 2050, and have set benchmarks along the way. Examples include Copenhagen (Denmark), Hamburg and Munich (Germany), Gothenburg (Sweden), Rizhao (China), and Sydney (Australia).[29]

While some cities have set explicit 100% renewable energy visions, others have instead established carbon-neutral or fossil-fuel-free goals that imply moving toward 100% renewable energy. In Sweden, Växjö aims to be fossil-fuel-free by 2030, and Gothenburg and Stockholm aim for the same by 2050. Copenhagen, Denmark, plans to be the world's first carbon-neutral capital by 2025. Many cities have also set specific carbon-reduction targets, many of which are in the range of 40–80% reduction from 1990 baselines by 2050, often with incremental goals to be met in 2025 or 2030. A wide range of other cities aim to become "green" cities in the 2030–2050 time frame, such as Sydney (Australia), Toronto and Vancouver (Canada), Paris (France), Berlin (Germany), Amsterdam (the Netherlands), London (U.K.), and Chicago, Portland, and Seattle (USA).[30]

The integration of renewable energy in the urban environment is also being advanced through the development of zero-emission or renewable energy neighborhoods and districts within cities. As large cities transition to decentralized renewable energy supply, they envision starting with smaller 100% renewable energy neighborhoods and districts. Local authorities are advancing the integration of renewable energy through self-sufficient communities within the larger city environment. Such districts allow for a step-wise scale-up of renewable energy and help local authorities to gain best practices, encourage business engagement, demonstrate innovations, and gain public interest and acceptance. Several cities such as Vancouver (Canada), Copenhagen (Denmark), Helsinki (Finland), Hamburg and Munich (Germany), Rotterdam (the Netherlands), Stockholm and Malmö (Sweden), and London (U.K.) have planned or begun implementing zero-emissions districts.[32]

National and local governments also plan a number of 100% renewable energy cities to be newly constructed "from the ground up." Examples include "Masdar City" in the United Arab Emirates, "PlanIT" Valley in Portugal, "Songdo" in South Korea, and "Tianjin Eco City" in China. Planned populations for these cities range from the thousands to the hundreds of thousands.[33]

Example of 100% Electricity

Munich, Germany, plans by 2025 to meet all city electricity demand from 100% renewable power through a combination of local capacity and out-of-city capacity ownership that provides renewable energy certificates. Local capacity will be a mix of hydro, solar PV, geothermal, biomass, biofuels, and biogas. The plan also envisions profiting from investments in renewable energy capacity Europe-wide in sufficient quantity to cover local demand, including solar PV farms in the German states of Saxony and Bavaria as well as in Spain, and wind farms in the North Sea.[31]

05

FUTURES AT THE NATIONAL AND EU LEVELS:

MARKET GROWTH AND POLICY SUPPORT

National renewable energy markets are projected to grow strongly in the coming decade and beyond, as shown by current policies and targets, and by scenario and expert projections. Snapshots of Europe, the United States, Japan, China, and India show many emerging and possible developments. Projected markets in a much greater number of developing countries will create a diverse geographic base.

This chapter provides brief national-level market projections and policy discussions for Europe, the United States, Japan, China, and India.[a] The chapter then covers more generally a range of market and policy points for developing countries considered together, including some specific national policy targets, plans, and market projections in a number of developing countries, as well as some regional projections for Africa, Asia, Latin America, and the Middle East.[1]

In interviews with national experts, many emphasized the strong linkage between market growth and future policies in these countries.[2] (*See "Great Debate 2" on page 13 for a fuller discussion of these linkages.)*

In a short space, it is impossible to provide the full range of market projections and policy discussions for all countries and regions. The reader is referred to the online supplement "Topical Discussion Report," which contains fuller country-specific information, including expert-contributed milestones and more "Great Debates."[3]

Europe

Europe's target for a 20% share of total final energy from renewables by 2020, adopted in 2008, coupled with feed-in-tariffs and many other strong support policies that date back a decade or more in many EU countries, have been instrumental in making Europe a global leader in renewable energy.[b] Many European experts believed that Europe would continue this leadership, although perhaps at a reduced pace given economic difficulties and the clear ascendancy of China in wind power since 2009, and solar PV more recently. European renewable energy advocates are pushing for a further target for 2030, such as the 45% target proposed by EREC (2011). Many experts believed that such a target was feasible and integral to Europe's continuing policy and market leadership in the 2020s.[4]

Industry experts were quite optimistic about wind power in Europe, both onshore and offshore, an optimism that is reflected in current scenario projections and also national targets. National policy targets for wind power by 2020 include Denmark (50% of its electricity); France (19 GW onshore and 6 GW offshore), Italy (12 GW onshore and 0.7 GW offshore) and Spain (35 GW onshore and 0.8 GW offshore). By 2030, two high-renewables scenarios show 400–500 GW of wind power in Europe (EWEA, 2011, "Pure Power," and GWEC, 2012, "Advanced"). By 2050, EWEA believes that wind power could supply half of Europe's electricity.[5]

European solar industry experts expressed optimistic visions for the adoption of solar PV throughout Europe as well. One expert projected that solar PV in Europe would reach 130–400 GW by 2020, reflecting three cases from "baseline" to "accelerated" to "paradigm shift." (For comparison, Europe had 51 GW in 2011.) Germany alone targets 52 GW by 2020, the expert noted, and believed that Germany would perhaps reach 60–70 GW. Beyond 2020, Europe-wide growth might level off somewhat, some experts thought. EREC (2010) projects 400 GW by 2030 and 1,000 GW by 2050 for Europe.[6]

Experts were optimistic about biomass for heating and combined heat and power (CHP) plants, especially in northern European countries. Biomass-based district heating systems, individual biomass (pellet) stoves, and biofuels for transport were all cited as high-growth markets in the future.[7]

European policymakers and industry experts highlighted several key areas of future policy in Europe that could influence future markets. These include: an EU-wide target for 2030, EU-wide grid infrastructure planning and strategy, a coming EU directive on the energy performance of buildings, the time frames for continuing and then phasing out policy support mechanisms like feed-in tariffs (many saw phase-outs starting in 2020–2030), the future of carbon policy and the Emissions Trading System, standardization ("harmonization") of electric utility rules and regulation, support for centralized versus decentralized investments, and local standards and codes for renewable heating. Many of these issues are the subject of current debates or were expected to become central debates in the coming years.[8]

Great Debate 9 | How Will Feed-in Tariffs Evolve?

Given lower technology costs, higher support costs to consumers as markets expand, and higher renewable power shares on grids, some European experts questioned how long Europe's policy support mechanisms would be needed, or how long governments would maintain them. Some saw the evolution of many support mechanisms during 2020–2030 to meet changed market conditions and power grid integration needs. And many saw continued policies through 2030 and beyond, particularly if a new target for 2030 is adopted, such as the 45% share proposed by EREC (2011). At least one scenario, Eurelectric (2009) "Power Choice," projects a phase-out of support mechanisms by 2030. Some experts believed that net metering policies were on the rise, and that as solar PV reaches and goes beyond grid parity *(see solar PV in Chapter 6)*, solar PV feed-in tariffs would evolve over time into net metering policies. *(See footnote on page 26 for definition of net metering.)*

Notes and discussion: See Annex 4.

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a) Throughout this chapter, market growth is reflected mainly in gigawatts (GW) of renewable power capacity. To put these GW figures in some context, refer to Table 4 on page 53, and also see the online supplement "Glossary and Basic Energy Concepts." Markets are typically measured in annual GW capacity added or the growth of total GW capacity existing, the former typically denoted by "annual market" and the later by "capacity" or simply a GW or percentage growth figure. Another common metric is growth of the annual market, meaning year-on-year increase in annual capacity added. These three distinct metrics can confuse unaware readers. Furthermore, capacity in GW is only partially indicative of total power generated (actual benefit received), as the same capacity of different types of renewables (or of any energy technology) in different conditions will provide widely different amounts of actual power generation.

b) The Europe 2020 target includes a 10% target for transport. National action plans could collectively reach a 21% share for heating. See Chapter 1 for discussion of country-specific targets for EU member countries. EC JRC (2011) expected Europe to slightly exceed these shares by 2020.

United States

Scenarios show a wide range of long-term market growth for renewable energy technologies in the United States. (See Table 3.) However, many U.S. experts foresaw great policy uncertainty beyond 2013 and believed that long-term renewables markets in the United States will be strongly tied to how policy decisions get resolved in the coming years. These experts wondered about extension of the Investment Tax Credit (which expires in 2016) and the Production Tax Credit (which was to expire in 2012 for wind and in 2013 for other technologies), as well as air quality regulations, carbon policies (or lack thereof), and fossil fuel subsidies.[9]

Many policy experts pointed to continuing strong state-level policy support as the foundation for continued growth in future markets, including Renewable Portfolio Standard (RPS) policies in a majority of states, as well as a variety of other subsidies and support mechanisms at the state level. Experts also were quite certain that new utility regulations were coming, at both the state and federal levels, to facilitate the integration of renewables at higher shares on power grids, including "smart grid" planning and grid management.[10]

Some U.S. solar experts foresaw growing solar PV markets regardless of policy outcomes, as unsubsidized solar PV reaches "grid parity" with residential electricity rates over the coming decade in more and more states, starting with high-rate states like Hawaii and California. *(See solar PV in Chapter 6 for more discussion of grid parity.)* One expert projected a huge increase in solar PV capacity in the coming years, from 70 GW in 2015, to 100–140 GW by 2020, to several hundred GW by 2030. (For comparison, 4 GW existed in 2011.) Going even further, the Lovins/RMI (2011) "Transform" scenario shows 700 GW by 2050 in a fully half-decentralized energy system.[11]

Still, many experts acknowledged the large impact that U.S. federal policy would have on future markets. For example, one expert projected an annual market of 5–6 GW per year by 2020 if the Investment Tax Credit were extended, but much slower growth in the absence of the credit. (For comparison, the annual market was 1.9 GW in 2011.) Another expert emphasized the role of state net metering policies and other state-level support in future markets, with or without the Investment Tax Credit. Some experts foresaw a broad array of applications for solar PV beginning to boom in the period 2013–2015, especially for commercial rooftops, which soon would capture half the market, some said.[12]

Likewise, U.S. wind industry experts foresaw continued growth of wind power markets regardless of policy outcomes, but much faster growth and larger markets if the Production Tax Credit is extended beyond 2012. For example, one expert projected an annual wind power market of up to 15 GW per year over the coming decade with continuation of the credit, but only 2–4 GW per year if the credit expires and wind markets rely solely on state-level RPS policies for support. (For comparison, the annual market was 7 GW in 2011.) "We really need the [Production Tax Credit] in the U.S. for 10 more years to become competitive," said the expert. Another expert added that the future of wind power also depends on whether state utility commissions take fuel price risk into account in regulatory frameworks.[13]

Japan

Following the Fukushima nuclear accident in March 2011, Japan was in the process of finalizing its "national green policy strategy" in late 2012. Proposed versions of this strategy have targeted a complete phase-out of nuclear power by 2040, as well as a 30% share of electricity from renewables by 2030. Japan also enacted a milestone feed-in tariff policy in late 2011 that began to change perceptions of Japan's renewable energy future, both within Japan and internationally. Markets for solar PV, wind, geothermal, biomass, and small hydro are all supported by the feed-in tariff. During 2012, there were regular announcements in the press of planned renewable energy projects by Japanese companies, including dozens of planned megawatt-scale solar PV plants.[14]

Japanese policy targets for 2020 include 33 GW of solar PV, 9.5 GW of wind, 1 GW of geothermal, and 4 GW of biomass. Dozens of local governments throughout Japan also have targets for shares and amounts of renewable energy for their cities and regions. (This now includes Fukushima Prefecture, which is targeting a 100% renewable energy share by 2040.) Japanese renewable energy experts

Table 3: U.S. Renewable Power Capacity by 2030–2035 and 2050 in Recent Scenarios

	Wind	Solar PV	CSP	Biomass	Geothermal	Ocean
	GW					
Actual 2011 Capacity for Comparison	47	4	0.5	14	3	0
By 2030–2035						
DOE EIA *Annual Energy Outlook* (2012)	70	8	1	6	6	—
IEA *World Energy Outlook* (2012) "New Policies"	160	70	10	40	8	1
IEA *World Energy Outlook* (2012) "450"	270	120	60	50	12	1
Greenpeace *Energy [R]evolution* (2012, U.S. edition)	650	390	140	1	50	15
By 2050						
NREL *Electricity Futures Study* (2012) "80% ITI"	460	170	60	80	25	—
Lovins/RMI *Reinventing Fire* (2011) "Renew"	500	480	80	40	15	—

Sources: See Annex 2. Actual 2011 from REN21 Renewables Global Status Report, *2012. Some figures rounded to nearest 5 or 10 GW from original sources. CSP stands for solar thermal power.*

were particularly optimistic about the future of solar PV, geothermal, and offshore (including floating) wind power. These experts acknowledged, however, many practical and policy difficulties facing investors and developers in the future. These include permission for geothermal drilling in national parks, land-use issues in high-wind coastal areas, transmission interconnections for onshore wind power, and offshore wind turbine interference with fishing and shipping.[15]

One Japanese solar PV industry executive projected that solar PV capacity could reach 100 GW in Japan by 2030, for an annual average market of 5 GW per year. He also believed that Japan could attain a 50% share of residential electricity use from solar PV by 2030, and that half of Japan's solar PV would be installed on residential rooftops, one-quarter on commercial rooftops, and one-quarter in utility-scale "mega" plants. (For comparison, Japan had 5 GW of solar PV capacity existing in 2011, with an annual market of 1.3 GW in 2011.) An older NEDO (2009) "PV Roadmap" projected an annual solar PV market of 6–12 GW by 2030. Greenpeace (2011) shows 100 GW existing by 2030.[16]

For wind power, industry experts projected 20–50 GW by 2030–2050. (For comparison, Japan had 2.5 GW of wind capacity in 2011.) Wind power capacity in scenario projections for 2050 range from 50 GW (Japan Wind Power Association, 2010) to 70 GW (Greenpeace, 2011). An older NEDO (2009) "White Paper" projected only 7 GW of wind power by 2030.[17]

China

In 2010, China became the global leader in renewable energy, in terms of annual investment, taking that title from Germany, which had held it for several years. Scenarios and expert opinion suggest that China will remain the global leader in the coming decades. A number of new renewable energy policies have been enacted since 2005, including feed-in tariffs, quotas for electric utilities, biomass power development programs, and solar PV support policies in some provinces. Most Chinese experts interviewed in 2011 seemed to take China's future leadership almost for granted, as if there was no turning back.[19]

Of all technologies, Chinese expert projections for hydropower were the most certain. In 2011, China had 212 GW of hydropower, including about 18 GW of pumped hydro. Experts consistently cited 400 GW as the ultimate level, and believed hydro would grow to 300–350 GW by 2020, consistent with an existing policy target of 300 GW for 2020. They believed that hydro would then reach 400 GW before 2030. In line with these, BNEF (2011) shows 400 GW by 2030. Beyond 2030, scenarios show a leveling off, with projections for 2050 in the range of 380–430 GW (LBNL, 2011; Zhang et al., 2010; China ERI, 2009). The ERI projection includes 60 GW of pumped hydro by 2050. Plans announced by State Grid in 2010 call for 21 GW of pumped hydro by 2015 and 41 GW by 2020.[20]

Projections for wind power were wider-ranging than hydro but still fairly consistent. In 2011, China had 62 GW of wind power, the highest of any single country. China's wind power target increased step-wise over several years, and by 2012, stood at 200 GW by 2020. All industry experts interviewed in 2011 believed wind power capacity would reach 150–200 GW by 2020. China added 18 GW of new capacity in 2011, and most experts saw continued 15–20 GW annual markets through 2020.[21]

Box 7 | State-Provincial Markets and Policies

State-provincial level markets and policies have been a significant feature of renewables' historical evolution, and many national experts pointed to leadership at the state-provincial level as a continuing driver in the future. Support policies, policy targets, utility regulation, and many other forms of local market support can be seen in U.S. states, in Canadian provinces, in Japan's prefectures, in Australian states, in Indian states, and in Chinese provinces. In many other countries, sub-national policies for renewables are a part of the national policy landscape.

In Canada, several provinces have policy targets or renewable portfolio standard (RPS) policies, and five provinces have capacity targets for wind power before 2020, ranging from 0.5 to 7 GW each, including Alberta, Manitoba, New Brunswick, Ontario, and Quebec. In Japan, at least two prefectures, Fukushima and Nagano, target 100% renewable energy in the long term, as a consequence of the Fukushima disaster, and other prefectures, such as Kanagawa, are active with policy. The roles of states in the United States and India are mentioned elsewhere in this chapter.

Biofuels blending mandates exist at the state-provincial level in at least 26 jurisdictions around the world. Several feed-in tariff policies exist, such as in the Australian Capital Territory and Nova Scotia (Canada), and others have policy targets for electricity share, as noted in Chapter 1, including Abu Dhabi (United Arab Emirates), Scotland (U.K.), South Australia, and Upper Austria. *(See also Chapter 4 on local/city policies.)*

Source: See Endnote 18 for this chapter.

Beyond 2020, some Chinese experts saw annual wind power markets increasing to 25–30 GW between 2020 and 2030, particularly if wind power becomes competitive with coal after 2020, they said. Their estimates for 2030 capacity ranged from 300 to 400 GW. After 2030, some believed markets might begin to saturate, and annual volume could decline to 5–10 GW. Estimates for 2050 ranged from 400 to 600 GW. Published scenarios are in line with these estimates and show 330–350 GW by 2030–2035 (IEA WEO, 2012; BNEF, 2011), and 400–500 GW by 2050 (China ERI; LBNL).[22]

Solar PV market projections were the most uncertain, reflecting much more nascent domestic markets and uncertain policy conditions. In 2011, China had 3 GW of total solar PV capacity, but most of that (2 GW) was added in 2011 alone, pointing to rapid market change during 2011–2012.[a] China's first policy target for solar PV was 1.8 GW by 2020, enacted in 2007. That target was later increased to 5 GW and then 20 GW. In 2012, China announced that the target would be 50 GW by 2020.[23]

In 2011 and 2012, new solar PV promotion policies, as well as much lower costs, started to influence domestic markets. Many Chinese experts, interviewed in 2011, believed that domestic solar PV

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a) *China's domestic market should not be confused with solar PV production for export. Prior to 2011, China had become a leading global manufacturer of solar PV, but virtually all production was exported.*

markets would "catch up" with other parts of the world by 2015–2020. One expert believed that 100 GW might be reached in 2020, but others thought that level might take until 2030. In the longer term, several experts did foresee 500–1,000 GW. One believed that 1,000 GW could ultimately reflect just distributed rooftops alone, with many utility-scale plants in addition. And one believed that solar energy in all forms could become a majority of energy supply in China by 2050. Scenarios show 200–250 GW for 2030–2035 (BNEF; IEA WEO; and Greenpeace, 2012), and 300–800 GW for 2050 (China ERI; Greenpeace).[24]

Expert views on biomass varied based on views of resource availability, use of biomass for competing purposes, biomass costs relative to other renewables, and whether large-scale power plants (up to 25 MW) are viable in large numbers given the geographically (and institutionally) diffuse nature of agricultural wastes. In 2011, China had 4 GW of biomass power and a policy target of 30 GW by 2020. Some experts believed that capacity might not exceed 30 GW in the long term. China ERI (2011) shows biomass power leveling off at 40 GW before 2050. Some experts believed that beyond 2025, biomass would be used mainly for cellulosic ethanol. Others saw biomass used primarily for household heating and cooling, for producing bio-methane, as feedstocks to chemical industries, and gasified on small scales for use with smaller gas engines.[25]

In 2011, China produced 2.3 billion liters of biofuels, mostly ethanol. Policy targets of 10 million tonnes of ethanol (12.6 billion liters) and 2 million tonnes of biodiesel (2.3 billion liters) exist for 2020. Many Chinese experts saw liquid biofuels becoming a major use of biomass in the future, starting in 2020–2025. They said wastes, crops, and jatropha all have big potential. "Biomass will be used for liquid fuels and chemical process inputs, but not very much for power generation," they said. But some saw limited potential for biofuels because of future industrial use of biomass resources.[26]

Finally, many Chinese experts were optimistic about the use of solar thermal for hot water, space heating, and industrial process heat. In 2010, China had 170 million square meters (m^2) of solar heating and a policy target of 300 million m^2 by 2020. One solar industry executive projected 600 million m^2 by 2030. The utilization of solar thermal could peak as quickly as 2030, another expert said, providing water heating in 30–50% of buildings, some space heating, and industrial process heat in low-land-density settings. Other experts thought that solar thermal for industrial process and water heating could start to take off before 2015. "Industrial applications will become very important," one said.[27]

India

Renewable energy policy in India continues to be a mixture of national-level and state-level initiatives. Renewable Portfolio Standard (RPS) regulations and feed-in tariff policies have existed at the state level for many years, and continue to be updated regularly. At the national level in recent years, India has adopted a feed-in tariff, instituted tradable renewable energy certificates (RECs), established a green-building rating system, and enacted a national energy conservation code for buildings that incorporates renewables.[28]

Other state-level policies continue to be adopted, such as solar PV support schemes, interest-free loans, electricity sales-duty exemptions, guaranteed grid access, and transmission wheeling policies, in states such as Andhra Pradesh, Gujarat, Karnataka, Rajasthan, and Tamil Nadu. As one expert noted, "the role being played by state governments in supporting renewables is often in support of their industrial development aspirations." This expert also noted that the Jawaharlal Nehru National Solar Mission for developing solar PV and solar thermal power (CSP) markets, which started in 2010 at the national level, subsequently spawned initiatives from several state governments that together match or exceed the federal effort.[29]

Wind power could be a major share of added power capacity through 2020 and beyond, said experts. In 2010, India ranked 5th in the world in wind power capacity, at over 13 GW. There is no national target for wind power, but one expert foresaw 90 GW by 2022 if a national electricity plan is met. Two scenarios show 90–100 GW by 2020 and 185–190 GW by 2030 (GWEC, 2012; Greenpeace, 2012). Risø (2010) shows 200 GW by 2050. Wind power in the future could be limited by transmission constraints, and overcoming this bottleneck will be a key part of future infrastructure development, as well as addressing variability through smart grids, energy storage, and getting major utility buy-in of renewables, experts said.[30]

Use of grid-tied solar PV is still small in India, about 1 GW in 2012. But the national solar target enacted in 2010 for 20 GW of grid-connected solar by 2022 (both PV and CSP) would start to accelerate development in coming years, said Indian experts. And some states have their own solar PV targets: for example, Chhattisgarh targets up to 1 GW by 2017.[31]

Most experts believed India would meet or exceed the 2022 solar target. Once (retail) grid parity is reached around 2015–2017, they said, markets would accelerate, although widespread net metering would be required, they said *(see also solar PV in Chapter 6)*. One solar expert foresaw many more utility-scale solar PV plants proliferating at scales of 1–50 MW, in addition to rooftop applications. The expert also said that thin-film PV markets could be larger in India than elsewhere due to India's high-temperature conditions. Solar thermal and CSP could also become important for renewable-assisted air conditioning and industrial process heat, especially in meeting India's policy target of 14 GWth of solar thermal capacity by 2022.[32]

Hydropower currently provides the majority of renewable electricity in India and will continue to grow, according to scenarios like Greenpeace (2012), which shows hydro capacity peaking by 2030, with 25 GW added by then.[33]

The use of biomass, biogas, small wind power, small hydro, and solar PV for rural "off-grid" energy will continue to be important because India will not achieve full electrification in the coming decades, said experts. So the "access" question for rural households will remain relevant in the long term. Among India's policy targets is the goal of 20 million rural lighting systems by 2022.[34] *(See more discussion of rural renewable energy in the following section on developing countries.)*

Developing Countries (Other Than China and India)

Through interviews, workshops, scenarios, and published articles, many perspectives on developing countries were collected from knowledgeable experts: managers, researchers, officials, and development experts. Virtually all experts expressed the view that markets will expand into a much greater number of developing countries on a vastly greater scale. This will create a much more diverse geographic base, beyond developing country leaders Brazil, China, and India.[35]

Great Debate 10 | What Is the Future of Coal Power in India Relative to Renewables?

Experts believed that a key choice facing India will be whether to increase imported coal for power generation (given that domestic production will not increase), or to turn increasingly to renewable energy for the majority of new power investment.

Some experts said that this question depends heavily on the availability and price of imported coal, and on future expectations about availability and price. One expert, however, noted in late 2012, "I thought this was already pretty much decided with the shelving of plans for 42 GW of coal capacity since early 2012 and Tata's announcement that it will build only renewables, not coal plants, because there's no business case for new coal plants." Some experts underlined, however, the expected growth of GDP and population, along with present-day chronic power shortages, to say that India faces huge needs for more power, and that coal was still a viable option.

If, as one projection shows, India's GDP will quadruple by 2030, then total power capacity would have to expand between 3-fold and 5-fold by 2030, according to one expert. In this scenario, renewables additions would have to exceed 100 GW through 2030 just for the renewables share of electricity to remain constant, as 400–700 GW of new capacity would be added by 2030, the expert said. Some experts believed that up to three-quarters of new power capacity added between now and 2030 will be renewable, if high prices of imported coal make wind and solar competitive with new coal power.

This could mean an added 300–500 GW of renewable power capacity by 2030. Greenpeace (2012) shows total power capacity increasing by more than 500 GW by 2030, with virtually all of those additions from renewables. Total coal power capacity peaks in the 2015–2020 time frame at 130 GW (up from 100 GW in 2009), and then declines to 100 GW in 2030 and 15 GW in 2050. By 2050, this scenario projects that over 90% of electricity, heating, and cooling will come from renewables, along with about 60% of transport fuels.

Notes and discussion: See Annex 4.

Experts believed that this expansion will accelerate through 2020 in leading countries such as Argentina, Chile, Colombia, Egypt, Ghana, Indonesia, Jordan, Kenya, Mexico, Nigeria, the Philippines, South Africa, and Thailand. And beyond 2020, renewables markets will become even broader-based in a larger number of countries, as developing countries take increasing leadership. The annual REN21 *Renewables Global Status Report* documents annual progress and deepening engagement in developing countries, for renewable energy policies, markets, and investments.[36] (See also Box 8.)

In recent years, developing countries have continued to enact a variety of policy targets for future shares and amounts of renewable energy. These targets underscore the emerging leadership in many countries for renewable energy futures, and foreshadow future markets. For example, countries targeting wind power by 2020, 2025, or 2030 include Argentina (1.2 GW), Brazil (16 GW), Egypt (7.2 GW), Jordan (1 GW), the Philippines (2.4 GW), South Africa (9.2 GW), and Thailand (1.2 GW). Examples for geothermal targets include Kenya (5 GW), the Philippines (3.5 GW), and Indonesia (13 GW). Examples for biomass power targets include Brazil (13 GW), Nigeria (30 MW), and Thailand (3.6 GW). Examples for hydro targets include Brazil (117 GW by 2021, from 84 GW in 2011) and Ethiopia (22 GW by 2030).[37]

Some countries have total renewable capacity targets, such as the Philippines (triple 2010 capacity by 2030) and Tunisia (40% of total power capacity by 2030). And at least 35 developing countries have policy targets for shares of electricity from renewables by either 2020 or 2030.[38] *(See Chapter 1 for sector-share targets, and annual editions of the REN21* Renewables Global Status Report *and associated online interactive map for complete targets database.)*

Several countries target rural (off-grid) renewable energy—for example, Bangladesh (150,000 biogas digesters by 2016 and 2.5 million solar PV systems by 2015), Benin (50% of rural electricity by 2025), Colombia (30% of rural energy capacity by 2030), Lesotho (35% of rural electricity by 2020), Micronesia (50% of rural electricity), and Uganda (100,000 biogas digesters by 2017). And a few countries target solar heating/hot water units or capacity, including Jordan (30% of households by 2020), Morocco (1.2 GWth by 2020), and Mozambique (100,000 units).[39]

Experts in developing countries repeatedly stressed several common issues that they believed will shape (or limit) renewables development in the future. The most commonly cited were: the availability of credit, technical know-how, and renewable resource data; the drive for local manufacturing and "local content" requirements; public education and information; development of long-term energy planning capacity and tools; and the imperatives of power capacity shortages. Others complained that already-enacted policies are not being implemented, that institutional responsibilities for forging new power market rules and roles is unclear, that short-term problems are crowding out long-term thinking, that conventional energy industries are mounting resistance to renewables, and that evaluation criteria in competitive bidding programs for new generation resources are unfair to renewables. Many pointed to security of energy supply as a growing motivation that would shape renewables markets.[40]

Beyond these issues, experts outlined several areas of opportunity and expected market trends:

■ **Electric power infrastructure.** Developing countries will need to build "lots of infrastructure" in the next 10 years, noted many experts. However, paths for infrastructure development may not follow traditional models, noted experts, who foresaw expanding markets uniquely tied to the lack of full rural electrification and weak centralized power grids in many countries. These paths include many "off-grid" options, continuing investment in hydro and geothermal power, and micro-grids instead of new centralized grids. Experts also noted that high shares of hydropower in many countries, as well as future opportunities for pumped hydro, provide opportunities for balancing variable renewables.[41] *(See also utility grid integration in Chapter 2, "Great Debate 5" on page 27, and more on rural renewable energy at the end of this section.)*

Box 8 | Brazil and South Africa

Along with China and India, Brazil and South Africa are members of the so-called "BRICS" group, distinguished by large, fast-growing economies. Although per-GDP investment in renewable energy in Brazil and South Africa is still far behind China, targets and scenarios point to high-renewables futures in these countries.

Brazil already receives more than 80% of its electricity from renewables, virtually all of that hydropower. And over half of passenger vehicle fuels come from ethanol, by far the highest share in the world, as a result of continuous policies dating back to the 1970s. Over the past decade, many renewable energy policies, such as public competitive bidding under the country's PROINFA program, spurred nascent renewables markets for wind and biomass power, and a growing share of small hydro (plants less than 30 MW). Also, policies at the local level in some cities have spurred solar hot water markets.

In the coming decade, scenarios and forecasts show a major wind power market emerging in Brazil, including a government projection that wind capacity will increase from 1.5 GW in 2011 to 16 GW by 2020. (For comparison, the annual market in 2011 was 0.6 GW.) By 2030, Brazil's national energy plan (2009) shows small hydro capacity doubling, biomass power quadrupling, wind power increasing almost 20-fold, and large hydro almost doubling (all relative to 2010). Taken together, the plan projects more than 100 GW of added renewables capacity between 2010 and 2030. For biofuels, at least one projection (EPE, 2012) shows a tripling of ethanol production from 2011 to 2020.

In 2012, South Africa introduced a 20-year resource plan calling for renewables to represent 38% of all new power capacity added through 2030. This would mean 22 GW of new renewable capacity, most of which is planned to be wind and solar PV power, with smaller amounts of hydro (2.6 GW) and CSP (1.2 GW). The resource plan would lead to a 43% share of electricity from renewables by 2030, which compares with a 50% share by the same time projected by Greenpeace (2011).

In the longer term, South African experts believed that renewables could supply up to half of the country's energy by 2050. They also emphasized the importance of CSP in South Africa's future, and foresaw much higher capacity than in the resource plan, perhaps to 20 GW by 2035. They believed that South Africa could become a world leader in CSP, with high local manufacturing content and competitive costs.

Experts also noted that solar PV "grid parity" was coming to parts of South Africa, and that PV markets were heading "off the charts," citing both rural uses and emerging net metering policies for urban uses. *(See solar PV in Chapter 6 for more discussion of grid parity.)* And experts pointed to domestic policies supportive of solar water heating and foresaw major market advances, such as most new buildings constructed with solar thermal.

Source: See Endnote 36 for this chapter.

■ **Diesel generator replacement.** Experts stressed the large markets emerging for replacing existing diesel generators with renewable-hybrid alternatives, in countries with large existing diesel capacity. The use of renewables for off-grid and island-grid infrastructure (including urban power grids) will become increasingly competitive with diesel generators, asserted experts, and with increasingly favorable economics. Many cited the use of hybrid wind-diesel systems or biomass power for replacing conventional diesel power systems.[42]

■ **Settlement patterns and population expansion.** Developing countries will face a number of development pressures in the future that renewable energy can address, said experts, noting that population growth and settlement expansion to new areas will require new energy services. For example, in lieu of costly grid expansion to these new areas, some African experts envisioned new mini-grids and renewable energy "islands" across the African landscape that allow small villages to be productive and support larger populations. One Egyptian expert saw the need to establish new areas of settlement outside of the Nile delta and valley to accommodate population growth—and saw those new areas served with renewables.[43]

■ **Power market regulations.** Almost all electric utility systems in OECD countries have undergone some process of restructuring or liberalization in past decades, including "unbundling" of generation, transmission, and distribution. Experts envisioned many developing countries going through this process in the coming decade, with consequently improved conditions for renewables, along with competitive markets for grid balancing services. Utility regulatory changes would also usher in net metering for distributed renewables, experts foresaw, bringing a new era of two-way power flows on local distribution systems, requiring new policies, new power distribution infrastructure, "smart grid" controls and meters, and integration of rooftop renewables into building codes, said experts.[44]

■ **Energy efficiency.** Experts noted that large improvements in the efficiency of energy use are possible, which will reduce the need for more supply additions, thus allowing renewable energy to attain higher shares. As one example, the IRENA (2012) study on the prospects for the African power sector shows an improvement in energy efficiency of 20–30% by 2050 (compared to the reference scenario), which accompanies the growth of renewables to a 73% electricity share. The Greenpeace (2011) scenario for South Africa shows 50% less energy consumption by 2050 due to efficiency, relative to the 2050 reference case.[45]

■ **Regional cooperation frameworks.** Experts noted that many developing countries are too small by themselves to create large market opportunities and attract high levels of investments. They noted that regional frameworks and projects for infrastructure development incorporating renewables will be important for some countries, and that such frameworks can lower transaction costs, mitigate risks, and attract larger investments from multilateral development institutions or private investors. They also noted that such frameworks can aid cross-border transfers of renewable power.[46]

■ **Research, education, and manufacturing.** Experts expected to see new research and manufacturing centers in developing countries, reflecting a shift to local knowledge and industry. They expected this shift to lower costs and make technologies more accessible. Experts also pointed to ongoing plans for future localization—requiring local content in renewable energy projects as a means to promote manufacturing and jobs. But they debated whether localization will produce higher costs, and what it would mean in practice. Experts also saw renewable energy increasingly integrated into universities, vocational and engineering schools, and public education programs by consumer organizations.[47]

Following are projections for individual technology markets across developing countries.[48]

■ **Hydropower** represents a majority of the existing power generation in many developing countries. In all scenarios, hydropower continues to grow strongly in developing countries. For Latin America, the Brazil National Energy Plan (2009) shows hydropower almost doubling by 2030 to 150 GW. Other Latin America regional projections for 2030 include 170 GW (Greenpeace, 2012) and 240 GW (World Bank, 2011). For Asia, Greenpeace (2012) shows non-OECD Asia (minus China) reaching 100 GW by 2050, and APEC/ADB (2009) projects hydro continuing to grow in the Asia-Pacific region by an average of 3% annually through 2030. For Africa, projections by 2050 include 50 GW (Greenpeace, 2012) and 150 GW (IRENA, 2012).[49]

■ **Small hydropower,** a subset of the overall hydro market, has been growing much faster than large hydro in many countries. As one example, the Brazil National Energy Plan (2009) shows small hydro doubling to 9 GW by 2030.[50]

■ **Traditional biomass** is already a major source of energy in developing countries, primarily "traditional biomass" for heating and cooking in rural areas. Experts foresaw one of the most important future trends in developing countries to be the continued and accelerating shift away from traditional biomass cookstoves to more modern forms of stoves and fuels, including efficient biomass cookstoves and stoves that burn biogas or biofuels.[51]

■ **Modern biomass** use is growing in many developing countries, and experts foresaw expansion of several key markets in the coming decades, including: (1) expanding wood chip/pellet markets in countries such as Argentina, Brazil, Chile, the Philippines, and Sri Lanka; (2) greater use of biogas for cooking, heating, and electricity generation in countries such as Nepal, Vietnam, and Kenya (in addition to markets in China and India); and (3) continued expansion of modern biomass power generation and cogeneration (combined heat and power) in countries such as Brazil, the Philippines, and Thailand, as well as throughout Africa—including in Kenya, Mauritius, Tanzania, Uganda, and Zimbabwe.[52]

■ **Wind power** was expected to boom across many developing countries in the coming decade, said many wind industry experts. By 2011, a total of 39 developing countries had existing wind power capacity, including 11 countries in Africa/Middle East, 20 countries in Latin America and the Caribbean, and eight countries in Asia. Significant additions in 2011 occurred in Argentina, Brazil, Cape Verde, Chile, Costa Rica, the Dominican Republic, Honduras, and Vietnam. By 2011, 35% of global wind power capacity existed in developing countries (including China and India), up from 10% in 2005.[53]

By 2030, scenarios show 80–95 GW of wind power in Africa (GWEC, 2012; IRENA, 2012), 100 GW in the Middle East, 130 GW in Latin America, and 210 GW in non-OECD Asia (Greenpeace, 2012).[54]

Expert statements also pointed to a coming wind power boom. "The next major expansions of wind markets will be to Latin America, including faster growth in Brazil, which is emerging as the next big player in wind power, and to a lesser extent to Africa, which is still hindered by lack of power grids," said one expert. "We might easily be surprised by developing country markets in the coming years, including Latin America, Africa, and Southeast Asia, with much greater market diversification," said a wind industry executive, who called existing projections for these regions "conservative."[55]

■ **Solar PV and solar thermal power (CSP)** markets have historically been concentrated in a small number of countries. In 2011, fully three-quarters of global solar PV capacity existed in just 5 developed countries. The share in developing countries was less than 6%. Experts insisted that this situation would not exist much longer, and that a major broadening of solar PV and CSP markets to developing countries will soon occur. By 2030, scenarios show 90 GW of solar PV and CSP in Africa (IRENA, 2012; Greenpeace, 2012), 260 GW in the Middle East, 100 GW in Latin America, and 260 GW in non-OECD Asia (Greenpeace, 2012).[56] *(See also solar PV and CSP in Chapter 6.)*

■ **Rural renewable energy** for (off-grid) settlements and smaller island communities has been a prominent aspect of rural development for decades, especially for the hundreds of millions of households still not served by central power grids. In particular, experts pointed to the continuing drive for more-efficient cookstoves that use traditional biomass as a central feature of rural energy futures. In off-grid areas, many renewable technologies today provide power for lighting and communications (for homes, schools, health care, and business); heat for space heating, cooking, and crop drying and processing; and motive-force for industrial fans, pumps, and equipment.[57] (See also Box 9 below.)

Future prospects for rural renewable energy include the continuation of these trends with solar PV, solar thermal, hybrid wind-solar-diesel systems, biogas, and biomass gasification. Experts continued to foresee these technologies used for so-called "productive uses," in provision of water, health care, education, and small business services. This report cannot cover all of these applications, so also see the Rural Renewable Energy chapter in annual editions of the REN21 *Renewables Global Status Report*.[58]

Box 9 | Solar PV for Rural (Off-Grid) Areas

"Solar PV is already becoming competitive with diesel generators, which represents a real revolution in off-grid electricity," said one Indian expert, who believed that off-grid markets for solar PV will become firmly established within five years once rural service infrastructure develops and business models become better proven. Many other experts pointed to the huge proliferation of mobile phones in rural areas and the need for charging by potentially hundreds of millions of rural households. "People walk miles to charge mobile phones," said one expert, who envisioned the proliferation of cheap solar mobile phone chargers becoming a significant turning point in the use of solar PV.

There are already many examples today of such markets, such as the well-known Grameen programs in Bangladesh for rural mobile phones and solar PV. Other experts expected major new markets in street and security lighting. Markets for rural solar lighting systems for households have been growing since the 1990s in many developing countries as part of the "access" agenda by governments, utilities, and rural development agencies.

Source: See Endnote 57 for this chapter.

06

EVOLUTION OF TECHNOLOGIES, COSTS, AND GLOBAL MARKET GROWTH

Global markets for renewable energy have boomed over the past decade. This expansion has brought considerable innovation and cost reduction and will continue to do so. Projections for future market growth are equally dramatic, driven in part by further technology improvements and continuation of cost trends. Markets have already reached the point where technology is no longer the "bottleneck," many say.

With the explosive growth of renewable energy markets over the past decade have come dramatic technology improvements and cost reductions. These growth rates reflect a "take-off" phase that has seen many renewable energy technologies become mainstream investments and undergo dramatic advances in performance, cost, and scale.[1] *(For details on the status of all technologies and markets, see annual editions of the REN21* Renewables Global Status Report. *For more on cost comparisons between renewables and other energy technologies, see "Great Debate 1" on page 12. For policies underlying market growth, see "Great Debate 2" on page 13, and Chapter 5. For more on technology integration, see Chapter 2.)*

In power generation, global wind power capacity grew by 20% in 2011 (to 238 GW), after growing by an annual average of 26% over the five-year period 2006–2011. Solar PV capacity grew by a record 74% in 2011 (to 70 GW), after growing by an average of 58% over the five-year period. Solar thermal power (CSP) grew by 35% in 2011. In contrast, hydropower, biomass, and geothermal power have been mature for decades, and five-year growth rates for these renewables were more on par with conventional energy technologies. In terms of total power generation capacity, renewable energy reached 1,360 GW in 2011, including 970 GW of hydropower. This meant that global renewable capacity represented about one-quarter of total global power capacity.[2]

Growing markets for hot water and space heating that incorporate biomass, solar thermal, and geothermal have also contributed to technology evolution and cost reduction.[a] Biomass remains the primary form of heat supply from renewables, and provides about one tenth of global energy supply, two-thirds of which is "traditional" biomass use *(see footnote on page 15)*. Another 10% of the biomass resource is used for electricity generation and combined heat and power (CHP). Most biomass is consumed locally, but international trade in wood pellets has grown since the mid-1990s.

Markets for solar thermal collectors (for hot water and heating) have been growing rapidly in recent years, and solar now provides almost as much heating capacity as modern biomass. Solar heating capacity grew by 27% in 2011, following 17% annual average growth over the five-year period 2006–2011. Geothermal heating capacity is roughly one-fifth that of biomass heating capacity and also growing.[3]

Transport fuels from renewables are primarily ethanol and biodiesel produced from a variety of biomass crops. Production of these two fuels together reached 107 billion liters in 2011, about 3% of total global road transport fuel consumption. Ethanol fuel production grew by an annual average of 17% over the five-year period 2006–2011, although growth was stagnant in 2011, and biodiesel grew by an annual average of 27% over the five years.[4]

Expert interviews and scenarios offer projections of continued dramatic global market growth in the coming decades, coupled with continuing technology improvements and cost reductions. These projections are explored in this chapter. Most common are projections for global power capacity, as shown in Table 4 from five scenarios to 2030. In these scenarios, wind power capacity increases between 4-fold and 12-fold by 2030, solar PV between 7-fold and 25-fold, CSP between 20-fold and 350-fold, biomass power between 3-fold and 5-fold (with one exception), geothermal between 4-fold and 15-fold, and hydro between 30% and 80%.[5]

The following sections explore projections for the evolution of markets, technologies, and costs for individual technologies. These include future cost projections by experts and scenarios. In general, scenarios and experts expect costs to decline for a host of reasons, such as increased market volumes that accelerate technology development, economies of scale in manufacturing, and materials advances.[6, b]

Table 4: Global Renewable Power Capacity by 2030 in Recent Scenarios

	Hydro	Wind	Solar PV	CSP	Biomass	Geothermal	Ocean
	GW						
Actual 2006 Capacity for Comparison	–	74	8	0.4	45	9.5	0.3
Actual 2011 Capacity for Comparison	970	238	70	1.8	72	11	0.5
IEA WEO (2012) "New Policies"	1,580	920	490	40	210	40	10
IEA WEO (2012) "450"	1,740	1,340	720	110	260	50	10
IEA ETP (2012) "2DS"	1,640	1,400	700	140	340	50	20
BNEF GREMO (2011)	—	1,350	1,200		260	30	—
IEA RETD (2010) "ACES"	1,300	2,700	1,000	120	340	—	—
Greenpeace (2012)	1,350	2,900	1,750	700	60	170	180

Sources: See Annex 2. Actual 2006 and 2011 from REN21 (2008, 2012).
Notes: CSP stands for solar thermal power. Figures for 2030 are rounded to nearest 10 GW or 50 GW from original sources. Hydropower figure for 2011 excludes pure pumped hydro capacity; a comparable figure for 2006 is not available, see REN21 (2012), notes to Table R2, and note on hydropower on page 168.

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a) *Markets for cooling from renewables are much less developed than for heating, but are also growing; see annual editions of the REN21* Renewables Global Status Report. *For more on both heating and cooling technologies, see buildings integration on page 26 and urban infrastructure integration on page 39.*

b) *Some experts questioned the sustainability of high levels of "manufactured" renewables like wind and solar PV in the very long term, in terms of material resources, rare earths, recycling, and toxic wastes. See Endnote 6.*

Current cost estimates by REN21 (2012) are also included in the following sections for comparison with future projections.[a] However, both current cost estimates and future projections are surrounded by considerable controversy, and the figures presented here are not claimed as definitive. In several instances, industry experts disputed REN21 estimates of current costs and said commercial costs were actually much lower, as evidenced by commercial contracts being signed in 2012, even excluding (backing out) any subsidies. Some of these disputes have been noted in the text.[7] (All costs given in this chapter are intended to reflect unsubsidized costs unless otherwise noted.)

Wind Power: Onshore

All industry experts saw wind power continuing as a very strong market for decades. Among the most optimistic projections was 1,000 GW globally by 2020, made by a wind industry executive. Another expert saw 50% of global electricity from wind by 2050 as possible, and "not insurmountable given enough gas and storage to balance." In 2011, 50 countries added new wind power capacity, and many experts expected a growing diversity of wind markets in many more countries around the world to take off before 2020.[8]

Some utilities are equally optimistic. For example, RWE said that "wind power is well on its way to becoming competitive even in a non-regulated market." And Gas Natural Fenosa said that "wind energy is one of the most mature renewable technologies and is the most widespread and has the greatest growth horizon world-wide."[9]

Contemporary onshore wind power costs are cited by REN21 (2012) as 5–16 U.S. cents/kWh, although some experts claimed that lower costs of 4–5 cents/kWh were more typical for good sites.[b] Regardless of the exact figures, industry experts pointed out that onshore wind power is already competitive with wholesale power prices in many locations, and some European experts expected wind power to achieve full grid (wholesale) parity with fossil fuel plants in Europe by 2015, with typical costs down to 8–10 U.S. cents/kWh equivalent.[10]

Other experts asserted that wind power at good wind sites in the United States, Europe, and many developing countries is already competitive with conventional wholesale power costs. "In some locations in Morocco, wind power is at parity or cheaper than coal," said one African expert. A previous edition of IEA WEO (2010) showed costs declining to about 6–9 cents/kWh during the period 2021–2035, but the most recent edition (2012) offers no cost projections. IEA ETP (2012) projects 5–10 cents/kWh by 2020.[11]

Industry experts saw many possible technology changes forthcoming, such as new materials, lower weight (especially of blades and nacelles), concrete towers instead of steel, permanent-magnet generators (which reduce wear on drive trains), direct drives, substitutes for rare earths (including non-magnet generators), deformable blade profiles, more sophisticated monitoring and reporting of performance, and more sophisticated optimization.[12]

Some believed that the wind turbine industry could evolve similar to the aircraft industry, reaching a plateau in size like in the 1970s but with growing sophistication and performance in other respects. "Lifetimes are likely to remain at 20 years because we are getting close to design limits; turbines are not as over-engineered as they were in the 1980s," said one expert. Transport and logistics will become more important, and manufacturers may even establish mobile factories to manufacture parts on-site.[13]

One wind industry executive also stressed the information technology side of wind power, and said: "Our industry is going to become more sophisticated—we are already a major global user of supercomputer power." The executive pointed to a much stronger focus in the future on information technology (IT) and monitoring (i.e., hundreds of measurement points on a single turbine), combined with smarter maintenance, which will mean less downtime because components will be replaced before failure. And maintenance will be done during low wind periods to reduce the impact of maintenance downtime. And further research and development opportunities in wind for the future will also make heavy use of computing power: aerodynamics/fluid dynamics, grid balancing, assessment of wind conditions, and wind site analysis that uses anti-correlations of wind resources for less variability.[14]

Experts pointed to the potential for much cheaper small-scale turbines, which some said could revolutionize the use of wind power in local power applications and for hybrid wind-diesel systems in off-grid applications *(see also developing countries in Chapter 5)*. REN21 (2012) gives current costs of small-scale wind turbines (less than 100 kW) of 15–20 cents/kWh in the United States, and costs of household-scale turbines (less than 3 kW) of 15–35 cents/kWh. WWEA (2012) shows more than 650,000 small wind turbines globally in 2010, and notes that: "Fully competitive small wind markets are … found in developing countries where off-grid and mini-grid applications prevail."[c] WWEA projects that the global capacity of small wind turbines will increase almost 10-fold between 2010 and 2020.[15]

Experts also foresaw other possible "game-changers" for wind power. Examples are low-speed turbines, vertical-axis designs, and towers that can be built on-site from the ground up or act as their own cranes. One expert said, "So many people and different types

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a) There are few published sources that give current cost ranges on a recurring global basis other than REN21. IEA (2012) Energy Technology Perspectives *gives cost projections just for the United States. However, many one-time studies capture current costs at the time of their publication, for example GEA (2012) and IPCC (2011), but often give costs only for a particular region. IRENA (2012) is a new publication on costs but was available too late for press.*

b) All costs in this chapter are in U.S. dollars.

c) The World Wind Energy Association defines "small wind" as less than 100 kW and notes that many definitions exist.

of companies are involved all along the value chain, from university research to IT companies to major industrial firms to specialized technology suppliers, that some major innovations are almost inevitable."[16]

Wind Power: Offshore

The IEA WEO (2010) offered this prognosis for offshore wind power: "Offshore wind turbine technology needs further development. At present, most offshore turbines are based on onshore turbine technology, modified to reflect practices and experiences in other offshore industries. The reliability of offshore turbines, which is currently lower than that of onshore wind turbines, needs to improve. More robust turbines, designed from the outset to operate in offshore conditions, need to be developed for the technology to take off.… Improved foundation designs can help bring costs down. Although offshore wind turbines are currently located in shallow water areas, significant potential exists in deep waters and new designs are being developed to allow capturing this potential. Floating turbines are one such design."[17]

Current offshore wind power costs are cited by REN21 (2012) as 11–22 cents/kWh. The IEA WEO (2010) projects costs declining to 6–9 cents/kWh during the period 2021–2035. The IEA ETP (2012) "Technology Roadmap" for wind power envisions improved economics of foundations, supply chains, and installation strategies through 2020, and then beyond 2020, a next generation of offshore wind turbines and floating foundations.[18]

Expert opinion about future markets for offshore wind power varied widely. Some experts believed that offshore wind could become fully half of the global wind power market by 2020. One said: "We will see steady incremental progress with offshore wind. Costs are higher but the wind is steadier so there is less need for balancing. Offshore wind farms are closer to coastal load centers, attractive from a technical point of view, and help to boost economies of depressed port and harbor facilities. Floating turbines are absolutely achievable, and might represent a major tipping point on offshore costs. We could see mass production, built onshore and then moved offshore, so won't require the extensive logistics of offshore construction."[19] *(For more pro-and-con discussion, see "Great Debate 11" on this page.)*

One Swedish expert was also optimistic, and saw a strong equivalence between onshore and offshore wind power markets in Sweden: "I think we'll see a lot more offshore in the next five years. In Sweden, the cost of offshore in cents/kWh is not higher than onshore, and there is no special support for offshore relative to onshore. Offshore can be located in the path of inter-country

Great Debate 11 | What Are the Pros and Cons of Offshore Wind Power?

Expert views on offshore wind power varied widely, and experts debated the pros and cons of offshore wind relative to onshore. The positive points cited by experts included less visual impact, less impact on shipping lanes near coastlines, higher wind speeds, bigger projects, no NIMBY ("not in my backyard") problems, proximity to coastal urban population centers, bigger project developers providing more credibility and investor security, more predictable wind patterns, scalability to very large size plants, and public relations value for oil companies and pension funds.

Many utilities are optimistic about the prospects for offshore wind power. For example, E.ON recently said that offshore wind has an "enormous potential for the future." And RWE said: "Over the next few years, [onshore wind power] will be joined by enormous offshore wind farms that offer a number of advantages. Apart from greater [public] acceptance, winds in coastal areas and at sea are stronger and more persistent." Iberdrola called offshore wind power "the second revolution in renewables."

Negative points cited by experts included higher costs than onshore wind and higher levels of policy support needed (feed-in tariff premiums). One expert said: "I don't expect offshore to be competitive without policy support until at least 2025–2030," and further said: "I doubt that offshore will ever be as cheap as onshore." Another offered: "Offshore wind markets will really be a matter of government support for a long time. It's not clear yet how to reduce offshore costs, since only one-third of the cost is the turbine."

Utilities also point to the technical and logistics difficulties: "The stresses on the equipment from wind, waves, salt water and ice are also greater [than onshore]. It is also more difficult to perform installation and servicing work at sea, and the distance to the coast requires special rules for connection to the grid," said Vattenfall. And "Huge challenges need to be overcome with regard to technology and materials," said RWE.

Some experts framed the question of offshore wind development as a social or institutional issue. One asked: "Should policy promote offshore to avoid the problems of onshore wind power social acceptance and land use?" Another, however, criticized the diversion of investment resources away from onshore installations that could be more locally owned and controlled. "The only reason we are seeing offshore development is because big utilities like big centralized projects—and that's not the right reason," said the expert.

Notes and discussion: See Annex 4. Sources for quotes: See Endnote 19 for this chapter.

transmission lines across the water. The deciding factor is how the infrastructure costs are allocated between transmission and the turbines and offshore plant itself."[20]

Technology experts envisioned definite technology evolution for offshore turbines. Possible future innovations include floating offshore configurations, offshore logistical platforms that can service entire groups of offshore turbines, longer lifetimes (now 25 years versus 20 years for onshore), and larger turbine sizes. One wind industry executive believed that offshore turbine sizes will reach at least 10 MW in size. Experts saw the maturing of supply chains, including vessels, harbor facilities, operations and maintenance and logistics strategies, new foundation concepts, fewer moving parts, new two-blade concepts, gearless turbines, and a greater focus on reliability and logistics to reduce operating costs and downtime.[21]

Solar PV

Many solar PV experts and visionaries were very optimistic about the future of solar PV. "A lot of new markets for solar PV are going to pop out of the woodwork as the cost per watt declines—the sky is the limit," said one. Another lamented persistent perceptions of solar PV as "exotic," when in fact its maturity is beginning to rival wind and geothermal. One longstanding industry expert projected that global solar PV capacity could reach 400–800 GW as soon as 2020. And by 2050, global solar PV capacity could reach as high as 8,000 GW, one visionary challenged.[22]

Expert estimates in 2011 for the annual solar PV market by 2015 ranged from 23 GW to 43 GW, and for the annual market by 2020 from 40 GW to 160 GW. (The annual market in fact reached a record 30 GW in 2011, as reported in mid-2012 after those estimates were made.) Europe accounted for 75% of the global market in 2011, but some experts believed that this would shift before 2020, with Europe's market share declining below 50% as markets in China, Japan, and other Asian countries take hold.[23] *(See also Chapter 5.)*

For a long time, many considered "grid parity" to be the "holy grail" of solar PV, dating back to the 1980s. Generally, "grid parity" is accepted by most to mean equivalence of solar PV generation costs with retail electricity prices. However, solar PV experts pointed out that this concept can be misleading or distorted due to subsidies, differential electricity prices across customer classes, seasonal or peak pricing, "smart" pricing plans that link prices to grid conditions, and net metering rules.[a] Grid parity *including* subsidies matters to investors, while grid parity *excluding* subsidies matters to policy-makers (as an indication that cost- or price-based policy support is no longer needed).[24]

In addition, if customers face "time of day" (peak) pricing, or prices based on grid conditions, then grid parity may well exist at peak times (or on high-demand days) but not at other times. Furthermore, financial experts pointed out that "cost of electricity" metrics, including the concept of grid parity, are not as important to investors as financial rate-of-return metrics—that is, does a solar PV project meet a given rate-of-return threshold? The answer can depend on factors outside of conventional "grid parity" assessments, and financial experts asserted that finance, not cost, has become the key constraint for solar PV markets.[25]

Many solar PV experts claimed that grid parity already exists in some locations around the world for certain types of consumers, although such claims often mean costs including subsidies rather than unsubsidized costs. Regions cited include Germany, Italy, Japan, Spain, parts of India, and parts of the United States, including California and Hawaii. But there was little consistency among expert claims.[26]

A typical comment was, "Yes, I agree that solar PV is close to grid parity in many places, and I would expect grid parity in parts of the United States, Japan, and Europe by 2015." One expert expressed optimism that by 2020, fully 30% of global electricity sales would be at retail price parity with solar PV. Another claimed that grid parity in the United States already existed in Hawaii and would come to California within 3–5 years, and to several other states by 2020. Another believed that "about 20% of the U.S. population is already at grid parity, and most of the rest will get there by 2020." The IEA ETP (2012) "Solar PV Roadmap" also shows grid parity by 2020 for most applications (in many regions).[27]

Historically, one common metric for PV progress has been module price in dollars per watt. This metric has undergone a long decline that has accelerated in recent years, and in 2011 it was approaching the historic "holy grail" level of $1/watt. Many experts pointed to the dramatic reductions in this metric in recent years. Said one Chinese solar PV industry manager: "Since 2000, manufacturing cost has been reduced by 3–4 times, from $6/watt in 2000 to below $1.50/watt today; back then, we thought $3/watt was going to be a big achievement, but we went right past that." Several experts (in 2011) predicted prices below $1/watt in the near future, including prices down to $0.80 for crystalline silicon before 2020.[28]

REN21 gives current solar PV costs in Europe of 22–44 US cents/kWh for rooftop installations and 20–37 US cents/kWh for utility-scale installations, depending on system size, efficiency, latitude, local solar radiation conditions, and other factors, although there are a wide range of estimates cited from other sources, including lower numbers in the 9–13 cents/kWh range, and much controversy

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a) *In some countries, grid parity is also confounded by public subsidies to retail consumer electricity prices. Cost- or price-based policy support is generally a capital investment subsidy or tax credit, or a feed-in tariff (preferential pricing). However, other forms of policy support may continue to be needed even at grid parity, such as net metering rules, interconnection standards, and guaranteed-purchase mandates. See Endnote 24 for this chapter for details. See footnote on page 26 for definition of net metering.*

about such numbers. In the long term, costs for solar PV are projected in several scenarios to fall below 10 cents/kWh.[29]

In particular, IEA ETP (2012) shows costs in 2030 at roughly 7–11 cents/kWh for utility-scale projects and 8–14 cents/kWh for rooftop installations. Greenpeace (2012) shows costs of 5–10 cents/kWh by 2030–2040, depending on the region.[30] (However, experts also pointed out that many published projections of future costs are too high for low-latitude countries because of the improved solar resource.)

Grid parity also accounts for "balance-of-system" costs, including mountings, wiring, and power inverters. Balance-of-system costs have historically represented about half of total costs, but have also been falling in tandem with PV panel costs. In recent years, more attention has focused on the cost reductions possible in balance-of-systems, including new mounting materials, cheaper electronics, and stand-alone DC systems that do not require inverters.[31]

As cost-reduction in PV modules slows down, "the balance of system is where the biggest cost reductions will occur—from $2.50/watt today to perhaps $1.30/watt by 2030—as solid-state inverters decline in cost and mounting hardware is eliminated," said one expert. Another said: "we will see continued cost reductions, not just the solar PV panels themselves, but also the costs of integrated installations, as component and system costs drop."[32]

Historical factors contributing to solar PV cost reduction have included wafer fabrication (thinner wafers and lower material costs), cheaper forms of atomic-layer deposition, process automation, economies of scale in manufacturing, and higher cell efficiencies. In the future, solar PV cost reductions could come from several directions, although there was some disagreement about which would prove the most important.[33]

"The way to cheaper PV is through higher efficiency of cells," asserted several solar PV experts. In contrast, one expert asserted that, "it's easier to reduce the manufactured cost per square meter than to improve efficiency." Yet another believed, "it is impossible to say where the technology will go!" Many firms are now conducting research on new materials, but one expert cautioned against any quick revolution, given that development cycles can take 5–10 years before commercial products are seen. "Silicon is going to be really tough to beat," the expert added.[34]

Beyond manufacturing cost reductions of existing crystal-silicon and thin-film technologies, experts cited the following directions for further cost reductions: (1) higher cell efficiencies, with crystal silicon reaching 20–24% and thin-film reaching 15% by 2020, followed by a whole range of PV products with efficiencies in the range of 5–40% beyond 2030; (2) greater use of thin-film, with market shares possibly reaching 30–40% by 2020–2030, up from 20% in 2010; (3) dye, polymer, and organic PV as cheaper, lower-efficiency alternatives beyond 2020, mostly useful for consumer applications; (4) use of more "earth abundant" materials in fabricating solar PV, beyond 2020; (5) new and cheaper foundation materials such as graphite to reduce the need for steel mountings; and (6) cheaper balance-of-system components, integrated with power systems and demand-side equipment control.[35]

Concentrating Solar Thermal Power (CSP)

Many experts believed that solar thermal power markets would become much stronger by 2020. One expert offered a very optimistic prognosis: "We could see 50–70 GW of CSP worldwide by 2020, which could include 5 GW in Spain, 5 GW in the rest of Europe (especially Turkey), 20 GW in the U.S., 30 GW in the Middle East/North Africa (especially Morocco), 5 GW in India, and possibly 5 GW in China." Another was even more optimistic: "The global CSP market could reach 25–50 GW/year by 2020 if some major companies enter the market, and even 50–100 GW/year is not unreasonable." Greenpeace (2012) shows over 2,000 GW of CSP by 2050.[36]

CSP power costs are cited as 19–29 cents/kWh by REN21 (2012). There are many divergent claims over the current "real" costs of CSP in today's markets, by industry, experts, and regulators, which hinders understanding of how far CSP costs have to fall before becoming competitive. Other industry estimates in 2011–2012 showed current costs as low as 10 cents/kWh for new projects. Cost ranges given by scenarios are 7–11 cents/kWh by 2030 (IEA ETP, 2012), 11–23 cents/kWh by 2035 (IEA, WEO 2010), and 6–10 cents/kWh in the long term (Greenpeace, 2012).[37]

The IEA WEO (2010) offered the following prognosis of solar CSP economics: "Further technology improvements and cost reductions are important, especially in the mirrors/reflectors, which account for around 20–40% of the overall capital costs, depending on the plant design. Power tower technologies are considered to have significant potential in this respect, with potential cost reductions for the heliostat on the order of a factor of two to three. Even more fundamental to the economics of CSP is increasing its availability, through the integration of storage (e.g., molten salt). While this significantly increases the upfront investment costs … it can be more than offset by the value of the increased hours of operation per day."[38]

CSP technology faces decades of evolution and offers many possible areas of cost reduction, according to experts. Most were optimistic that CSP will have a prominent place in energy systems of the future, and that development trends of the previous five years are only the beginning of a strong decade through 2020. One expert gave this long-term prognosis: "CSP development will probably remain policy dependent through 2025 or 2030, depending on natural gas prices. After that, it will enter a competitive period with steep learning curves, and by 2050 will be installed at rapid rates reminiscent of natural gas turbines in the 1980s and 1990s. These time frames could be accelerated if natural gas prices rise steeply or become more volatile, such that fuel price risk becomes a major factor."[39]

The IEA ETP (2010) "Technology Roadmap" envisions continued innovation in CSP though 2020, and then envisions a number of specific innovations during 2020–2030, including higher working temperatures (higher efficiency), larger storage capacities, supercritical plants, desalination by co-generation, and tower plants with air receivers and gas turbines. The roadmap envisions networks of HVDC transmission lines to bring CSP power from remote areas, and increased policy support and incentives as costs become closer to competitive. Beyond 2030, incentives may no longer be needed, and solar CSP storage makes major contributions to balancing power grids. The roadmap concludes that, "in the sunniest countries, CSP can be expected to become a competitive source of bulk power in peak and intermediate loads by 2020, and of base-load power by 2025 to 2030."[40]

But CSP also faces headwinds, according to experts, including: (1) cheaper competing solar PV costs if CSP storage and other attributes are discounted; (2) land and water use (although hybrid dry/wet cooling can be used in areas with limited water resources); and (3) transmission access in remote desert regions. In particular, there was much disagreement about the future competitiveness of CSP versus solar PV. CSP plants can offer many hours of energy storage that solar PV cannot, and this was frequently cited as a key asset for CSP plants, relative to solar PV. With enough storage, a CSP plant can offer all the capabilities of a conventional generator, providing firm dispatchable power, as well as grid balancing, spinning reserve, and ancillary services, but with even greater flexibility than a conventional fossil fuel or nuclear plant.[41]

Experts stressed that part of CSP technology evolution will take the form of novel applications, some of which are emerging already. Such applications include: (1) managing grid variability and providing peak power using thermal energy storage embedded within the CSP plant; (2) dedicated CSP plants powering desalination plants in coastal areas; (3) embedded CSP plants in industrial facilities to provide power and industrial process heat; (4) pre-heating feed-water for a coal power plant to reduce coal consumption; (4) integration with combined-cycle natural gas plants (already occurring); and (5) producing gas or liquid fuels including hydrogen.[42]

Biomass Power and Heat

Many biomass experts interviewed believed that biomass' main contribution in the long term will be to heat supply, and that markets for biomass will gravitate toward both combined-heat-and-power (CHP) and heat-only systems, along with co-production of gas and liquid fuels. For example, one expert projected that, "by 2050, renewables will provide more than 80% of global heat supply, half of that from biomass. However, the IEA (WEO, 2010) foresaw more biomass use for power generation: "Global modern primary biomass consumption nearly triples between 2008 and 2035 … most of the increase in biomass comes from the electricity sector and transportation. By 2035, power generation becomes the largest biomass-consuming sector." The GEA (2012) projects that bioenergy use of all forms doubles or triples by 2050, for power, heat, and transport, including co-processing with coal or natural gas with carbon capture and storage.[43] *(See also Box 4 on page 26.)*

Experts viewed the future of biomass from four distinct viewpoints:

- **Fuel supplies.** A breakthrough in biomass demand could come as biomass becomes a mainstream commodity in commercial markets in standard forms like pellets or bio-heating oil (from pyrolysis/torrefaction), said experts. In particular, they expected pellets to become a widespread commodity, efficiently transported internationally. And while some experts questioned how much biomass could be produced given competition for land and food, others saw no real limits because of the huge resources available from agricultural and forest wastes, and from new approaches to growing biomass crops on surplus land.[44]

- **Technical conversion pathway/process.** Most biomass used today is simply burned for heat and power. The second most common process is anaerobic conversion to biogas. Experts foresaw increased production of biogas from sewage plants, manure, and organic waste, and cheaper biogas plants made with new materials. Some also saw new applications for the biogas: "Biogas will be used for transport, as it doesn't need to be cleaned for use in a vehicle engine to the same extent it needs to be clean for a gas turbine," said one expert. Some foresaw much greater use of thermal gasification, while others questioned whether gasification would achieve wide scope.[45]

- **Heating technologies.** Experts envisioned much greater use of biomass heating technologies, including CHP plants, district heating systems, cooling systems for commercial and public buildings, and industrial process heat. Future CHP systems might predominantly fall into the "small or medium scale" of 5–10 MW, but also at smaller sizes of 1 MW, or larger sizes up to 100 MW.[46]

- **Integration into agricultural and forestry industries through integrated "bio-refineries."** According to some experts, the future would see fewer stand-alone bioenergy production sites, and rather would trend toward multi-purpose co-production systems, which co-produce biofuels, sugar, electricity, and biogas, and also utilize leftover waste for fertilizer, chemicals, biofuels, animal feed, and other chemicals. These "integrated bio-refineries" could become part of the food system by 2020, and lead to integrated "bio-based" industries for food, fuels, chemicals, textiles, paper, and other products.[47]

Biomass applications are extremely diverse, and so few generalizations can be made about costs. Greenpeace (2012) characterizes costs in this way: "The crucial factor for the economics of biomass utilization is the cost of the feedstock, which today ranges from a negative cost for waste wood … through inexpensive residual materials to the more expensive energy crops. The resulting spectrum of energy generation costs is correspondingly broad. One of the most economic options is the use of waste wood in … CHP plants. Gasification of solid biomass, on the other hand, which opens up a wide range of applications, is still relatively expensive." In the long term, Greenpeace expects that favorable electricity production costs will be achieved by using wood gas both in micro CHP units and in gas-and-steam power plants, and says, "there is [also] great potential to use solid biomass for heat generation in both small and large heating centers linked to local heating networks."[48]

Hydropower

Hydropower has been a mature technology for decades, and scenarios like GEA (2012) show stable costs for hydro in the future. As noted in Chapter 2, the storage inherent in most hydropower provides capacity for managing variable renewables on power grids. Many projections show continued market growth for all forms of hydro, particularly in developing countries.[49] *(See Table 4 on page 53 and also Chapter 5 for many country-specific projections.)*

Many experts foresaw an expanding future role for pumped hydropower, particularly as a form of energy storage to balance variable renewables, including using rapid-reaction turbines and variable-speed pumps. NREL (2012) notes that: "Pumped-storage hydropower is considered a mature technology. However, incremental improvements in efficiency are possible, and the flexibility of existing and future plants may be improved using variable-speed drive technologies. Other possible developments include use of saltwater pumped-storage hydro facilities in coastal regions and underground pumped-storage hydro." IEA ETP (2012) similarly notes that new projects or retrofits are incorporating variable-speed pumps that increase the ability of pumped hydro to provide grid flexibility on shorter time scales.[50]

REN21 (2012) shows 130 GW of pumped hydro capacity globally in 2011, more than one-third of this in Europe. REN21 also notes that Europe plans an additional 27 GW by 2020, that the United States has 34 GW under permit, and that China increased its five-year plan (2011–2015) target for pumped hydro to 80 GW. IEA ETP (2012) notes that historically, pumped hydro could be justified economically by arbitrage in daily electricity price spreads, but that in recent decades, natural gas has reduced spreads such that, "at present, energy arbitrage, the traditional driver for investment in pumped hydro, does not stand up in market conditions." However, IEA ETP (2012) also shows pumped hydro levelized energy costs, at about 12 cents/kWh, to be significantly less than other storage options like batteries. GEA (2012) shows pumped hydro costs in the range of 3–9 cents/kWh.[51]

Geothermal

Geothermal is considered a mature technology. REN21 estimates current geothermal power costs at 6–11 cents/kWh. Some scenarios do show future declines in costs with technology improvements. For example, Greenpeace (2012) shows geothermal power costs declining from 15 cents/kWh today to 9 cents/kWh by 2050. Greenpeace says: "[Geothermal electricity] was previously limited to sites with specific geological conditions, but further intensive research and development work has enabled widened potential sites. In particular the creation of large underground heat exchange surfaces—Enhanced Geothermal Systems (EGS)—and the improvement of low temperature power conversion, for example with the Organic Rankine Cycle, could make it possible to produce geothermal electricity anywhere. Advanced heat and power cogeneration plants will also improve the economics of geothermal electricity. As a large part of the costs for a geothermal power plant come from deep underground drilling, further development of innovative drilling technology is expected."[52]

Ocean Energy

Market projections for ocean energy are difficult because the technology is still not commercial. By 2011, a handful of projects were in operation around the world, notably in France and Korea, and the ocean energy industry appeared poised for full commercial-scale development. Some experts offered the possibility of future breakthroughs. GEA (2012) shows ocean energy costs of 9–38 cents/kWh in 2009, depending on the technology, and projects potential declines in the future to 6–20 cents/kWh for ocean-thermal power (OTEC), 9–30 cents/kWh for tidal power, and 8–30 cents/kWh for wave power.[53]

Greenpeace (2012) sees potential for lower costs in the coming decades: "The cost of energy from initial tidal and wave energy farms has been estimated to be in the range of 25–95 US cents/kWh, and for initial tidal stream farms in the range of 14–28 US cents/kWh. Generation costs of 8–10 US cents/kWh are expected by 2030. Key areas for development will include concept design, optimization of the device configuration, reduction of capital costs [with] alternative structural materials, economies of scale, and learning from operation.... In the long term, ocean energy has the potential to become one of the most competitive and cost effective forms of generation."[54]

Biofuels

Several industry experts believed that by 2050, biofuels could provide at least 25–35% of the world's transport fuels, although other experts questioned high shares based on sustainability and resource constraints. *(See "Great Debate 12" on this page.)* One expert believed that the share could reach even higher, and become based predominantly on crop wastes, thus negating concerns about land use and sustainability—if vehicles became super-efficient and total transport energy demand is much less. Experts also disagreed about whether biofuels in the long term would remain mostly so-called "first generation," or whether "advanced" biofuels (i.e., cellulosic-ethanol and bio-synthetic gas) would eventually dominate markets. Many experts foresaw increased research, development and commercialization efforts, but some were uncertain of the ultimate results of such efforts.[55]

Oil companies are relatively optimistic about biofuels, and many are investing or expecting to invest in biofuels research and production. "Advanced biofuels … will play an increasing role," said Chevron, which like many oil companies was actively investing in advanced biofuels research. The IEA (WEO, 2012) says: "Advanced biofuels … are assumed to become commercially available (though not yet competitive with conventional fuels) around 2020 in the New Policies Scenario. By 2035, advanced biofuels make up 18% of total biofuel production." An IEA (2011) "Technology Roadmap" for biofuels envisions demonstrations of commercial-scale production of cellulosic-ethanol, biomass-to-liquids diesel, hydrotreated vegetable oil, and bio-synthetic gas by 2015. Beyond 2015, the roadmap envisioned innovative "bio-refinery" concepts, and beyond 2020, feasible production of algae-derived biofuels and other novel biofuels routes.[56]

Cellulosic ethanol plants are still considerably more expensive to build than corn ethanol plants in the United States, by a factor of 2–3 in higher investment costs, said one expert. So costs will have to decline significantly, although cellulosic feedstocks are cheaper, so capital investment costs give only part of the picture. Experts pointed to continuing incremental improvements in costs through a variety of possible processes, including hybrid processes combining biochemical and thermo-chemical conversion.[57]

Fundamentally, there remains a wide variety of expert opinion: some believe commercialization is close at hand, while others believe commercialization may never occur. Factors include developing cheaper enzymes, feedstock prices, technological learning, and sustainability issues. The IEA WEO (2012) "Current Policies" scenario projects that advanced biofuels, like biomass-to-liquid biodiesel or cellulosic ethanol, will become commercial by 2025, while the "450" scenario projects this happening much sooner, by 2015.[58]

There are a variety of advanced biofuels technologies in research stages that may one day achieve commercial viability. Experts pointed to several possibilities, including biomass-gasification-to-liquid conversion pathways, sugar-to-biodiesel conversion using yeast fermentation, bacteria for producing biodiesel from cellulosic materials, and algae as a potential biofuel feedstock.[59]

Great Debate 12 | How Sustainable Can Biofuels Become in the Long Term?

The sustainability of biofuels has attracted increased attention over the past several years. In Europe, a 2009 EU directive for renewable energy targets a 10% share of transport energy from biofuels and electricity by 2020. The directive requires that biofuels must generate minimum levels of greenhouse gas emissions reductions, compared with fossil fuels, if biofuels are to count toward meeting the target. Similar requirements exist for the U.S. Renewable Fuel Standard and California's state standard. Brazil also adopted new sustainability policies for sugarcane ethanol in 2009.

These types of policies notwithstanding, several experts were concerned about sustainability issues with current-generation biofuels. They noted issues like land use, deforestation, biodiversity, food prices and security, and social issues with local populations. And some believed that only advanced biofuels, particularly from agricultural wastes and from crops on marginal lands like switch grass, would ensure future sustainability. One developing country expert said: "I am afraid the world is placing excessive emphasis on biofuels. This would mean diversion of land in developing and poor countries from food crops to fuel crops—a strategy that may not be acceptable to all countries."

The IEA (2011) "Technology Roadmap" for biofuels says that high shares of biofuels in the long term pose "a considerable challenge given competition for land and feedstocks from rapidly growing demand for food and fiber, and for … biomass for generating heat and power." But the roadmap concludes that ultimately it should be possible, from residues and waste, along with sustainably grown energy crops. *(For more discussion, see REN21* Renewables 2010 Global Status Report*, Sidebar 7, page 43.)*

Source: See Endnote 55 for this chapter. Notes and discussion: See Annex 4.

CONCLUSION: TRANSFORMATIONAL CHANGE?

Many experts in the course of interviews for this report believed that futures with high shares of renewable energy are possible, and that this is a matter of choice, not of technology or economics. All of the necessary technologies exist, they said, and the long-term economics across different choices are relatively similar, or even tilt in renewables' favor, they believed. "If we don't have a renewable energy future, it's not because we can't—it's because we decided not to," said one. Others believed that the diverse motivations behind renewable energy, together with the changing economics and risks of energy technology portfolios, not just individual technologies, would drive transformational changes sooner than many expect.

Experts concerned about climate change said that significantly more renewable energy would be needed to meet mitigation goals, and that this would also drive transformational change. They pointed out that climate mitigation scenarios must compare the costs of renewables with other mitigation technologies, primarily energy efficiency, carbon capture and storage for fossil fuels, and nuclear power. Of these options, energy efficiency is generally considered the cheapest, they said. But beyond efficiency, some questioned whether carbon capture and storage would become commercial enough, and asserted that nuclear power would remain too expensive and socially unacceptable. *(See also Box 2 on page 16.)*

Many of the industry and utility managers interviewed were already hard at work bringing about high-renewables futures, in places like Denmark, Germany, and Spain. To them, a future with high shares of renewable energy was already inevitable, in part because of long-term national targets and already-high existing shares. *(See Chapter 1.)* To them, the main question was, "how will all the energy system pieces fit together in the most efficient way, and how long will it take to transform the system?"

Indeed, transformational change is clearly implied by some existing national policy targets. For example, Denmark's targets for a 50% electricity share and 40% heating share by 2020 (and 100% shares for both by 2050) will force transformational change in the electricity and heating sectors. Germany's targets for at least 35% electricity share by 2020 and 80% by 2050 will do likewise. (And, experts noted, perhaps sooner than expected: Germany's electricity share had already reached a reported 25% in the first nine months of 2012. And one said: "European utilities in particular are facing trouble right now because they have to invest in the grids themselves and put increased attention on grid balancing, both at centralized and distributed levels, in order to accommodate renewable energy policy goals and targets to be fulfilled in the next 5–10 years.")

Some experts saw transformation just around the corner, not just technically, but also financially and institutionally. One said: "Electric utility companies will face some of the greatest challenges in technical and institutional restructuring that they have ever faced in the past 100 years." Another said: "Transportation systems will definitely become less homogeneous, with a multitude of fuel types and vehicle types, and with local solutions tailored to local conditions and geography. The days of 'one size fits all' transport are numbered."

Beyond the transformation of power grids and transport, many experts also pointed to coming transformations in buildings and construction. They noted that change could be much slower than with power and transport, due to the long lifetimes of buildings. But they framed transformation in terms of new renewables-integrated building materials and components becoming standard products, and in terms of the acceptance and adoption by architects/engineers and developers of renewable power, heating, and cooling technologies as standard elements of homes and commercial buildings. This would usher in a new era of building design and construction, said experts, including the adoption of so-called "near-zero-energy," "net-zero-energy," and "passive" buildings noted in Chapter 2.

The idea that technical transformation would lead to financial transformation was expressed by one expert in this way: "At 80–90% renewable power share on grids, you can keep the lights on but not necessarily keep the financial and business structures intact and viable."

Indeed, the coming of solar PV "retail grid parity" to many locales and regions around the world, as noted in Chapter 6, was cited by some experts as heralding a transformation in the way utilities must be managed, financed, and operated—and a transformation potentially so rapid that many utilities would be caught scrambling for new technical approaches as well as new business models to remain viable. This is already happening today, said some experts, who said grid parity had already come to some locales.

Transformational change is also implied by many of the other technical integration challenges facing electric utilities noted in Chapter 2, as well as the choice of utilities themselves to "lead, follow, push back, or perish." *(See "Great Debate 6" on page 34.)*

Experts foresaw that some utilities and energy companies will lead the coming transformations, and pointed to utilities that are already engaged in rethinking, planning, and implementing new strategies. However, experts also warned that with the coming of large amounts of distributed generation by end-users, utility companies could lose sales revenue from existing investments. At the margin, smaller shares are not threatening. But as renewable shares get bigger, an incentive emerges for utilities to resist or even actively discourage renewable energy, so as to not lose market share, in this case to their own customers.

Spain is a case where such utility resistance has been manifesting already, according to one Spanish expert, given large shares of renewables seen in recent years. Large utility companies that once led renewable energy development were turning back in 2012 to championing coal and actively blocking new renewable energy policies for self-generation, said the expert. Even gas companies in Spain, previously having entered solar hot water markets, were feeling the effects from reduced gas demand, the expert said.

In interviews, some policymakers questioned the role of policies in leading transformation, given that most existing policies are "incremental" in nature. The policy "bridge" to a transformed energy system was not necessarily clear to them. The viewpoints in this report point to several features of such a bridge, starting with revised concepts of cost competitiveness and "subsidies" across all energy technologies, continuing with sector-specific policies (i.e., power grids, buildings, transport) that support integration in individual sectors, and innovation and action at all levels, whether local, national, or regional. Viewpoints also suggest that such a policy bridge would include energy policies that place greater emphasis on financial risk-return metrics and risk-reducing energy-portfolio approaches rather than traditional cost-based and technology-based approaches.[a]

Viewpoints suggest that new forms of finance, whether at the community-ownership level, or at the level of national pension funds or sovereign wealth funds, coupled with new risk-mitigation financial instruments, will also usher in transformation.

And viewpoints suggest that transformation will come from the existing role of China in global renewable energy markets, and from the emerging roles of a large number of developing countries in terms of policy support, markets, development motivations, energy security, and local manufacturing. And that rural energy "access" with renewables for hundreds of millions of rural households would also be transformative, from home lighting to small industry to replacement of millions of diesel generators.

Some experts saw the transformation of energy systems as an instrument of social equity—and used phrases like "energy democracy" to denote the control and choice that decentralized forms of renewable energy can bring. Some saw "soft" strategies like alliance building and communications, and building stakeholder groups at local levels, as key parts of decentralized energy futures. They favored less centralized investment, even of renewables technologies themselves, and more community-based power systems. Some experts noted that public acceptance of nearby infrastructure like wind farms and transmission lines varies with the degree to which local communities feel that this infrastructure is serving them directly, or the degree to which they have an ownership or controlling stake. *(See also "Great Debate 5" on page 27.)*

Some experts saw transformation as driven by consumer choice and perception as well, not strictly by technologies or economics. This includes, for example, consumer decisions about which types of vehicles to buy, how the vehicles will be owned and used, how people wish to integrate vehicles with their home energy systems, and how they will allow their electric vehicles to support grid balancing. Certainly, consumer choice is already playing a large role in the proliferation of rooftop solar PV systems in some countries, noted experts, along with consumer decisions to purchase green power at the retail level. *(See also "Great Debate 8" on page 37.)*

Experts emphasized that "transformation" implies more than just integration. One asked: "Do we really need renewables to fit into the existing system, or do we need all energy technologies to evolve in different ways and with different roles and shares into a transformed energy system?" Many of the ideas noted in Chapter 2, in terms of modifying the operation of existing fossil fuel power plants, new roles for natural gas and the implications for natural gas technologies, and even hybrid fossil fuel-renewable power plants, point to a co-evolution of all energy technologies together, not just the addition of renewables. But the long infrastructure lifetimes of existing energy technologies play a role in how long the transition will take. *(See the idea of "lock in" in the report's Introduction.)*

Finally, experts pointed to "whole-system" thinking when it comes to energy, transport, buildings, and industry, including the role of energy efficiency. Such whole-system thinking is also noted throughout this report. End-use equipment choices and higher end-use energy efficiency, for example, are crucial components of an energy system built with renewable energy. Interviewees stressed perspectives of wheel-to-wheels, cradle-to-grave, and eco-industry, and other systems thinking. And experts pointed out that "whole-system" thinking does not apply only on technical levels, but also on institutional, policy, business, and social levels.

In the words of one visionary: "We can be almost certain that the future will not be a linear growth line from today. We always underestimate the future, which then produces surprises. I'm sure we're underestimating the growth of renewables as well."

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a) For more on policies and transformational change, a good reference is the "Policies" chapter in IPCC (2011). The IPCC report's Chapter 8 on "Integration" is also highly relevant.

EPILOGUE: SPEAKING PERSONALLY

(VIEWS OF THE AUTHOR)

As noted from the start, this report is intended to objectively portray the range of credible views and possibilities about the future of renewable energy, expressed by an array of experts and scenarios. In writing the report, I put aside my personal views in order to present the fullest range of possibilities. Here, however, I take the liberty to express my own views, many of which mirror content in the preceding chapters. While most readers should find their own views represented somewhere in the report, some readers may disagree with mine. My views come from personal experience working in the field of renewable energy since 1986, and from the work I conducted in 2011–2012 as the basis for this report.

Overall, I think there are excellent prospects for the world to become predominantly powered (and fueled) by renewable energy by the 2040–2050 timeframe (including electricity, heating, cooling, and transport). Indeed, this should be an explicit political and social goal worldwide. As to what "predominantly" means, I would say something like 80–90%. I don't believe that we can reach "100%," as many now advocate, although "100%" is a useful political and social archetype. Rather, I think we need to allow for a modest share of fossil fuels to accompany renewables, particularly for those needs that are most difficult to meet with renewables, including freight transport and shipping, high-temperature industrial process heat, airline travel (unless we start using passenger airships again), and some natural gas use in power grids to balance variability.

At some point before 2020, the question of renewables' fundamental economic competitiveness will cease to be an issue. Renewable technology costs will continue to decline, while fossil fuel prices will continue to increase. Investors will recognize renewables as sound, low-risk investments, and renewables will become a preferred target of equity finance and seen as a strong inflation hedge.

Eventually, the main questions will simply become questions of finance, rates of return, infrastructure lifetimes, rates of replacement of existing energy infrastructure, and the evolution of high-efficiency end-uses, from appliances to cars to homes to factories. These end-uses will be "paired" with renewables as integrated energy services.

However, materials constraints for manufactured renewable technologies (including supplies of specific elements and rare earths), recycling (especially of batteries), and toxic wastes could eventually present a formidable challenge. I am swayed by both pessimistic and optimistic assessments of how well we can manage such a challenge.

Governments should continue to support renewables through the 2020s because a host of institutional and social issues for integration of renewables will continue to require attention, foremost among them a host of policies and practices for utility grid integration (as discussed in Chapter 2) and new policies and practices for efficient, low-energy building construction integrated with renewable heating and cooling.

Governments should also undertake crash programs for electric and thermal storage technologies, which have the greatest potential to have a transformative impact. And governments should abandon all support for nuclear power, which is too expensive, unnecessary in view of what renewables can do, and unworthy of the legacy we leave to future generations.

Most experts agree that electricity will be the easiest to supply from renewables. I believe that the world will achieve close to 100% electricity from renewables in the long run without much difficulty. And I believe that this can be achieved even without a major energy storage breakthrough—given the many other available options for managing grid variability. Utilities and regulators will figure it out, but renewables are growing so fast that there is not much time. Energy storage will help as well, and commercial battery storage technologies are closer than most realize, for both local and centralized levels. Pumped hydro storage is already well established, and I believe it can be expanded greatly to manage variability, in spite of environmental issues, to become an important part of a renewable energy future.

In the coming years, there will be an explosion of solar PV rooftops across the world, big and small. Fifteen or 20 years from now, a "bare" rooftop will seem very strange to us, and most new construction will include PV as routine practice. This will lead to a parallel explosion in micro-grids (both residential and commercial), community-scale power systems, and autonomous-home systems. The grid will become a much more complex hybrid of centralized and distributed power, with a much greater variety of contractual models between suppliers and consumers. For bulk power supply and industry, the "big grid" resources—wind, solar thermal power (CSP), and geothermal—will predominate. I happen to think that most biomass in the long run will be used for heating and transport fuels and not electricity, but this is uncertain.

Solar heating and cooling have great promise. There is no reason why many new and existing buildings should not be outfitted with solar heating and cooling systems integrated into building architecture. And we will see dedicated CSP plants that double as industrial heat supply. It also seems that there could be a boom in geothermal heat pumps given proper incentives and integration with building codes and regulations. And for countries in northern climates, or those with high quantities of readily available agricultural wastes, wood pellets for residential and small-commercial heating could become ubiquitous, with large and sophisticated markets for wood pellet distribution. Similarly, there are large opportunities for piped and containerized biogas for home heating and cooking.

The single most important driver for renewables-based heating and cooling in the future will be innovations and changes in building construction, including widespread adoption of so-called "passive" or "zero-energy" building models that require very little heating energy, even in cold winter climates, due to super insulation, solar gain, thermal storage, and high-efficiency heating equipment. Only when such buildings are widespread can renewables play a large role in heating and cooling. Such buildings are not much more expensive than ordinary construction, but the architecture and construction industry is far from providing off-the-shelf, least-cost, and integrated solutions for passive buildings.

I see no reason that virtually all passenger transport cannot become electric in the long term, leading to 100% renewable passenger transport. However, this cannot be accomplished with current battery technology, which is still quite expensive. But the transition to much smaller and cheaper electric micro-vehicles, coupled with new lightweight materials for conventional-size electric vehicles, and new forms of vehicle ownership and mobility services, lead me to believe that a high share of mobility will be served by electricity in the future, perhaps as soon as 2020–2025. Battery technology remains a big wild card, but it seems inevitable that battery technology breakthroughs will occur with advances in new materials.

Given that all passenger transport will become electric (except for air travel), biofuels will be most important for non-passenger transport, such as freight, and perhaps for some industrial uses. However, I don't believe that biofuels from food crops will be a part of our transport future, as land will be needed for human food consumption given growing populations and climatic changes that affect agricultural productivity, as well as problematic sustainability issues. Advanced biofuels made from cellulose that is grown on marginal lands and from agricultural waste could become very significant, but I remain unconvinced that cellulose-to-biofuels technology is a sure thing. Other types of advanced biofuels show promise.

As for hydrogen fuel-cell vehicles, I think fuel cells for converting hydrogen into electricity are best left in homes and buildings where the substantial waste heat from this process can be utilized productively, not in vehicles where it cannot. And I remain unconvinced that fuel cells will ever be cheap enough.

In the future, I see renewable energy investments proceeding along three main tracks:

1. "Mega projects." Large-scale onshore and offshore wind farms, grid-tied CSP plants, autonomous CSP for desalination, multi-megawatt-scale ground-mounted solar PV, large biorefineries, and large-scale energy storage projects will be driven and financed by large companies and institutional investors, including national governments.
2. "Big rooftops." Commercial and industrial companies will put renewables on their rooftops, primarily solar PV and solar heating/cooling, integrated with geothermal heat pumps and intermediate-scale storage technologies. Public entities will also lease public rooftops and a wide range of other public infrastructure for its "rooftop-like" qualities.
3. "Communities and autonomous consumers." Communities, small groups, and individual investors will install rooftop renewables, shared heat supplies, jointly owned wind turbines, and other community-based power using a wide range of local renewables and storage technologies. New forms of consumer finance, vendor finance, and utility on-bill finance will help greatly.

The financial difficulties that were affecting economies around the world at the close of 2012 will likely affect all three tracks for many years. These conditions will likely bring investor risk-aversion and possibly much higher inflation-induced interest rates, which would certainly dampen investments for many years. But where OECD countries may fall back for a time due to financial difficulties, I remain convinced that China, India, and many other developing countries will take up the slack soon enough.

What must happen for the visions in this report, and my personal vision expressed here, to become reality in the coming decades? First, we must believe these things are possible. That belief is getting easier every year as market and investment trends provide confirmation. Then, we must look to the countless individual decisions made everyday by consumers, homeowners, utilities, construction firms, corporate executives, financiers, and many others, and how those decisions can better align with a renewable energy future. Much can also be achieved through decisions by local groups, whether at the community level, the sub-neighborhood level, or the homeowner association level. Better education and training is fundamental to all of the above decisions. Research and development (both public and private) for new technologies, especially driven by new materials, will certainly make the future come easier and faster. But we don't need to wait for those breakthroughs—we have enough at our disposal already. Finally, governments have an important role to play in the many ways outlined in this report, although with perhaps less focus on costs and more on risks, and certainly with more attention to the necessary sector-specific policies for electric power, buildings, industry, and transport.

I intend to personally see the transformations discussed in this report happen by 2040–2050, if not sooner. Onward to a renewable energy future!

Eric Martinot

ANNEX 1 – LIST OF INTERVIEWS

A series of interviews with 170 individuals was undertaken from late 2010 through mid-2012 to gain expert and industry views of the future of renewable energy. These interviews were focused on the long term, 2020 and beyond. (The long-term nature of solicited views makes them less prone to becoming outdated by subsequent short-term developments, although this is certainly a consideration.)

Persons interviewed included heads of industry associations, business people, financiers, researchers, consultants, academics, public advocates, policymakers, multilateral (intergovernmental) agency staff, electric utility managers, regulatory staff, journalists, and city government officials. Interviews included 16 executives (CEOs, presidents, or executive vice presidents) and two parliamentarians.

Interviews were conducted as unstructured discussions, rather than formal question-response sessions, often based on a set of 4–8 questions posed in advance, and tailored to the expertise and interest of each interviewee. Most interviews were conducted in-person at the place of business of the interviewee, while a few were conducted by phone. Interviews were typically 45 minutes to 1.5 hours in length, although some lasted up to three hours. Report author Eric Martinot conducted most interviews. Additional interviews on local/city and developing country topics were conducted by Lily Riahi of the REN21 Secretariat.

All interviewees were promised anonymity of remarks, so names cannot be cited within the body of the report. As noted in the Preface, the purpose of the interviews was not to elicit quotes from specific experts, but rather to compile an overall mosaic of information that captures a credible range of views of the future. Some quotes have been used in the text, taken from interviews without attribution, to make the text more interesting and to provide a more direct experience of interview results. All quotes in the report come from interviews except where publication citations are given.

The majority of interviews were conducted with experts and executives in Europe and the United States, with an additional 15 interviews in Japan, 22 in China, and 16 in India, South Africa, and other developing countries. Supplementing the individual interviews in developing countries, three additional roundtable discussions were held, specifically as input to the report, in India (organized by The Energy and Resources Institute—TERI), Morocco (organized by the African Renewable Energy Alliance and the World Future Council), and South Africa (organized by the South Africa National Energy Development Institute). Two additional roundtable discussions were held in Germany (organized by the World Council for Renewable Energy) and the United States (organized by the National Renewable Energy Laboratory). The contribution of all interviewees and workshop participants is greatly appreciated.

Pallas Agterberg (Alliander)
Donald Aitken (Donald Aitken Associates)
Matthias Altmann (Ludwig-Bölkow-Systemtechnik GmbH)
Adnan Amin (International Renewable Energy Agency–IRENA)
Kjell Andersson (Swedish Bioenergy Association)
Doug Arent (National Renewable Energy Laboratory–NREL)
Dan Arvizu (NREL)
Alan AtKisson (AtKisson and Associates)
Roger Ballentine (Green Strategies)
Pedro Ballesteros Torres (European Commission/Covenant of Mayors)
Marlett Balmer (Deutsche Gesellschaft für Internationale Zusammenarbeit)
Morgan Bazilian (formerly UN Industrial Development Organization)
Kubeshnie Bhugwandin (Eskom, South Africa)
Lawrence Bloom (formerly Noble Cities Plc)
Denise Bode (American Wind Energy Association)
Gunnar Braun (Verband kommunaler Unternehmen e.V., Landesgruppe Bayern)
Joost Brinkman (Accenture)
David Cadman (City of Vancouver Council)
Sanjeev Chaurasia (Credit Suisse)
Chen Mozi (China Electric Power Research Institute)
Mike Cleary (NREL)
Luis Crespo (European Solar Thermal Electricity Association)
Lena Dahlman (Swedish Bioenergy Association)
Guy Dauncey (BC Sustainable Energy Association)
Paul Denholm (NREL)
Pedro Dias (European Solar Thermal Industry Federation)
Du Xiangwan (Chinese Academy of Engineering)
Mike Eckhart (Citigroup)
Jorgen Edstrom (Copenhagen Energy)
Sachio Ehara (Kyushu University)
Mohamed El-Ashry (UN Foundation)
Ditlev Engel (Vestas)
Fort Felker (NREL)
Hans-Josef Fell (German Parliament)
Manfred Fischedick (Wuppertal Institute)
Doerte Fouquet (Becker Büttner Held)
Paolo Frankl (International Energy Agency—IEA)
Lisa Frantzis (Navigant Consulting)
Uwe Fritsche (Öko-Institut)
Gang Wu (Chinese Academy of Sciences)
Nick Gardner (BNP Paribas)
Carlos Gasco (IEA)
Dolf Gielen (IRENA)
Herbert Girardet (World Future Council)
Cristina Gomez (Red Eléctrica de España)
Stefan Gsänger (World Wind Energy Association)
Karin Haara (World Bioenergy Association)
Toshishige Hamano (Sharp)
Kirsty Hamilton (Chatham House)
Lars Hansen (Dong Energy)
Aksel Hauge Pedersen (Dong Energy)
Steve Hauser (NREL)
Rainer Hinrichs-Rahlwes (European Renewable Energies Federation)
Winfried Hoffmann (European Photovoltaic Industry Association)
Jeffrey Holzschuh (Morgan Stanley)
Toshio Hori (Green Power Investment Corporation)
Huang Ming (Himin Solar Corp.)
Roland Hulstrom (NREL)
Jiang Kejun (China Energy Research Institute)

Jiang Liping (China State Grid Energy Research Institute)

Henrik Johansson (City of Växjö)

Thomas Johansson (Lund University)

Eveline Jonkhoff (Gemeente Amsterdam)

Hans Jørgen Koch (Danish Energy Agency)

Peter Jørgensen (Energinet.dk)

Tomas Kåberger (formerly Swedish Energy Agency)

Vinod Kala (Emergent Ventures India)

Dan Kammen (University of California at Berkeley)

Christian Kjaer (European Wind Energy Association)

David Kline (NREL)

Jonker Klunne (Council for Scientific and Industrial Research, South Africa)

Jochen Kreusel (ABB Asea Brown Boveri)

Arun Kumar (Alternate Hydro Energy Centre, India)

Minoru Kumazaki (Japan Wood Pellet Association)

Kiyoshi Kurokawa (Health and Global Policy Institute)

Stephen Lacey (ClimateProgress.org)

Niels Ladefoged (European Commission)

Ole Langniss (Fichtner GmbH)

Geoff Lawler (City of Melbourne)

Stef le Fèvre (City of Amsterdam)

Jeremy Leggett (Solar Century)

Debra Lew (NREL)

Li Junfeng (Chinese Renewable Energy Industries Association)

Bo Lidegaard (Politiken)

Michael Liebreich (Bloomberg New Energy Finance)

Christine Lins (formerly European Renewable Energy Council)

Liu Bin (China CECEP Wind Power Corp.)

Amory Lovins (Rocky Mountain Institute)

Ma Xiulu (Baoding Yingli)

Ernesto Macias (Alliance for Rural Electrification)

Preben Maegaard (Danish Folkecenter)

Thembakazi Mali (South African National Energy Development Institute—SANEDI)

Jaume Margarit (IDAE Institute for Energy Diversification and Efficiency)

José María González Veléz (Spanish Renewable Energy Association)

Andreas Maryensson Lamppa (formerly City of Växjö)

Robert McFarlane (McFarlane Associates)

Gustav Melin (European Biomass Association)

Sebastian Meyer (Azure International)

Wolfgang Meyer (Zukunftsrat Hamburg)

Alan Miller (International Finance Corporation)

Mackay Miller (NREL)

Arne Mogren (European Climate Foundation)

David Mooney (NREL)

Miwa Mori (Passive House Japan)

Toru Morotomi (Kyoto University)

Fredrick Morse (Abengoa Solar)

Josiah Munda (Tshwane University of Technology)

Yoshihisa Murasawa (Tokyo University)

Ed Murray (Aztec Solar)

Sabine Nallinger (City of Munich Council)

Kevin Nassiep (SANEDI)

Pancho Ndebele (Southern Africa Solar Thermal and Electricity Association)

Ni Weidou (Tsinghua University)

Kiyoshi Nishimura (Osaka University)

Kent Nyström (World Bioenergy Association)

Andre Otto (SANEDI)

Walt Patterson (Chatham House)

Terry Penney (NREL)

Emiliano Perezagua Gil (European PV Technology Platform)

Brian Perusse (AES Energy Storage)

Anil Pinto (Siemens South East Asia)

Klaus-Peter Pischke (KfW Development Bank)

Martin Powell (London Development Agency)

Michaela Pulkert (HVB - UniCredit Group)

Mario Ragwitz (Fraunhofer ISI)

David Renne (International Solar Energy Society)

Wilson Rickerson (Meister Consultants Group)

Dima Rifai (Paradigm Change Capital Partners)

Jan Rispens (Erneuerbare Energien Hamburg Clusteragentur GmbH)

Brad Roberts (Electricity Storage Association)

Tetsuo Saitou (Japan Wind Power Association)

Elizabeth Salerno (American Wind Energy Association)

Armin Sandhoevel (Allianz Climate Solutions)

Yasushi Santo (YS Energy Research)

Steve Sawyer (Global Wind Energy Council)

Jason Schäffler (Renewable Energy and Energy Efficiency Partnership)

Martin Schöpe (German Ministry for Environment)

Markus Schüller (Fichtner GmbH)

Tilman Schwencke (Mainstream Renewable Power)

Jigar Shah (Carbon War Room)

Shi Dinghuan (China Renewable Energy Society)

Shi Pengfei (China Wind Energy Association)

Shi Zhengrong (Suntech)

Walter Short (NREL)

Scott Sklar (Stella Group)

V. Subramanian (Indian Wind Energy Association)

Toru Suzuki (Hokkaido Green Fund)

Hiroshi Takahashi (Fujitsu Research Institute)

Nobuo Taniguchi (formerly Tokyo Municipal Government)

Tao Gang (Sinovel)

Sven Teske (Greenpeace International)

Molly Tirpak Sterkel (California Public Utilities Commission)

Claude Turmes (European Parliament)

Dirk Uwe Sauer (Aachen University)

Daniel Vallentin (Wuppertal Institute)

Roberto Vigotti (OME)

Wang Zhongying (China Center for Renewable Energy Development)

Carl Weinberg (Weinberg Associates)

Oliver Weinmann (Vatenfall)

Lutz Weischer (World Resources Institute)

Karsten Wessel (IBA Hamburg)

Bob Williams (Princeton University)

Heikki Willstedt Mesa (Spanish Wind Energy Association)

Ryan Wiser (Lawrence Berkeley National Laboratory)

Wu Chuangzhi (Guangdong Energy Institute)

Wu Gang (Goldwind)

Yang Xiaosheng (Longyuan)

Dana Younger (International Finance Corporation)

Arthouros Zervos (European Renewable Energy Council)

Zhang Dongxiao (Beijing University)

Zhang Xiliang (Tsinghua University)

ANNEX 2 – LIST OF SCENARIOS COVERED

Text Citation	Region	Full Reference
APEC/ADB (2009)	Asia and the Pacific	Asia-Pacific Economic Cooperation/Asian Development Bank. 2009. *Energy Outlook for Asia and the Pacific.* Mandaluyong City, Philippines. 400 pp.
BNEF (2011)	Global and China	Bloomberg New Energy Finance. 2011. *Global Renewable Energy Market Outlook* (GREMO). London.
BP (2012)	Global	BP. 2012. *BP Energy Outlook 2030.* London. 88 pp.
Brazil MME (2010)	Brazil	Brazil Ministry of Mines and Energy. 2010. "Outlook for Alternative Renewable Energy in Brazil." Brasilia. 28 pp.
China ERI (2009)	China	China Energy Research Institute. 2009. *China's Low-Carbon Development Pathways by 2050.* Beijing. 168 pp.
China ERI (2011)	China	China Energy Research Institute. 2011. "Potential Secure, Low-Carbon Growth Pathways for the Chinese Economy." Beijing. 27 pp.
CREIA (2012)	China	Chinese Renewable Energy Industries Association. 2012. "Study of High Percentage Renewable Energy in China." Beijing.
EC (2009)	Europe	European Commission. 2009. *EU Energy Trends to 2030.* Luxembourg. 184 pp.
EC (2011)	Europe	European Commission. 2011. "Energy Roadmap 2050." Luxembourg. 22 pp.
EREC (2010)	Europe	European Renewable Energy Council. 2010. *RE-thinking 2050: 100% Renewable Energy Vision for the European Union.* Brussels. 76 pp.
Eurelectric (2009)	Europe	Eurelectric. 2009. *Power Choices – Pathways to Carbon Neutral Electricity in Europe by 2050.* Brussels. 96 pp.
EWEA (2011)	Europe	European Wind Energy Association. 2011. *Pure Power: Wind Energy Targets for 2020 and 2030.* Brussels. 97 pp.
ExxonMobil (2012)	Global	ExxonMobil. 2012. *ExxonMobil – The Outlook for Energy: A View to 2040.* Irving, Texas. 52 pp.
Garg (2012)	India	Garg, P. 2012. "Energy Scenario and Vision 2020 in India." *Journal of Sustainable Energy & Environment.* Vol. 3. Pp. 7–17.
GEA (2012)	Global	Riahi, K. et al. 2012. "Energy Pathways for Sustainable Development (Chapter 17)." In *Global Energy Assessment – Toward a Sustainable Future.* Cambridge University Press. Cambridge, U.K. and International Institute for Applied Systems Analysis. Laxenburg, Austria. Pp. 1203–1306. (1866 pp. total)
Greenpeace (2012) (Global and China)	Global	Greenpeace/European Renewable Energy Council (EREC)/Global Wind Energy Council (GWEC). 2012. *Energy [R]evolution: A Sustainable World Energy Outlook.* Amsterdam. 339 pp.
Greenpeace (2012) (Europe)	Europe	Greenpeace/European Renewable Energy Council (EREC). 2012. *Energy [R]evolution European Union.* Brussels. 128 pp.
Greenpeace (2012) (India)	India	Greenpeace/European Renewable Energy Council (EREC)/Global Wind Energy Council (GWEC). 2012. *Energy [R]evolution India.* Richmond Town Bangalore, India. 80 pp.
Greenpeace (2011) (Japan)	Japan	Greenpeace/European Renewable Energy Council (EREC). 2011. *Energy [R]evolution Japan.* Tokyo. 108 pp.
Greenpeace (2011) (South Africa)	South Africa	Greenpeace/European Renewable Energy Council (EREC). 2011. *Energy [R]evolution South Africa.* Johannesburg. 108 pp.
Greenpeace (2012) (United States)	United States	Greenpeace/European Renewable Energy Council (EREC)/Global Wind Energy Council (GWEC). 2012. *Energy [R]evolution United States.* Forthcoming.
GWEC (2012)	Global	Global Wind Energy Council. 2012. *Global Wind Energy Outlook.* Brussels. 52 pp.
GWEC (2011) (India)	India	Global Wind Energy Council/World Institute of Sustainable Energy (WISE)/Indian Wind Turbine Manufacturing Association (IWTMA). 2011. *Indian Wind Energy Outlook.* Brussels. 64 pp.
IEA ETP (2010)	Global	International Energy Agency. 2010. *Energy Technology Perspectives.* Paris. 706 pp.
IEA ETP (2012)	Global	International Energy Agency. 2012. *Energy Technology Perspectives.* Paris. 688 pp.
IEA RETD (2010)	Global	Renewable Energy Technology Deployment Implementing Agreement of the IEA. 2010. *Achieving Climate Stabilization in an Insecure World: Does Renewable Energy Hold the Key?* Report prepared by Navigant Consulting. Burlington, Massachusetts. 59 pp.

Text Citation	Region	Full Reference
IEA WEO (2010)	Global	International Energy Agency. 2010. *World Energy Outlook 2010.* Paris. 738 pp.
IEA WEO (2011)	Global	International Energy Agency. 2011. *World Energy Outlook 2011.* Paris. 664 pp.
IEA WEO (2012)	Global	International Energy Agency. 2012. *World Energy Outlook 2012.* Paris. 672 pp.
IPCC (2011)	Global	Intergovernmental Panel on Climate Change. 2011. *Renewable Energy Sources and Climate Change Mitigation Special Report.* New York. 1076 pp.
IRENA (2012)	Africa	International Renewable Energy Agency. 2012. *Prospects for the African Power Sector. Scenarios and Strategies for Africa Project.* Abu Dhabi. 60 pp.
ISEP (2011)	Japan	Institute for Sustainable Energy Policies. 2011. "From 'Unplanned Power Outages' towards a 'Strategic Energy Shift': Report on Energy Shift after March 11th." Tokyo. 22 pp.
JWPA (2012)	Japan	Japan Wind Power Association. 2012. "Potential for Introduction of Wind Power Generation and Mid/Long Term Installation Goals (V3.2)." Tokyo. 12 pp.
LBNL (2011)	China	Lawrence Berkeley National Laboratory. 2011. *China's Energy and Carbon Emissions Outlook to 2050.* Berkeley, California. 66 pp.
Lovins/RMI (2011)	United States	Lovins, Amory, and Rocky Mountain Institute. 2011. *Reinventing Fire: Bold Business Solutions for the New Energy Era.* White River Junction, Vermont. Chelsea Green Publishing. 352 pp.
METI (2010)	Japan	Ministry of Economy, Trade and Industry. 2010. "The Strategic Energy Plan of Japan." Tokyo. (In Japanese)
NEDO (2009a)	Japan	New Energy and Industrial Technology Development Organization. 2009. "White Paper on Renewable Energy Technologies." Kawasaki, Japan.
NEDO (2009b)	Japan	New Energy and Industrial Technology Development Organization. 2009. *PV Roadmap Toward 2030.* Kawasaki, Japan. 126 pp.
NREL (2012)	United States	National Renewable Energy Laboratory. 2012. *Renewable Electricity Futures Study* (volumes 1 to 4). Golden, Colorado. 854 pp.
Risø (2010)	Global	Risø National Laboratory/Denmark Technical University. 2010. *Risø Energy Report 9: Non-Fossil Energy Technologies in 2050 and Beyond.* Roskilde, Denmark. 90 pp.
SEI (2009)	Europe	Stockholm Environment Institute/Friends of the Earth. 2009. *Europe's Share of Climate Change.* Stockholm. 68 pp.
SOFRECO (2011)	Africa	SOFRECO. 2011. *Africa Energy Outlook 2040.* (Report done in consortium with Ascon Africa, Sofrecom, Nathan Sysra, Cabira, and MWH). Clichy, France. ONRI.1/PIDA/2010/04. 125 pp.
UCS (2009)	United States	Union of Concerned Scientists. 2009. "Climate 2030: A National Blueprint for a Clean Energy Economy." Cambridge, Massachusetts. 16 pp.
UNIDO (2010)	Global	United Nations Industrial Development Organization. 2010. *Renewable Energy in Industrial Applications: An Assessment of the 2050 Potential.* Vienna. 60 pp.
US DOE EIA (2011)	Global	U.S. Department of Energy. Energy Information Administration. 2011. *International Energy Outlook 2011.* Washington, D.C. 292 pp.
US DOE EIA (2012)	United States	U.S. Department of Energy. Energy Information Administration. 2012. *Annual Energy Outlook 2012.* Washington, D.C. 240 pp.
World Bank (2010)	East Asia	World Bank/AusAid. 2010. *Wind of Change – East Asia`s Sustainable Energy Future.* Washington, D.C. 162 pp.
World Bank (2011)	Latin America	World Bank. 2011. *Meeting the Balance of Electricity Supply and Demand in Latin America and the Caribbean.* Washington, D.C. 194 pp.
WWF (2011)	Global	World Wide Fund for Nature/Ecofys. 2011. *The Energy Report: 100% Renewable Energy by 2050.* Gland, Switzerland. 256 pp.
WWF Japan (2011)	Japan	World Wide Fund for Nature Japan. "Energy Scenario. 100% Renewable Energy." Kiko Network. Tokyo. (In Japanese)
Zhang et al. (2010)	China	Zhang, Xiliang et al. 2010. "A study of the role played by renewable energies in China's sustainable energy supply." *Energy.* Vol. 35. Pp. 4392–99.

ANNEX 3 – SCENARIOS, MODELS, AND VARIABLES INFLUENCING RENEWABLE ENERGY FUTURES

When experts were asked about the future of renewable energy, many replied that the future depends on policies, financing, business conditions, energy market regulation, cost reductions, social issues, and other factors that are outlined throughout this report. Far fewer replied that technology development itself was a key factor. Their views also depended on the kinds of comparisons that are being made between renewables and conventional energy technologies, including cost comparisons. *(For more on cost-competitiveness with conventional energy, see "Great Debate 1" on page 12 and "Great Debates 1–3" in Annex 4.)*

At least 18 "key variables" emerged from interviews and scenarios, presented in the following section. Experts considered many of these variables when thinking about renewable energy futures in interviews. Scenario models incorporate many or all of these variables as either (exogenous) inputs or as internal (endogenous) variables. Scenario outcomes depend on how these variables are used, or what values are assumed for them if treated as inputs.

Most scenarios consider variables such as economic growth (GDP), energy intensity and demand, fuel costs, carbon prices, technology costs, and degree of policy action. These variables could be considered the drivers for renewable energy and other energy technologies, and may be modeled based on storylines of socio-economic conditions, expectations about technological change, policy drivers, projected growth rates, or other considerations.

Scenarios can be categorized as either descriptive or normative. Under descriptive studies, "forecasts" predict likely futures from current trends, using extrapolation and modeling; "exploratory scenarios" emphasize the drivers of possible futures, without specifying a predetermined end state; and "technical scenarios" explore technology possibilities and configurations, emphasizing feasibility and implications of different options.

Under normative studies, "visions" elaborate desirable and plausible futures, emphasizing benefits; "backcasts" start with a predetermined end point—a desirable (or constrained) future—and then investigate pathways and technology configurations leading there; and "roadmaps" prescribe sequences of policies and measures. The scenarios covered in this report are a mixture of these types. As noted in Box 2 on page 16, many high-renewables scenarios are backcasts based on future carbon-related constraints.

Scenarios are an important tool for dealing with complexity and uncertainty about the future. They allow exploration of alternative futures and can provide insights to policymakers and the public alike. However, scenarios are not predictions. Rather, they can be seen as "if … then" queries: If policies accelerate the growth of renewables, what is the difference between situations with and without policies? If renewables costs decline, how will markets shift investment patterns? If CO_2 emissions should be stabilized, what combinations of technologies will achieve stabilization? These questions must be answered under sets of conditions and/or interrelationships for population, economic growth, energy demand, technology changes, technology and fuel costs, environmental emissions, and structural changes in the economy.

Modeling tools are commonly used to carry out scenario analysis, with a range of software tools available. Categories of models include techno-economic, partial and general equilibrium, simulation, optimization, and end-use accounting. The entire economy may be modeled, or just the energy system or energy demand. The IEA World Energy Model, used for the *World Energy Outlook*, has been refined for two decades and comprises 16,000 equations defining interrelationships among energy, economy, technology, investment, resources, and environment. In general, the model and modeling approach have a significant impact on both data requirements and results.

Variables Influencing Renewable Energy Futures

1. Population growth and demographics. Population affects energy demand and economic output and thus energy use. The United Nations projects a global population of 9 billion by 2050. Demographic changes also affect needed infrastructure and energy services.

2. Gross domestic product (GDP) and energy intensity of GDP. Economic output affects energy demand. The energy intensity of GDP reflects the structure of the economy, in terms of energy-intensive activities vs. low-energy activities (i.e., manufacturing vs. service).

3. Energy efficiency and per-capita energy consumption. How much additional energy efficiency is possible, and how much can be achieved in practice? Some scenarios show large energy efficiency gains that reduce total energy consumption by substantial amounts, relative to a baseline case without energy efficiency gains. *(See Box 2 on page 16.)*

4. Renewable energy technology costs. How will costs decline over time? Many policy-intensive scenarios show continued cost reductions through 2050. Some scenarios include "learning curves" in their models, which project future cost reductions based on past history and cumulative technology production over time. *(See also cost projections in Chapter 6.)*

5. Policy action. There is wide recognition that policies have underpinned renewable energy development over the past decades, and that the need for policies will continue well into the future. Therefore, both the degree of policy action and the description of policies are central to scenarios. Reference scenarios typically envision low levels of policy action, while policy-driven scenarios envision full implementation of existing policies plus often stronger future policies. *(See also "Great Debate 2" on page 13.)*

6. Fossil fuel subsidies and taxes. Subsidies and taxes for competing fuels affect the competitiveness of those fuels relative to renewables. Models project whether subsidies remain at current levels, or whether they are phased out, and by when. Most scenarios do not account for phasing out subsidies, but there are exceptions. For example, the IEA WEO (2010) "New Policies" scenario shows a phase-out of subsidies in net-oil-importing countries by 2020. *(See also "Great Debate 1" on page 12.)*

7. Interest rates (discount rates). Renewable energy investments are capital-intensive and thus heavily dependent on the cost of capital. Finance experts underlined that interest rates are "factor one" in the analysis of future projections and possibilities. Small changes in interest rate can have large consequences. Scenarios have to assume interest (discount) rates far into the future in modeling economic competitiveness.

8. Finance availability and risk-return profiles. How much finance will be available for infrastructure investments, at what levels of risk and return? This question relates to macroeconomic and financial conditions in general, and the willingness of large institutional investors to fund infrastructure investments given their time, risk, and return profiles. Scenarios generally do not model these parameters.

9. Carbon prices and taxes. To what degree will carbon prices and taxes affect the economics of renewable energy? Many scenarios model future carbon prices and taxes. But experts point out that carbon prices are very uncertain, and depend very much on market rules and in many cases government allocations of credits.

10. Natural gas prices, price volatility, and demand. What happens to future gas prices and gas demand? Experts saw natural gas power generation as the main continuing competitor with renewable energy, but also noted that the two are complementary. Many scenarios project a large shift from coal to natural gas. Experts pointed to natural gas price volatility, and the need for (and cost of) gas price hedging, as part of the competitiveness equation.

11. Coal prices and demand. Does coal remain a central feature of our energy systems, or is coal "on the way out" as some visionaries suggest? Most scenarios show global coal use increasing. For example, US DOE EIA (2011) shows global coal use increasing 50 percent by 2035, but almost all the increase occurs in non-OECD Asia, where China nearly doubles its coal consumption by 2035.

12. Oil prices. What happens to future oil prices? Most scenarios show long-term oil prices in the $100–150 per barrel range continuing for decades. Among many possible effects, oil prices affect the competitiveness of biofuels for transport, and indirectly influence natural gas prices.

13. Nuclear power acceptance and government support. How much will governments continue to support nuclear power? How will political and social acceptance change, as it did in some countries after the 2011 Fukushima accident? Experts noted debates about the true costs of nuclear power, whether nuclear becomes a source of carbon credits, and whether nuclear power investments would be made in the absence of accident insurance provided by governments. Very few scenarios model these factors.

14. Shale gas cost and availability. What production quantities of shale gas are feasible and how will shale gas affect natural gas prices? Some experts in the United States and China considered shale gas prospects as one important determinant of renewable futures in those countries. One U.S. expert said, "Cheap shale gas is here," and cited an electricity cost of 5–6 cents/kWh from shale gas, cheap enough to undercut renewables, the expert said. However, others said the verdict remains uncertain as to how commercial shale gas will become.

15. Carbon capture and storage (CCS) technology cost and viability. Will CCS become commercial? When? Experts expressed a range of views about whether CCS would become commercially viable. Many believed the answer would be important to the future of renewables, as many carbon-constrained scenarios show tradeoffs between higher amounts of future renewables and the use of CCS with coal and natural gas. *(See also Box 2 on page 16.)*

16. Power transmission network expansion, environmental and social issues. Can ways be found to expand and strengthen networks in ways that are socially acceptable? Many experts believed that stronger networks will be essential to renewables' future *(see Chapter 2),* but they were uncertain about the degree to which networks could be expanded given environmental and social issues in developed countries, and the levels of investment required in developing countries.

17. Population and resource geography. The location of population centers relative to areas of renewable resources affects how much transmission must exist to accommodate renewables. Experts pointed to claims that the "best" renewable resources in specific regions are far from population centers and thus more difficult to harness. One expert, however, brushed aside resource geography as a major constraint, and said, "the notion that we must use 'the best wind areas' or 'the best solar areas' is a big and pervasive fallacy."

18. Climate change perception and reality. How will perceptions about climate change evolve over time? How quickly will the climate actually change? These questions will affect political and social willingness and mandate to reduce carbon emissions and employ renewables.

ANNEX 4 – GREAT DEBATES AND TOPICAL DISCUSSION REPORT

Interviews conducted for this report *(see Annex 1)* revealed differences of opinion and points of uncertainty on issues related to renewable energy costs, policies, technologies, investment, and integration. These differences of opinion were framed into a series of "Great Debates" about the future of renewable energy, 30 of which are summarized here. For further reading on these subjects, see the cited cross-references and endnotes, and the listed topics from the online supplement, "Topical Discussion Report" (available at http://www.ren21.net/gfr). That report also contains many more "Great Debates" discussions.

Great Debates *(See endnotes for references and further reading)*	**Topic number and name in "Topical Discussion Report" for further reading**
Cost comparisons	
Is renewable energy more expensive than conventional energy? Experts pointed out factors that skew cost comparisons, including existing subsidies to fossil fuels and nuclear power, future fuel price risk, environmental costs, social costs, and many other factors and risks.[1] *(See Great Debate 1, page 12.)*	2. "Cost Comparisons" 3. "Key Variables"
What is the right way to make economic decisions and comparisons between competing technology alternatives, such as between renewables and fossil fuels? Metrics include levelized cost of energy (LCOE), financial rate of return (IRR), and total future energy system cost. Experts advocated for decisions more strongly based on financial risk-return perspectives, including a "mathematics of diversification" to reduce energy system/portfolio risk.[2] *(See Great Debate 1, page 12.)*	2. "Cost Comparisons" 3. "Key Variables" 4. "Energy Systems"
How should fair economic comparisons incorporate conventional energy subsidies, recognize fossil fuel price risk, account for social costs, and include (internalize) environmental costs? Some advocated removing subsidies for fossil fuels, while others saw subsidies for renewable energy as "leveling the playing field." Emissions policies are one method of partly including environmental costs, and experts called for new mechanisms to account for social costs.[3] *(See Great Debate 1, page 12.)*	2. "Cost Comparisons" 3. "Key Variables"

Policy evolution	
What is the future role of policy? At the national, state, provincial, and local/city levels, policies have played a major role in driving renewable energy markets, investments, and industry growth in the past. Experts expected policies to remain a critical part of the future, and offered a range of views about the future role of policy.[4] *(See Great Debate 2, page 13, and national policy examples in Chapter 5.)*	6. "Policies" 20. "Cities" 21–28. Country topics
How will feed-in tariffs evolve? Given lower technology costs, higher support costs, and higher renewable power shares on grids, some experts questioned how long feed-in tariffs would be needed, in Europe in particular, or how long governments would maintain them. Some saw evolution during 2020–2030 to meet market conditions and power grid integration needs.[5] *(See Great Debate 9, page 45)*	6. "Policies" 21. "Europe"
What role should (or will) carbon-based policies have in promoting renewable energy? European experts debated the role of the Emissions Trading System (ETS). Some envisioned full-fledged currency-like markets, and one expert said, "the ETS could be the end of coal." Others called the ETS ineffective, partly due to low carbon prices.[6]	6. "Policies"

Utility power grid integration and policy

Is energy storage necessary for high levels of renewables? Experts pointed to many options to manage variability besides storage, and dispelled myths about storage being needed above some arbitrary share of renewables. Some said little or no energy storage would be needed to attain even high shares, and others pointed out that needs depend on grid characteristics and energy sources.[7] *(See Great Debate 3, page 25.)*	12. “Power Grids” 14. “Energy Storage”
What policies (if any) are needed to establish a ”price” in power markets for flexibility and balance? Experts pointed out that many balancing/ancillary markets today are captive markets, but will need to become competitive. ”We need new electricity market design—more competition for ancillary services and better integrated spot and future markets,” said one expert.[8] *(See utility power grids in Chapter 2, page 23.)*	12. ”Power Grids”
How can utilities better use demand-response to manage variability, and what policies are needed (if any) to support demand-response? In the words of one expert: ”Policymakers are beginning to understand that demand-response is really important for renewables, especially for industry and large commercial buildings. Is demand-response sufficient? Probably not, but it becomes one of the first priorities to balance power grids with higher levels of variable renewables.”[9] *(See utility power grids in Chapter 2, page 23.)*	12. ”Power Grids”
Is the concept of ”base load” meaningful for future energy systems? Experts pointed out that several different definitions of ”base load” exist, and that meanings can be technical, economic, or institutional in nature. They questioned whether other concepts would better serve future thinking, and said that with some definitions, renewable energy could be considered ”base load.”[10] *(See Great Debate 4, page 25.)*	12. ”Power Grids” 15. ”Base Load”
Centralized or decentralized power grids? Experts had divergent views on the question of distributed (decentralized) energy systems and the degree to which current centralized power systems will evolve into more decentralized and distributed versions. Some believed that centrally managed grids would become relics, while another said, ”the economic case still very much favors centralized power systems.”[11] *(See Great Debate 5, page 27.)*	12. ”Power Grids” 13. ”Distributed Grids” 19. ”Cities”

Transport and buildings integration

How soon will builders and architects embrace ”low-energy” or ”passive” house designs? Experts said ”low-energy” or ”passive house” designs were not much more expensive than ordinary construction, but such designs had yet to be embraced by the building industry.[12] *(See buildings in Chapter 2, page 26.)*	17. ”Buildings” 19. ”Cities”
How soon will affordable battery-electric vehicles with ”acceptable” driving ranges emerge? Experts debated how fast battery technology performance would improve and costs would decline. Others pointed to changing social views of ”acceptable” driving range as recharging infrastructure emerges, and to high-efficiency micro-vehicles and the next generation of lightweight vehicle technologies as factors reducing the importance of this question.[13] *(See transport in Chapter 2, page 30.)*	16. ”Electric Vehicles” 20. ”Local Mobility”
Which transport technologies will ultimately prevail for integrating renewables into transport? Many technologies and fuels offer possibilities for integrating renewables into transport, including biofuels, plug-in hybrids, electric vehicles, hydrogen fuel-cell vehicles, synthetic natural gas, and compressed air. Expert views pointed to all these, although the future seemed quite uncertain to most. Some foresaw a coming full-scale transformation to electric vehicles.[14] *(See transport in Chapter 2, page 30, and biofuels in Chapter 6, page 60.)*	12. "Power Grids" 16. ”Electric Vehicles” 20. "Local Mobility" 30. "Biomass and Biofuels"

Investment and business models

Will utilities lead, follow, push back, or perish? With increasing levels of renewables, the business models and revenue streams of many existing energy companies are coming under stress. How will existing energy companies respond to that stress? Some utilities simply may no longer be viable, said one expert. Many experts believed utilities would rise to the challenge. However, not all were certain that utilities would lead.[15] *(See Great Debate 6, page 34.)*	10. "Business Models" 11. "Energy Companies"
What roles will oil and gas companies play? Will oil companies be major players in future renewable energy markets? Oil companies are positioning themselves as biofuels suppliers and investors in other forms of renewables. Some experts believed that offshore logistics capabilities will mean a major role for oil companies in offshore wind power. Due to the complementary fit of natural gas and renewables, experts foresaw greater involvement by gas companies.[16] *(See Great Debate 7, page 35.)*	4. "Energy Systems" 11. "Energy Companies"
Are existing sources of finance set to reach their limit? To what level of annual investment in renewables can bank lending, private equity, and utility balance-sheet finance reach, before new sources like pension funds, sovereign wealth funds, and others will be needed as central rather than peripheral sources? Some finance experts believed that attaining higher investment levels would require major involvement from such new sources.[17] *(See investment in Chapter 3, page 33.)*	9. "Investment"
Will green power purchasing scale up like organic food has? Green power sales are setting new records but are still a tiny fraction of total power sales. Will households or companies dramatically scale up their purchases from green power suppliers? Corporate governance is trending toward climate neutrality and greater green power purchasing, but at some point do other investment models become more significant than green power?[18] *(See Great Debate 8, page 37.)*	10. "Business Models"
Which business models will best suit offshore wind power? Some experts believed that further cost reduction and a quantum leap in market size are contingent on new business models emerging that recognize that a majority of project costs are not for the turbines themselves, and that long-term operation and maintenance costs present the biggest investment risk.[19] *(See business models in Chapter 3, page 36.)*	10. "Business Models" 29. "Wind Power"

Country/region-specific debates

How soon will solar PV markets surge in China? Until recently, virtually all solar PV production in China was exported, with a very small domestic market. Since 2010, emerging new support policies have led experts to believe that a surge in domestic solar PV markets was "just around the corner." Many linked market growth to further policy development, while others saw solar PV cost reductions driving new markets.[20] *(See China in Chapter 5, page 47, and solar PV in Chapter 6, page 56.)*	24. "China" 28. "Solar Power"
What is the future of coal power in India relative to renewables? Experts believed that a key choice facing India will be whether to increase imported coal for power generation, or to turn increasingly to renewable energy for the majority of new power investment. Some said this question depends on the availability and price of imported coal; others linked it to the imperatives of GDP growth.[21] *(See Great Debate 10, page 49.)*	2. "Cost Comparisons" 4. "Energy Systems" 25. "India"
Should (or will) Europe, the Mediterranean, and North Africa evolve a "super grid" that links these regions and distant renewable resources? Some European experts advocated for a strong "super grid" across Europe to more strongly link different resource regions and provide balancing. Some also advocated for the so-called "Desertec" project to develop renewables in North Africa linked through new grids back to Europe.[22]	12. "Power Grids" 21. "Europe"

What will happen in the United States if the Production Tax Credit (PTC) and Investment Tax Credit (ITC) are not renewed? All U.S. experts acknowledged the large impact that federal support policies would have on future markets, but also noted that existing state-level policies still provided some long-term certainties. Experts gave various prognoses of what markets would do if the PTC and/or ITC expire.[23] *(See United States in Chapter 5, page 46.)*	6. “Policies” 22. “United States”
How extensive will ”south-south” technology transfer become in the coming decade, and to what extent will Chinese manufacturing spread to other developing countries? Said one developing country expert, ”South-south energy development and technology transfer will no longer be a cliché but will be real—people in developing countries really need to learn how to build, design, install renewables and will start to seriously learn from each other.”[24] *(See developing countries in Chapter 5, page 48.)*	27. “Developing Countries”

Technologies	
When does solar PV reach grid parity and what does that mean? Many experts said grid parity already exists in many locations around the world and would soon come to many more, transforming electric utility systems both technically and financially. Scenarios generally put grid parity farther in the future. Some experts disputed the meaning of ”grid parity” itself.[25] *(See solar PV in Chapter 6, page 56.)*	2. "Cost Comparisons" 12. "Utility Grids" 13. "Distributed Grids" 28. “Solar Power”
In what ways does solar thermal power (CSP) with embedded energy storage capture the balancing value from storage, or serve industrial uses? Experts pointed to many potential uses of CSP for grid balancing, industrial process heat, desalination, and other stand-alone applications. These new applications have yet to capture the full value of CSP, said experts.[26] *(See industry in Chapter 2, page 29, and CSP in Chapter 6, page 57.)*	12. "Power Grids" 14. "Energy Storage" 18. “Industry” 28. “Solar Power”
What are the pros and cons of offshore wind power? Pros include less visual and noise impact, no NIMBY (”not in my backyard”) issues, more predictable wind patterns, and bigger project sizes. Cons include higher costs and policy support needed, technical and logistics difficulties, and centralized nature crowding out decentralized options.[27] *(See Great Debate 11, page 55.)*	29. “Wind Power”
Which markets will make the most use of biomass resources in the future? Some believed that biomass was better left for heat supply, including gasification and combined heat and power, while others envisioned much greater power generation. Others said that the question is wrong, as integrated ”biorefineries” of the future yield multiple products with high efficiency, linked with other industrial sectors.[28] *(See buildings in Chapter 2, page 26, heat supply in Chapter 4, page 40, and biomass in Chapter 6, page 58.)*	30. "Biomass and Biofuels"
How long will it take to commercialize cellulosic-ethanol? Some said that this technology is already commercial, given a number of plants already in operation. Others said that the technology is still, as it has been for several years, ”a few years away.” A few said they have given up waiting and did not believe that cellulosic ethanol would ever be commercial.[29] *(See biofuels in Chapter 6, page 60.)*	30. "Biomass and Biofuels"
How sustainable can biofuels become in the long term? Experts were divided over the long-term future of so-called first-generation biofuels, in large part due to sustainability issues, including land use, deforestation, food prices and security, and social issues.[30] *(See Great Debate 12, page 60.)*	30. "Biomass and Biofuels"

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REN21
c/o UNEP
15, Rue de Milan
F-75441 Paris CEDEX 09
France

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