Workshop on Developing Metrics and Assessing Progress Towards a Clean Energy Economy

Organized by the Experts' Group on R&D Priority Setting and Evaluation

International Energy Agency
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iea Energy Technology Network

This report is an account of the workshop lead by the IEA Experts' Group on R&D Priority Setting and Evaluation, held 16-17 November 2011. Workshop participants and invited experts explored metrics for measuring and monitoring progress toward a clean energy economy and explored best practice in applying those metrics to assess progress in selected technology areas. The results reported herein are intended to support the IEA Committee on Energy Research and Technology and, more generally, the IEA Secretariat. The views and opinions expressed in this report do not necessarily reflect those of the International Energy Agency or its Member countries.

International Energy Agency

The International Energy Agency (IEA), an autonomous agency, was established in November 1974. Its mandate is two-fold: to promote energy security amongst its member countries through collective response to physical disruptions in oil supply and to advise member countries on sound energy policy.

The IEA carries out a comprehensive programme of energy co-operation among 28 advanced economies[1], each of which is obliged to hold oil stocks equivalent to 90 days of its net imports. The Agency aims to:

- Secure member countries' access to reliable and ample supplies of all forms of energy; in particular, through maintaining effective emergency response capabilities in case of oil supply disruptions.
- Promote sustainable energy policies that spur economic growth and environmental protection in a global context – particularly in terms of reducing greenhouse-gas emissions that contribute to climate change.
- Improve transparency of international markets through collection and analysis of energy data.
- Support global collaboration on energy technology to secure future energy supplies and mitigate their environmental impact, including through improved energy efficiency and development and deployment of low-carbon technologies.
- Find solutions to global energy challenges through engagement and dialogue with non-member countries, industry, international organisations, and other stakeholders.

IEA Experts' Group on R&D Priority Setting and Evaluation

Research, development, and deployment of innovative technologies is crucial to meeting future energy challenges. The capacity of countries to apply sound tools in developing effective national research and development (R&D) strategies and programmes is becoming increasingly important. The IEA Experts' Group on R&D Priority Setting and Evaluation (EGRD) was established by the IEA Committee on Energy Research and Technology (CERT) to promote development and refinement of analytical approaches to energy technology analysis, R&D priority setting, and assessment of benefits from R&D activities.

Senior experts engaged in national and international R&D efforts collaborate on topical issues through international workshops, information exchange, networking, and outreach. Nineteen countries and the European Commission participate in the current programme of work. The results reported herein are intended as input to and support of ongoing work of the CERT and, more generally, that of the IEA Secretariat.

For information specific to this workshop, including the background paper and presentations, see http://www.iea.org/work/workshopdetail.asp?WS_ID=538. For more information on activities of the EGRD, see www.iea.org/about/experts.asp.

[1] Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Japan, Korea (Republic of), Luxembourg, Netherlands, New Zealand, Norway, Poland, Portugal, Slovak Republic, Spain, Sweden, Switzerland, Turkey, United Kingdom, United States; The European Commission also participates in the work of the IEA.

Foreword

Future global energy systems must reliably and affordably meet rapidly expanding energy needs. The community of nations, collectively, must avoid the most serious consequences of climate change by significantly reducing future greenhouse gas (GHG) emissions. Meeting these dual goals is not just a daunting task from a technology perspective, but an urgent matter of timing.

Visualisation of this urgency may be realised by examining a range of GHG-constrained scenarios, as presented in *Energy Technology Perspectives 2010* (ETP2010). The ETP2010 Blue Map scenario outlines the scope and pace of the energy technology transformation required to 2050 — how much and by when. This work provides a useful and forward-looking benchmark for measuring and evaluating current progress toward clean energy technology development and deployment goals.

On 16-17 November 2011, the IEA Experts' Group on R&D Priority Setting and Evaluation (EGRD) convened a workshop to explore: (a) progress, as measured against the BLUE Map benchmark; and, more fundamentally, (b) frameworks of metrics used for measuring and monitoring such progress. Specifically, the EGRD sought to support the IEA Secretariat and enhance ongoing work in this area by:

(1) Providing informed input to the *Energy Technology Perspectives 2012* (ETP2012) report, in particular the work on technology progress.

(2) Contributing, longer term, to development of an enhanced framework of metrics for monitoring and measuring technology progress based on routinely available data.

The workshop's preparations built on previous work of the IEA and the EGRD. The workshop drew on the knowledge and expertise of an array of informed leaders from business and industry, research institutes, and governmental entities. The workshop benefited from the EGRD members, many of whom are national experts in clean energy R&D, from invited experts from the IEA energy technology network (e.g. Working Parties, Experts' Groups, and Implementing Agreements), and the private sector.

The workshop's findings are presented in the following pages as follows:

- status and progress of eight selected clean energy technologies;
- assessment of the metrics for monitoring and measuring technological progress;
- suggestions for a broadened approach to a more comprehensive metrics framework; and
- recommendations for enhanced international collaboration on clean energy technology research and development (R&D) from the experts who participated in the event.

ACKNOWLEDGEMENTS

The IEA Experts' Group on R&D Priority Setting and Evaluation (EGRD) would like to thank Craig Zamuda, John Peterson, and Robert Marlay of the United States Department of Energy for authoring this report.

The EGRD would like to thank the following experts for their valuable contributions during the workshop: IEA (Lewis Fulton, Antonia Gawel, Uwe Remme, and Carrie Pottinger), government institutions (Russ Conklin, Sascha Schroeder, Fedora Quattrocchi, Charles Taylor, and Frank Witte), and the private sector (Wim Sinke, Josef Spitzer, Rod Janssen, Frank Klinckenberg, and Andrew Chu). The EGRD would also like to thank the additional experts present that provided input to the technology surveys.

Catherine Smith provided administrative support. Drafting and production assistance for many of the workshop materials and the report were provided by Energetics Incorporated.

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Executive Summary

Rapidly expanding energy needs and the serious consequences of climate change have rendered meeting future global energy needs an urgent matter of timing as well as a daunting technological challenge. To help nations around the world address this challenge, the IEA Experts' Group on R&D Priority Setting and Evaluation (EGRD) examined the status and trends in clean energy technology progress and sought to develop a harmonised framework of technology-specific sets of metrics for monitoring and measuring future progress. Relying on expert opinion, the EGRD arrived at a limited set of recommended R&D investment opportunities.

Progress

While progress continues to be made in the development and deployment of clean energy technologies, the rate of progress to date appears to be insufficient to meet expectations as outlined in the IEA *Energy Technology Perspectives 2010* (ETP 2010) BLUE Map scenarios.

As an example, while the BLUE Map scenarios assume that the costs for most new generation technologies will decline, the costs for nearly all (with the exception of solar photovoltaics [PV]) appear to be constant or rising over the last several years. The likelihood that deployment of these technologies will meet the pace envisioned by BLUE Map scenarios appears to be diminishing.

For practical reasons, the EGRD workshop limited the assessment to those clean energy technologies that have the greatest potential to reduce greenhouse gas (GHG) emissions and that were within the scope of IEA[2]. Comments on specific technologies follow:

- Solar PV: Good progress is being made on deployment and reducing PV costs, but the recent reductions and general lack of predictability of policy support threaten to diminish the pace of near-term installations necessary to keep driving down costs.
- Wind: Onshore wind deployment is exceeding BLUE Map goals. However, offshore wind faces several technical and cost challenges. In particular, some measures show offshore wind costs rising significantly over the last two years. Grid integration is also a barrier for both solar and wind.
- Bioenergy: Small-scale heating and large-scale co-firing using bio-sources are now cost-competitive. Other bioenergy technologies will likely continue to require policy assistance for some time. Challenges to meet BLUE Map scenarios include upgrading feedstock and feedstock availability, which may have been overestimated in previous studies.
- Carbon Capture and Storage (CCS): CCS progress is lagging. Many demonstration projects are behind schedule, or cancelled. Barriers include high costs, scale-up, transportation of CO_2, liability, lack of policy support and public acceptance in some countries, and immature monitoring, modelling, and understanding of underground storage characteristics.

[2] Nuclear as a technology is the responsibility of the Nuclear Energy Agency of the Organisation for Economic Co-operation and Development (OECD).

- Energy-Efficient Buildings: The performance of energy efficient building technologies, per se, is sufficient. However, they are not being implemented fast enough, especially for retrofits required in developed countries in order to meet BLUE Map goals. There is a large opportunity in taking a systems approach to integrating electricity and heat grids with buildings.
- Energy Efficient Appliances: Progress is lagging in this area. Current deployment is less than half the rate of change assumed in the 450 parts per million (ppm) scenario in the IEA *World Energy Outlook 2011*. More rapid progress could be made by extending standards and labelling to cover more of total appliance energy usage. Architects, engineers, and designers could employ a systems approach to integrating appliances with the buildings and systems they serve, even if the appliances involved are already efficient. The technology area could be boosted by accelerating the rate at which new efficiency targets must be met.
- Energy Storage and Vehicle Batteries: Sales of electric vehicles (EV) are not keeping pace with industry expectations, but EV sales are higher than initial sales of hybrid electric vehicles when they were first introduced. The cost reductions necessary for broader commercial adoption are believed to be achievable, in part, because batteries benefit from use in many consumer products, which increases volume, economies of scale, and rapid innovation. If linked to the grid, there is an opportunity to accelerate deployment of EVs via added compensation for providing ancillary services to the grid, such supplemental electricity reserves, voltage control, etc.
- Smart Grids: Smart grid technologies are progressing rapidly. They are expected to see substantial market growth during the next decade and beyond. However, full deployment will take decades, the technologies may not be optimised to work together, and many challenges remain. Interoperability standards and conformance testing protocols represent major opportunities for international cooperative R&D.

R&D Opportunities

Several opportunities exist for improving international cooperation on research and development efforts to address areas not progressing as described in the BLUE Map scenario, including the need to: (1) reduce costs (e.g. the cost of materials and carbon dioxide capture); (2) improve efficiency (e.g. PV solar and battery storage); and (3) enhance system integration (e.g. buildings, and renewable energy into the grid). Specific disciplines ripe for coordinated actions include the following:

- Solar PV: low-cost, sustainable materials, grid integration at systems level, and advanced storage;
- Wind: offshore wind technologies (e.g. foundations, turbines), advanced materials, storage, and grid design and integration;
- Bioenergy: feedstock supply and upgrading, and integrated biorefineries;
- CCS: cost-effective advanced capture technologies, transport and underground storage modelling, characterisation of storage potential and competing uses, monitoring tools, scale-up, CO_2 usage, and sharing intellectual property;
- Buildings: systems integration approaches, and standards and codes;

- Appliances: rebound effect, coverage of standards and labelling, and advanced appliances systems;
- Energy Storage and Vehicle Batteries: fast charge systems integration of EVs with grid energy services, new materials and energy storage architectures, and studies establishing the benefits of ancillary services that could be provided by vehicle batteries; and
- Smart Grids: interoperability standards and conformance testing protocols, cyber security, common frameworks, tools, and methodologies, and the advancement of many individual technologies. Smart grid presents major opportunities for international cooperative R&D.

Technology progress would also benefit from the sharing of implementation tool kits for siting and winning local acquiescence. Coordinating reviews of existing barriers for each technology, addressing cost reduction, and policy enhancement (e.g. via technology push, market pull, and non-technical policy solutions) are essential elements of strategy to meeting future goals. Such coordination can also help mitigate private R&D expenditures and costs and improve the depth and breadth of performance data resources from which meaningful metrics can be developed.

Metrics

Some existing metrics are relatively easy to obtain and quantify, but they tend to indicate past progress (i.e., lagging indicators) rather than predict future progress (i.e., leading indicators). The workshop identified several areas of opportunity for each technology, including cost metrics, technology performance metrics, and private R&D funding metrics. All three of these areas indicate potential future progress better than many of the existing metrics. For some of the additional metrics areas identified, obtaining data may be very difficult, which is the reason for taking a long-term view over a period of years to enable future data collection.

Private sources and public-private partnerships are creating opportunities for areas in which it may be difficult to obtain data. Examples include the United Nations Environment Programme (UNEP)/Bloomberg data on private R&D, the Ernst and Young Country Attractiveness Indices, and the Bloomberg Levelised Cost of Energy (LCOE) metrics. In particular, the Country Attractiveness Indices may give countries knowledge of leverage points that enable them to increase the probability of success in their country for clean energy technologies.

The workshop was designed to gather metrics to represent technology progress by using a long-term conceptual framework to suggest the most productive ways to expand data collection in the future.

Many metrics have large uncertainties associated with them. Some studies and databases are starting to acknowledge the uncertainties and reflect them in their graphics and data.

Conclusion

While overall progress in the development and deployment of clean energy technologies to avoid the serious consequences of climate change and meet expanding global energy needs[3] is not being achieved

[3] As defined by the IEA *Energy Technology Perspectives 2010* BLUE Map Scenario to 2050.

under current domestic and international policies and market conditions, a number of actions can be taken to accelerate progress.

In the body of the report, key barriers to progress in eight clean energy technologies are highlighted. Opportunities for accelerating clean energy technology development and deployment are identified, in terms of both R&D investment and policy actions to support market penetration. Finally, the current monitoring framework is assessed and a more comprehensive framework is proposed.

The findings from the workshop as presented here are designed to complement the IEA Secretariat's efforts on tracking technology progress aiming at informing policy discussions in IEA member countries through the Committee on Energy Research and Technology and the Clean Energy Ministerial (CEM).

Introduction

The International Energy Agency (IEA) Experts' Group on R&D Priority Setting and Evaluation (EGRD) convened this workshop with two objectives: to assess technology progress against IEA's Energy Technology Perspectives 2010 BLUE Map (BLUE Map) scenarios, and to discuss the development of a set of metrics for monitoring, evaluating, and effectively communicating historical and recent progress on technologies important to the success of the *Energy Technology Perspectives* (ETP) BLUE Map scenarios. Experts on specific technologies assessed technology progress, estimated the likelihood of meeting BLUE Map deployment goals by 2050, identified barriers to progress, and suggested opportunities for action.

For practical reasons, it was not possible for the EGRD workshop to examine all clean energy technologies. For example, nuclear as a technology, is outside the scope of the IEA. The EGRD selected those technologies that provided the greatest potential reductions in greenhouse gas (GHG) emissions: major generation technologies, end-use technologies, and crosscutting and/or enabling energy technologies. The sample was selected from a list of 14 technology areas of the IEA Secretariat and the CEM. Particular emphasis was given to technology areas with opportunities for accelerating technical progress and cost reductions. The technology areas were selected to represent a range of technologies envisioned to make major contributions to meeting BLUE Map goals:

(1) Energy supply: solar photovoltaics, concentrating solar power (CSP), wind power, biofuels and biomass, and coal power generation with carbon capture and storage (CCS).
(2) Energy demand: energy efficient buildings — heating and cooling, and efficient electrical end-use equipment (4E).
(3) Crosscutting and/or enabling technologies: energy storage (e.g. vehicle batteries), and smart grids.

Assessing Energy Technology Progress

The EGRD workshop engaged energy technology experts, metrics, and ETP BLUE Map scenario output data and underlying modelling assumptions to assess progress of developing and deploying energy technologies. The combined input provided a gauge of progress from which to estimate the likelihood of meeting BLUE Map deployment goals by 2050, identify barriers to progress, and suggest opportunities for action.

For each of the technology areas examined, participants addressed the following questions:

- Which technologies appear to be making progress as expected compared to ETP BLUE Map scenarios from present day to 2050, and which are not?
- What are the major barriers inhibiting greater development and deployment? Can the barriers be categorised (e.g. policy, socioeconomic, and technical and/or cost)?
- What are the most important messages for the audience (IEA Member Countries, Clean Energy Ministers, etc)?
- What are the most important actions that IEA Member countries can take to address barriers?

- What are the best opportunities to enhance R&D cooperation to address technical and cost-reduction barriers for technologies that are not progressing as expected?

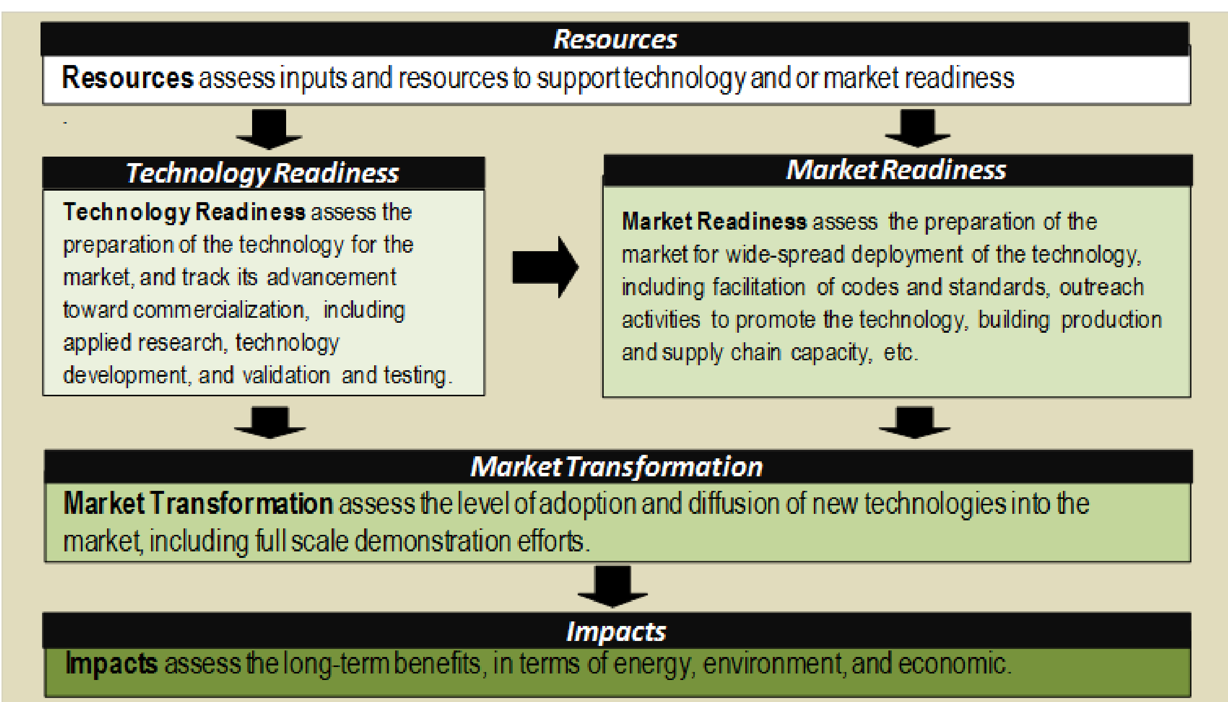
Developing Metrics

The workshop participants also discussed the development of a long-term framework of metrics for routinely measuring and monitoring energy technology progress. A framework of metrics allows the international community to develop a comprehensive, integrated methodology to measure technology progress towards the goals set forth in the ETP series of documents. Such a methodology measures technology progress in a way that is carefully constructed to be valid, comparable between technologies, and accommodates changing approaches over time.

The workshop was designed to gather progress metrics by using a long-term conceptual framework to suggest the most productive ways to expand data collection in the future. The IEA gathers data for and produces progress reports using a combination of government surveys, private data sources, and published studies. For many years, the IEA has collected metrics on energy technologies and has continually expanded both the metrics collected and the countries included in the collection. These efforts have been complicated by different definitions and categories used among the various countries, the lack of resources on the part of many countries to complete the surveys, the uncertainty inherent in many metrics, and concerns about submitting data sometimes viewed as sensitive and/or proprietary.

Building onto these data collection and metrics development efforts, the workshop participants considered a draft integrated framework consisting of five classes of metrics organised around the life cycle of an energy technology from concept to commercialisation (Figure 1).

Figure 1: Performance Metrics Framework Classes



The diagram above presents an organising framework for classifying quantifiable indicators, or metrics, about the status (and progress) of clean energy technologies. While the attributes of each technology may vary, the framework provides a common language for comparing metrics across the technologies. The framework envisions a developmental "flow" (arrows) from resources (inputs) to impacts (outcomes), and various stages in between. External factors (e.g. global economy, policy contexts, commodity prices, and so on) are critical to understanding status and predicting future prospects, but they are outside the area of a technology's control. They are not shown here, but left to others (and integrated assessment models) to evaluate.

The EGRD also examined approaches to effectively communicate results to inform decision-making, feed into the prioritisation or restructuring of research investments and related policies, and achieve desired outcomes. For the longer term, the EGRD will synthesise outputs from the workshop and propose a systematic, integrated framework of metrics and leading indicators for use in the future by R&D planners.

In constructing the framework, developing metrics, and communicating results, the group considered questions such as the following:

- What are the elements of an effective, integrated framework for monitoring, evaluating, and communicating progress on key technologies?
- What metrics are the most meaningful and indicative of progress, and can they form a real-time set of leading indicators that would signal the need for action?
- What lessons can be learned from the private sector, or from public-private partnerships, in monitoring progress on technology development and commercialisation?
- What approaches are most effective in communicating results to inform decision-making, feed into the prioritisation or restructuring of research investments and related policies, and achieve desired outcomes?

Workshop participants

Workshop participants included EGRD national experts, R&D decision makers, strategic planners, and programme managers concerned with global progress on clean energy technology development and deployment, including:

- Rob Kool, EGRD Chair (Netherlands)
- Robert Marlay, EGRD Vice Chair (United States)
- Carrie Pottinger, EGRD Secretary, International Energy Agency

Other EGRD members as well as non-member technical expert participants, in alphabetical order are listed below. Country names in italics designate EGRD primary or alternate delegates:

- Makoto Akai, National Institute of Advanced Industrial Science and Technology (Japan)
- Andrew Chu, A123 Systems
- Russell Conklin, Department of Energy
- Ugo Farinelli, Italian Association of Energy Economics (Italy)
- Lewis Fulton, International Energy Agency

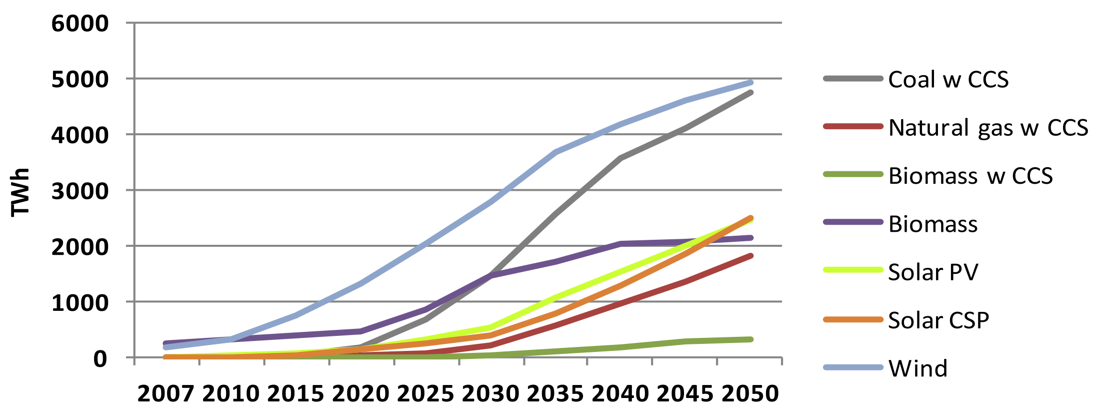
- Antonia Gawel, International Energy Agency
- Herbert Greisberger, Austrian Energy Institute (Austria)
- Sylvain Hercberg, EDF
- Birte Holst Jørgensen, Risø DTU (Denmark)
- Rod Janssen, Consultant
- Amb. Richard Jones, Deputy Executive Director, International Energy Agency
- Frank Klinckenberg, Consultant
- Teresa Leao, National Laboratory for Energy and Geology (Portugal)
- Jun Li, International Research Center on Environment and Development
- Jesús García Martín, Iberdrola Distribution (Spain)
- John Peterson, Department of Energy
- Stathis Peteves, Joint Research Centre (European Commission)
- Fedora Quattrocchi, National Institute of Technology (Italy)
- Uwe Remme, International Energy Agency
- Sascha Schroeder, Risø DTU (Denmark)
- Wim Sinke, Utrecht University (Netherlands)
- Peter Slobodian, Department of Resources, Energy and Tourism (Australia)
- Benjamin Smith, Nordic Energy
- Josef Spitzer, Graz University of Technology
- Charles Taylor, National Energy Technology Laboratory
- Ludwig Vandermaelen, Federal Public Service Economy (Belgium)
- Mike Walker, Department for Environment, Food and Rural Affairs
- Frank Witte, Agentschap NL (Netherlands)
- Craig Zamuda, Department of Energy (United States)

Perspective

Future global energy systems must meet rapidly expanding energy needs. The community of nations, collectively, must avoid the most serious consequences of climate change by significantly reducing future GHG emissions.

Meeting these goals is not only a daunting task from a technology perspective, but also an urgent matter of timing, as illustrated by the range of GHG-constrained scenarios in the ETP report. The ETP BLUE Map scenarios outline the scope and pace of the energy technology transformation required by 2050 — how much and by when (Figure 2). The scenarios address reductions of at least 50% in global CO_2 emissions compared to 2000 levels by 2050, to limit the long-term global average temperature rise to between 2.0°C and 2.4°C. Such scenarios may be useful as comparative benchmarks for measuring and evaluating progress towards clean energy technology development and deployment goals.

Figure 2: BLUE Map Electricity Generation for Selected Generation Technologies



Note: Does not include generation from nuclear, hydro, or fossil without CCS.
Source: ETP2010, IEA analysis, data for 2010 through 2045 are estimates.

In April 2011, the IEA released the *Clean Energy Progress Report* as input to the 2011 Clean Energy Ministerial[4] (CEM2). Building on this work, the IEA is enhancing this analysis as part of the ETP2012 publication. An early release of this work will serve as input to the third Clean Energy Ministerial (CEM3) meeting, to be held in London in April 2012. ETP2012 will discuss, in part, the extent to which technologies are matching the scope and pace of clean energy development and deployment.

The 2012 *Clean Energy Progress Report* will include an integrated framework of metrics on key technologies that, when juxtaposed with scenarios and underlying modelling assumptions, could serve as a set of leading indicators for R&D planners. The metrics could document technology status and trends in readiness improvement. Comparisons to baselines, such as the ETP BLUE Map scenarios, could

[4] Participants include Argentina, Australia, Brazil, Canada, China, Denmark, Finland, France, Germany, India, Indonesia, Italy, Japan, the Republic of Korea, Mexico, Norway, Russia, Saudi Arabia, South Africa, Spain, Sweden, Turkey, the United Arab Emirates, the United, Kingdom, the United States, and the European Union.

indicate areas needing attention. When combined with expert opinion and technical foresight, they could suggest opportunities for IEA and CEM member countries' actions, individually or collectively.

The EGRD hopes to support this effort by reporting on energy technology progress compared to ETP BLUE Map scenario benchmarks and by facilitating the development of a set of metrics for monitoring, evaluating, and effectively communicating progress on technologies important to the success of the BLUE Map scenarios.

IEA Tools and Analysis to Accelerate the Clean Energy Technology Revolution: Energy Technology Perspectives 2012

Lew Fulton, Head, Energy Technology Policy, IEA

- Link to presentation slides

The IEA Energy Technology Policy Division focuses on global strategies to accelerate market penetration and diffusion of a variety of energy technologies and conducts a range of short- and longer-term analyses related to technology and policy issues. IEA added a number of supporting and supplemental analyses to its suite of services, including sector-specific analyses, technology roadmaps, R&D assessments, indicator tracking and progress reports, and technology network activities (e.g. Implementing Agreements).

The *Energy Technology Perspectives* (ETP) publication is considered the analytical centrepiece, covering various energy technology issues within a global context. The ETP report is the division's most ambitious project on technology, and it aids energy policy makers and other stakeholders by identifying efficient pathways to a low-carbon energy system, identifying and assessing policy options that can affect the necessary changes in society, and providing near-term guidance based on long-term analysis. Priorities in ETP2012 include a more detailed glimpse into the next decade of energy technology progress, possible synergies among energy systems, the changing role of fossil fuel-based technologies, and additional region-specific results, including technology projections for 10 key countries and regions.

The IEA *Technology Roadmaps* address the barriers to technology deployment and aim to reach agreement among stakeholders on the steps required to reduce those barriers. The IEA *Technology Roadmaps* have demonstrated a clear impact in informing initiatives, policies, and debate but implementation requires further effort. By mid-2013, 18 *Technology Roadmaps* and a *How-to Guide* will have been released. [5]

Another IEA project, Accelerating Energy Innovation (AEI), provides guidance to policy makers for identifying strategies, policy instruments, and evaluation tools for low-carbon energy technology R&D supported by public funds. This project will also help identify best practices for R&D spending to ensure that spending is aligned with priorities and priorities that are selected rationally.

[5] Bioenergy; biofuels for transport; carbon capture and storage for power generation; carbon capture and storage for industry; cement; chemical catalysis; concentrating solar power; energy-efficient building envelopes; high-efficiency/low-emissions coal; geothermal heat and power; hybrid/electric vehicles; hydropower; nuclear; smart grids; solar heating and cooling; vehicle fuel economy; wind (global) and wind (specific to China).

The EGRD can play an important role in examining the use of various metrics to measure progress towards ETP BLUE Map targets, specifically relating short- to long-term considerations and the issues of data availability and reliability. This may include leveraging the roadmaps process to help with tracking progress and further examination of the unique issues related to R&D, such as identifying the best measures of effectiveness and tracking private sector R&D.

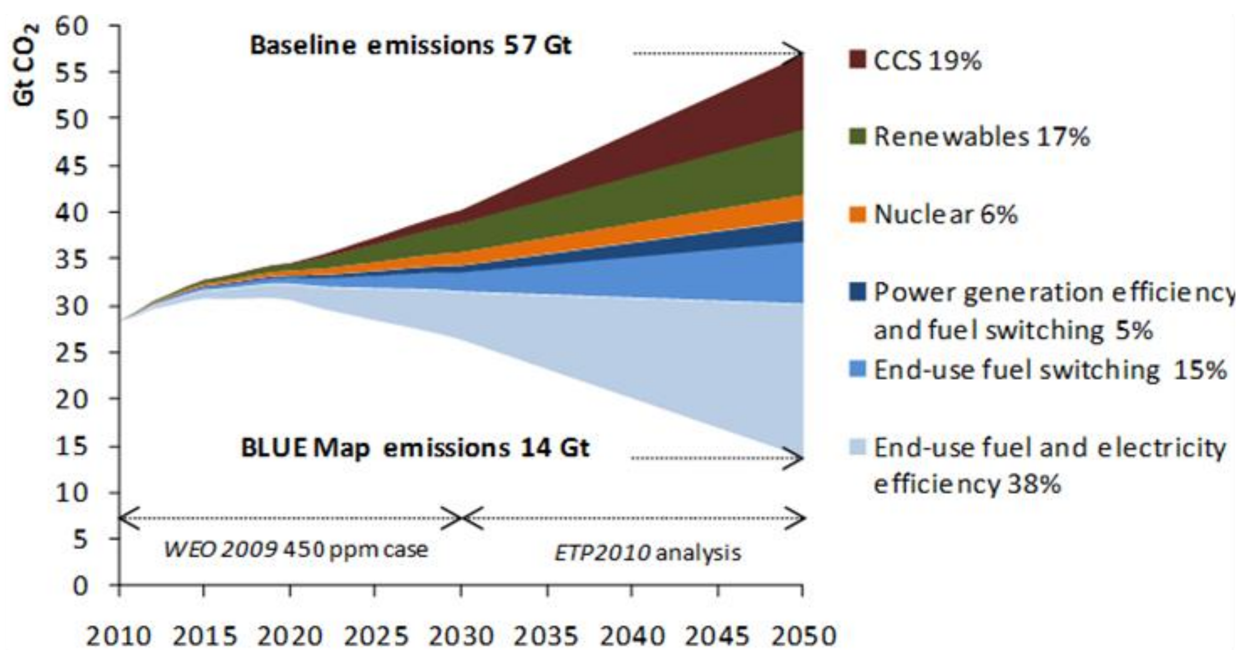
Energy Technology Perspectives, BLUE Map Scenario: Goals, Targets, and Assumptions

Uwe Remme, Analyst, Energy Technology Policy, IEA

- Link to presentation slides

ETP2010 and ETP2012 analyse regional and global trends in the deployment of fossil fuel-based and clean energy technologies. The reports provide strategies for technology deployment, assess policy options, and provide guidance for near-term action. The analysis examines increases in CO_2 emissions according to two very different scenarios: the baseline scenario and the BLUE Map scenario. The baseline scenario assumes the status quo and projects that CO_2 emissions will increase to 57 Gigatonnes (Gt) per year in 2050 if no new policies are introduced. The BLUE Map scenario assumes that global energy-related CO_2 emissions are reduced to half their 2005 levels by 2050 — to 14 Gt — and is broadly optimistic for all technologies (Figure 3). The BLUE Map scenario adheres to the 450 parts per million (ppm) case described in *World Energy Outlook 2009*, from 2010 until 2030, and is extended to 2050 in the ETP2010 analysis. It investigates the contributions of the industrial, buildings, transportation, and power generation sectors as well as other contributing segments of the global economy.

Figure 3: Wide Range of Technologies Needed to Reduce Global CO_2 Emissions in BLUE Map Scenario



The BLUE Map scenario identifies several key technologies and technology categories considered necessary to reduce energy-related CO_2 emissions substantially and specifies the contributions they are expected to make towards meeting BLUE Map goals. The range of technologies (and their expected contributions towards GHG emissions reductions by 2050) include: CCS (19%), renewable energy (17%), nuclear energy (6%), power generation efficiency and fuel switching (5%), end-use fuel switching (15%), and end-use fuel and electricity efficiency (38%).

The ETP is based on a technology-based model approach that covers the entire energy system from primary energy (i.e. fossil based, renewable, and nuclear) through conversion (e.g. electricity production and refineries) and the end-use sectors (i.e. industry, buildings, and transportation), to useful energy service demand (e.g. material demands, heating, and cooling). The ETP model uses a number of parameters as inputs: technical and economic technology parameters, demand and load curves, future and current fuel costs, and policy constraints.

The model generates output values including energy and emissions flows, new capacity additions, and marginal cost and price estimates. Investment costs and learning rates assumptions are incorporated where possible, as well as projections for growth in gross domestic product (GDP) to 2050. The ETP2012 will expand regional coverage compared to ETP2010 to 28 regions linked by trade in coal, oil, petroleum products, pipeline gas, liquefied natural gas (LNG), biodiesel, ethanol, torrified biomass, and electricity. The trade links between these regions mirror the systems-level approach that is needed for an analysis of this scope.

Monitoring and Evaluating Progress in Developing and Deploying Low-Carbon Technologies: Energy Technology Perspectives 2012 Progress Tracking

Antonia Gawel, Analyst, Energy Technology Policy, IEA

- Link to presentation slides

The IEA is currently monitoring and reporting on clean energy progress for the Clean Energy Ministerial (CEM) and the Group of Twenty (G-20).[6]

For the second annual CEM meeting (CEM2), the IEA developed the *Clean Energy Progress Report* to assess progress of technologies against the ETP BLUE Map scenario. The analysis showed that clean energy progress is mixed (Figure 4). While some clean energy technologies, such as wind and solar, were achieving or exceeding growth rates, other technologies, including CSP, CCS, and electric vehicles, were not meeting the rate of growth needed to reach ETP2010 BLUE Map targets. The report reviewed key technologies against ETP2010 BLUE Map objectives, evaluated spending on public R&D, took stock of current technology deployment and key policy developments, identified gaps in action, and made recommendations to CEM ministers.

[6] Argentina, Australia, Brazil, Canada, China, France, Germany, India, Indonesia, Italy, Japan, the Republic of Korea, Mexico, Russia, Saudi Arabia, South Africa, Turkey, the United, Kingdom, the United States, and the European Union.

Figure 4: Assessment of Deployment Progress for Select Technologies, compared to ETP2010 BLUE Map targets

Technology	Current rate	Required annual growth to 2020	Current status	Blue Map target 2020
Biofuel	18%	7%	2.54 EJ	5.04 EJ
Biomass power	7%	4%	54 GW	82 GW
Hydropower	5%	2%	980 GW	1219 GW
Solar PV	60%	19%	21 GW	126 GW
Wind power	27%	12%	195 GW	575 GW
Energy intensity of manufacturing	-1.30%	-0.60%	3.73 MJ	3.81 MJ
Geothermal power	4%	7%	11 GW	21 GW
Nuclear power	3%	4%	430 GW	512 GW
CSP	8%	50%	0.6 GW	42 GW
Electricity generation with CCS	Zero projects	3 GW per year	Zero projects	28 GW
Electric vehicles	-	Doubling of sales each year from 10 000 EV/PHEV sales in 2011 to reach Blue Map target	-	7 million sales in 2020

(green)	Achieving or exceeding levels, maintain the course
(yellow)	Progress but more concerted effort needed
(red)	Sizeable gap between deployment and goals

Source: Clean Energy Ministerial Progress Report 2011.

The IEA recommendations to the ministers at the CEM were to prioritise energy efficiency through targeted policies, finance, and procurement; implement adaptive renewable energy policies; allocate funding to large-scale CCS projects in power and industrial sectors; and facilitate commitments to building sustained electric vehicle markets and installing enabling infrastructure.

Building on 2011 *Clean Energy Progress Report* analysis*,* the IEA worked with the G-20 Clean Energy and Energy Efficiency (C3E) Working Group to develop a status report of clean energy and energy efficiency technology and policy progress in G-20 countries. The IEA encourages processes like the CEM and the G-20 C3E to make firm and ambitious commitments regarding progress towards achieving these goals.

A second progress report will be presented at the third annual CEM meeting (CEM3) April 2012 and will be integrated into the *Energy Technology Perspectives 2012* publication. It presents a more complete progress assessment framework with enhanced data coverage (additional countries, research, and private data sources) and quality. The progress assessment framework will evaluate the current status of the various technologies, the ETP2012 requirements by 2020, and an assessment of whether the technology is progressing in line with ETP objectives. The technologies are evaluated in terms of technology progress (performance and cost), market creation (policy drivers and investment levels), and technology penetration (capacity/generation, growth rates, share of market, and market concentration). A preliminary version of the framework template is shown in Figure 5. Analysing the results of the framework evaluation can identify which key short-term issues may be influencing data trends and which key short-term factors are likely to help or hinder technology progress.

Figure 5: Preliminary Version of the ETP2012 Technology Progress Assessment Framework

	Technology Progress		Market Creation		Technology Penetration			
	Technology performance	Technology cost	Policy drivers	Investment levels	Capacity/ Generation	Growth rates	Share of market	Market concentration
Current Status								
ETP 2012 requirements by 2020								

Key challenges in tracking progress include the lack of robust evaluation of R&D spending effectiveness and the lack of data availability and comparability.[7] Data for tracking progress is being gathered through IEA statistics, external sources, direct engagement with IEA and IEA non-Member countries, private data sources (e.g. Bloomberg New Energy Finance or technology-specific databases), and publicly available sources. Current data on technology demonstration and deployment, national policies, and public spending on R&D is elicited directly from countries. Research by IEA is providing additional data on technology costs and performance, private spending on R&D, technology investments, and any other relevant available data.

[7] Public RD&D peaked in 2009 due to stimulus efforts; 2010 preliminary data looks like a return to 2008 levels; although there may be a small increase.

Assessing Progress Towards a Clean Energy Economy

This section provides a synopsis of recent progress towards BLUE Map goals and judgments regarding the likelihood that the technology areas examined by EGRD will achieve these goals, and it highlights key opportunities for tracking metrics on eight clean energy technologies that are among the most impactful areas in terms of GHG emissions reductions potential. A summary of each technology area's contribution to BLUE Map deployment goals is shown in Table 1.

The areas examined by EGRD, highlighted in yellow in the table, include energy supply (solar photovoltaics, concentrating solar power [CSP], wind power, biofuels and biomass, and coal power generation with carbon capture and storage [CCS]), energy demand (energy efficient buildings — heating and cooling, and efficient electrical end-use equipment [4E]), and cross-cutting technologies (energy storage – vehicle batteries, and smart grids).

Table 1: Contribution towards BLUE Map Scenario Goals by Technology Area

	Key Technology Area	Corresponding IEA Technologies & Roadmaps	Contributions to Goals ETP 2012 Blue Map Scenarios (Sum to 2050)	Units	Blue Map Deployment Tracks			
					2007	2015	2030	2050
Energy Supply	Renewable Energy and Fuels	Electricity: Solar PV (incl. Rooftop)		T kWh/yr	0.00	0.06	0.53	2.47
		Electricity: CSP		T kWh/yr	0.00	0.02	0.40	2.49
		Electricity: Wind Power		T kWh/yr	0.17	1.32	2.78	4.92
		Electricity: Hydro		T kWh/yr	3.08	3.73	4.94	5.75
		Electricity: Geothermal		T kWh/yr	0.06	0.11	0.31	1.01
		Biomass (incl. w/ CCS)		T kWh/yr	0.26	0.38	1.48	2.46
		Biofuels		EJ	N/A	3.40	10.1	32
	Low-Emission, Fossil-Based Fuels and Power	Electricity: Fossil w/CCS		T kWh/yr	0.00	0.03	1.65	6.56
	Geological Storage	Carbon Storage	N/A	$GtCO_2$ Cum	0.00			145
	Nuclear Fission	Electricity: Nuclear Fission		T kWh/yr	2.72	3.29	5.36	9.61
	Hydrogen	Hydrogen		EJ	0.00			8.37
	Fuel Cells	Fuel Cells	N/A	% of Vehicle Sales	0%	0%	3%	20%
Energy Demand	Industry	Final Energy Reduction		EJ	0.0	11.8	32.2	56.5
	Buildings	Final Energy Reduction		EJ	0.00	6.66	30.6	63.1
	Transportation	Final Energy Reduction		EJ	0.00	3.23	27.3	66.3
Crosscutting	Electric Grid and Infrastructure	Peak Load Reduction	N/A	% Reduction	N/A	0%	6%	10%
	Grid Storage	Grid Storage Required for Intermittants	N/A	GW	100*			122-189
	Batteries for Vehicles	EV/PHEV Roadmap	N/A	EV/PHEV Sales	0.012*	1.48		

* 2010 Value, EV/PHEV Sales in Millions

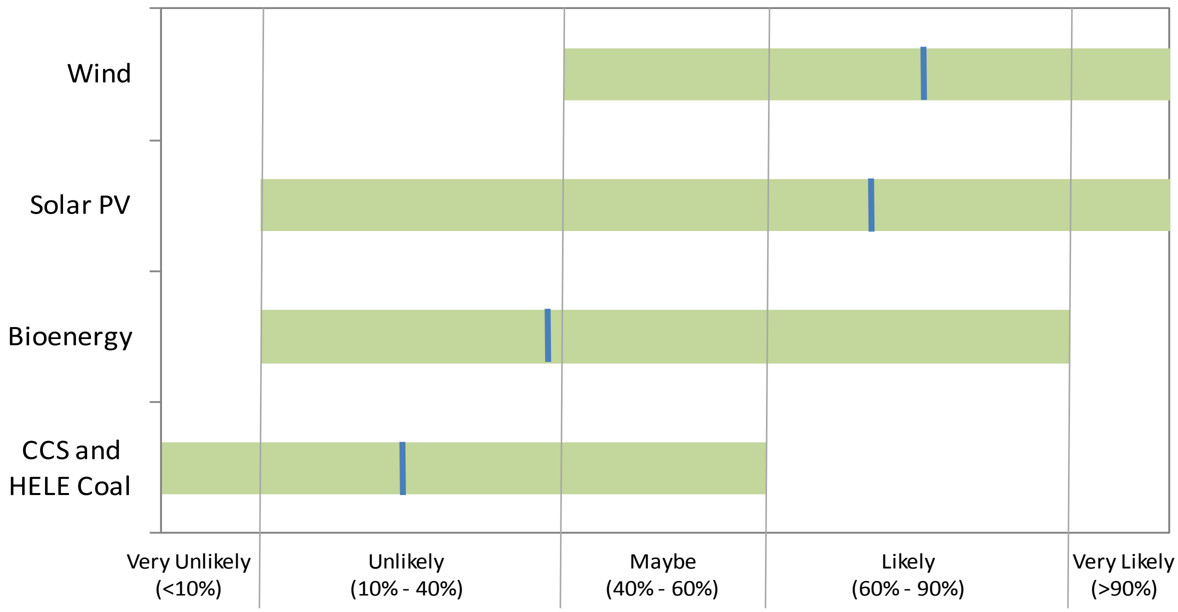
Source: ETP2010; data for 2015 and 2030 are estimated.

Energy Supply

Based on a survey of workshop participants, among the four energy supply technologies examined, wind and solar PV are considered the most likely to achieve BLUE Map scenario targets.[8]

Progress in achieving deployment of bioenergy technologies and low-emission coal technologies is less certain. On average, both of those technologies are considered unlikely to meet the BLUE Map targets.

Figure 6: Likelihood that Select Energy Supply Technologies Will Meet IEA BLUE Map Scenario Targets



Note: Bars indicate range of responses from survey of workshop participants; lines show mean response.
Source: Workshop survey responses.

The remainder of this section provides brief summaries of progress, metrics, and opportunities for R&D collaboration for each of the technology areas examined by EGRD. Each subsection summarizes technology-specific presentations from experts, and follows with a summary of additional input provided by workshop participants.

[8] The estimated likelihoods of BLUE Map goal attainment are based on results of a survey among EGRD workshop participants. Participants were asked; for example, "What is the likelihood that the technology will deploy as described in the BLUE Map scenario?" For the purposes of the likelihood assessments; participants assumed that existing policies remained in place through 2050; and there were no significant new policies implemented (e.g. global price on carbon). See Appendix G for more information and full survey results.

Solar PV

Wim Sinke , Programme & Strategy Solar Energy, Energy Research Centre of the Netherlands

- Link to presentation slides

Key Takeaways: PV solar development and deployment is currently on track to meet BLUE Map targets, but serious challenges remain to maintaining the current pace. Important challenges include the cost and predictability of policies/incentives, low-cost sustainable materials, advanced storage to address intermittent nature of production, and grid integration.

Progress Score:[9]

Very Unlikely	Unlikely	Maybe	Likely (60 - 90%)	Very Likely
			✓	

Recent Trends and Technological Progress

Solar PV deployment has grown significantly worldwide and has developed far beyond a niche technology. Global capacity is currently about 0.04 terawatts (TW) — Germany represents roughly half of these installations and approximately 3% of global generation. Solar PV needs to increase its contribution from both electricity generation *and* thermal energy in order to make a more significant impact in global energy markets.

However, PV is not ready to stand alone without policy support. To reach these deployment levels, the costs need to be between 5 and 15 cents per kilowatt-hour (kWh), corresponding to installed costs of approximately USD 1 or EUR 1 per watt. Current costs are more than twice that amount. The estimated PV technology learning rate[10] is 22%, suggesting that costs are falling considerably (75% since 2000), an encouraging sign for continued progress. Increased deployment and generation and further cost reductions (ideally below USD 0.05/kWh or EUR 0.10/kWh) — a main objective of the SunShot Initiative in the United States[11] — will help drive technology development. According to a study by the European Photovoltaic Industry Association (EPIA), European PV Levelised Cost of Energy (LCOE) is expected to continue to drop through 2020, from about EUR 0.203 /kWh (USD 0.26/kWh) in 2011 to about EUR0.08-EUR 0.17/kWh (USD 0.10-USD 0.22/kWh) in 2020. A European Photovoltaic Industry Association (EPIA) study expects PV generation costs to be competitive with generation costs of power from natural gas combined-cycle gas turbine (CCGT) power plants by 2020. However, these declines assume continued increases in deployment volume. With policy support declining, sometimes abruptly, the necessary deployments may not take place to continue these decreases in costs. Ideally, policy support would be reliably mapped out ahead of time, with gradual declines built in as the costs decline to commercially competitive levels.

[9] The Progress Score is the technology area's estimated likelihood of BLUE Map goal attainment, according to results of a survey among EGRD workshop participants. See Appendix G.

[10] The learning rate is defined as the percentage reduction in cost associated with a cumulative doubling in capacity.

[11] The SunShot Initiative aims to attain cost-competitive utility-scale PV deployment by 2020, with a goal of achieving system costs of USD 1 per watt via balance-of-system (BOS) module efficiency improvements and manufacturing cost reductions. The goal of USD 1 per watt is comparable to USD 0.05–USD 0.06/kWh.

Annual PV cell and module production has grown significantly worldwide since 2007, with China as the current leader in global production. Other major producers of PV cells and modules include Taiwan, Japan, Europe, and the United States. Global production reached nearly 24,000 megawatts (MW) annually in 2010. Cumulative installed capacity has also skyrocketed since the mid-2000s, jumping from less than 5,000 MW of installed PV power to about 38 GW in 2010. While Germany is leading the world in cumulative installed capacity, other significant capacity exists in Spain, Italy, Japan, and the United States.

Increased scale and differentiation of application has led commercial thin-film (and flat-plate) technologies to reach module efficiencies of 7% to 13%. Similarly, commercial (concentrator) applications of multi-junction modules have shown growth that has brought this technology to module efficiencies of 25% to 30%. Multi-junction concentrators have reached efficiencies over 40% in the laboratory.

Significant improvements are needed to meet ambitious deployment goals. Key challenges remain in PV performance, cost, and sustainability issues for cell and module development, PV systems on the whole, and system integration. Cost needs to improve by a factor of 5, and efficiency needs to improve by a factor of 2.

The IEA *Solar PV Technology Roadmap* report describes a multifaceted approach for increasing deployment of PV that includes a regulatory framework and support schemes, market facilitation and transformation, and technology development and R&D efforts to advance the development of solar PV technologies. These or similar activities will help the technology cross the “valley of death” and transition from incentive-driven to self-sustaining markets.

While capacity goals and low-cost objectives are useful, quality must come first and will help fuel communications efforts and increase public acceptance. The market shift from “technology push” to “market pull” would benefit from leading companies amassing in-house R&D capacity to increase industry’s role in major R&D programmes. This would allow public R&D efforts to shift from multilateral joint development projects to more open innovation models; bilateral competitive R&D; and development of more high-risk, high-reward options[12] beyond the scope of industry. For solar PV generation to reach a larger scale of deployment by 2020 and beyond, it may be necessary for markets to evolve past the status quo (dominated by wafer-based silicon [Si]) towards more thin-film Si and thin-film cadmium telluride (CdTe) modules and incorporate others into the mix of widely deployed PV technologies.

To help increase the scale of deployment, a systems approach could be beneficial. This includes a variety of solutions that involve more use of standalone, grid-connected, and even mini-grid applications;

[12] The Advanced Research Projects Agency-Energy, or ARPA-E, is an example of this type of organisation.

building integrated PV (BIPV) and building applied PV (BAPV);[13] and potential applications for PV hybrids (PV-wind, PV-thermal, etc.), among others.

Metrics to track PV's progress should capture sustainable system prices (including recycling), generation costs and perceived risk, availability, and lifetime operations and maintenance (O&M) costs. Two additional measures may be useful in evaluating progress: *dynamic grid parity* and *generation value competitiveness*. Dynamic grid parity estimates when the present value of long-term revenues (earnings and savings) from PV electricity supply is equal to the long-term cost of receiving traditionally produced/supplied power over the grid. The generation value competitiveness measure captures the point at which adding PV to the power generation portfolio becomes equally attractive, from an investor's point of view, as investing in traditional fossil-fuel-based technology.

Improvements are needed for the material inputs, which may be significant factors in reducing payback periods, specifically for monocrystalline and multicrystalline Silicon (Si) cells. Breakthroughs in applied research for new materials and storage capacity would increase cost-competitiveness.

Solar PV Discussion

Progress of Solar PV Development and Deployment

Today, solar photovoltaic technology represents about 38 GW of global capacity and may be cost competitive in the next decade. PV's contribution to BLUE Map targets in the ETP2010 appear likely to be met.[14] Assuming continued cost declines, the next major limitation to PV deployment will be grid integration.

Metrics for Monitoring Progress

The most important areas to measure progress include the following:

- Capital cost
- Private R&D investments
- Technology performance (e.g. reliability, efficiency, and life span)
- Sustainability of PV modules and systems
- Storage capacity for PV applications
- Availability of useful solar power

These areas are critical for expanded deployment of solar PV technologies, and they represent important leading indicators to track solar PV's growth. Figure 7 characterises the importance of potential metric areas compared to an estimate of the adequacy of the current situation for each area.[15]

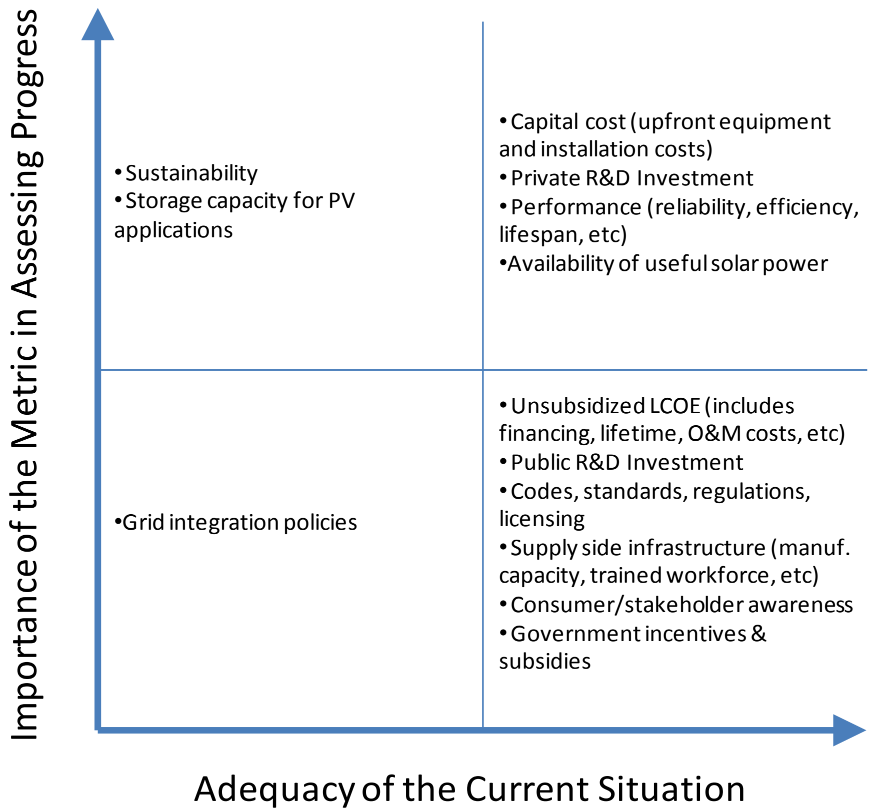
[13] BIPV is defined as the integration of PV technologies into the design of the skin and roof of the building before construction. BAPV is defined as a retrofit of PV technologies added to the building after construction.

[14] Based on a survey conducted among EGRD workshop participants, more than one-third indicated that it is very likely (>90%) that solar PV will deploy as described in the BLUE Map scenario; and more than one-half indicated that solar PV is "likely" or "very likely" to meet the targets. See Appendix G for more details.

[15] The framework shown in Appendix D has specific metrics for each of these areas. Workshop participants were also asked to rate the importance of generic categories of metrics on the survey form. In addition, they rated the adequacy of the current situation for each generic metric. Those metrics are placed in the figure according to the ratings by the participants.

Metrics in the upper left quadrant are considered most important for monitoring progress but for which the current situation is not adequate.[16] These areas may benefit from increased attention by policy makers or the private sector in accelerating the advancement of PV.

Figure 7: Importance and Adequacy of Potential Metrics for Assessing Progress of Solar PV Technologies



Key Messages for Leaders

- Explore approaches for developing more sustainable PV systems
- Develop a long-term strategy that does not heavily rely on subsidies and incentives and help lower legal and other barriers to grid integration
- Create reliable investment conditions through long-term commitments to R&D and policy certainty
- Facilitate partnerships in industry to help achieve economies of scale and further reduce costs and improve performance
- Consider the potential in developing nations and those in need of electrification

Opportunities for R&D Cooperation

- Develop new, low-cost, more sustainable materials to diversify the raw material inputs and lower life-cycle environmental impacts

[16] Based on adequacy scores from the survey. See Appendix G.

- Research advanced storage applications
- Conduct systems-level research to improve and accelerate grid integration at the transmission and distribution level
- Conduct systems R&D to improve efficiency, enhance product reliability, and extend lifetimes while reducing costs
- Concentrate efforts on BIPV systems

Wind Power

Birte Holst Jørgensen and Sascha Schroeder, Systems Analysis, Risø DTU National Laboratory for Sustainable Energy (Denmark)

- ➢ Link to presentation slides

Key Takeaways: Onshore deployment currently exceeds BLUE Map scenario goals, but challenges remain particularly for offshore wind. Important challenges include rising costs for offshore wind, permitting and siting time, and grid integration.

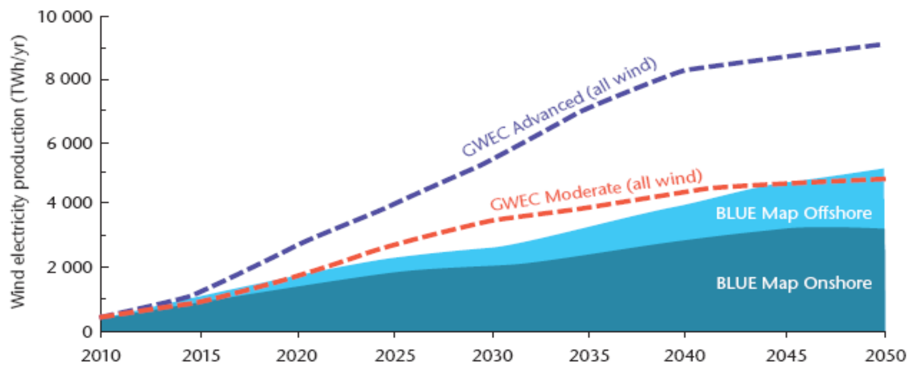
Progress Score:[17]

Very Unlikely	Unlikely	Maybe	**Likely (60 - 90%)**	Very Likely
			✓	

Wind power technology is among the more mature renewable energy technologies, and it has undergone significant advancements in the past decade. Wind energy is roughly on track to meet BLUE Map targets, although the contribution attributed to wind energy shown in ETP2010 may not be ambitious enough to meet the overall emissions reductions goals. There is approximately 197 GW of installed capacity in 2010, according to the Global Wind Energy Council (GWEC), compared to 159 GW in the BLUE Map. GWEC predicts that electricity production from wind will exceed the BLUE Map scenario (Figure 8).

[17] The Progress Score is the technology area's estimated likelihood of BLUE Map goal attainment, according to results of a survey among EGRD workshop participants. See Appendix G.

Figure 8: Wind Electricity Production in ETP 2008 BLUE Map Scenario Compared to Industry Analysis by GWEC



Source: IEA (2008a), Global Wind Energy Council (GWEC).

The maturity of global markets is illustrated, in part, by the fact that nearly all of the Group of Twenty (G-20) countries are active in helping to deploy wind technologies. There are several nations leading the manufacturing efforts, and no single nation or company has a dominating presence in the markets; the largest market share of all manufacturers globally belonged to the Danish company Vestas, with only 14.8% in 2010. Other nations among the top five manufacturers include China (Sinovel with 11.1% and Goldwind with 9.5%), the United States (GE Wind with 9.6%) and Germany (Enercon with 7.2%).

In assessing its progress, key indicators such as R&D spending, O&M costs, learning rates, and unit sizes provide insights into the extent to which wind energy is on track to achieving deployment goals outlined in the IEA's BLUE Map scenario. Overall, total R&D spending on wind energy has increased since 2000. The top six nations spending R&D funds on wind power include Denmark, Germany, Japan, Korea, the United Kingdom, and the United States. According to the Danish Technology Catalogue, both onshore and offshore investment costs are projected to keep pace with the IEA BLUE Map scenario. The O&M costs are projected to be at the lower end of the range specified by the IEA BLUE Map scenario and are expected to experience further declines. Learning rates for wind technologies are about 10% per megawatt-hour (MWh) and 6.7% per MW. The size of wind turbines is also increasing, with units over 100 metres in diameter already available, with the potential for further increases in size (in the range of 200 m) and altitude (including airborne units). Collectively, these data demonstrate progress being made for wind energy, and promising leading indicators for meeting future BLUE Map targets.

Additional key metrics are the Levelised Cost of Energy (LCOE)[18] and energetic amortisation time — the period of time taken for all energetic expenditures involved in the construction of the facility to be compensated by the energy production. Reduction in weight is not a good indicator because sometimes more weight is good, as when additional capacity requires it. Time duration from application to grid connection is a good indicator for success streamlining the siting and permitting processes. Appendix D shows additional possible metrics for wind.

[18] Note that LCOE data for wind is provided in the Performance Metrics Framework section. The data show that offshore wind LCOEs has risen significantly over the last two years.

While wind technology has been steadily advancing, current market barriers and policy issues may slow the progress of further developments. A number of potential solutions to address these barriers are suggested. Integrated system planning may provide an effective option in some cases, especially in locations seeking to develop offshore wind that will benefit multiple regions. Market support schemes are effective in some countries, although governments would benefit from further policy analysis to ensure that quotas and incentives are not set too high. Quotas often overpay for the deployment desired. Subsidies, including feed-in tariffs, may help spur further market uptake. Reliable market conditions will be required for the necessary investments to be made, whether these conditions are fostered through R&D funding, market supports, or other methods.

Support schemes in the European Union illustrate the range of options available to nations to help the advanced deployment of wind power technologies. Examples include investment support schemes (such as capital grants, fiscal incentives, and price reductions on goods) and operating support schemes, which cover both price-based support (feed-in tariffs [FITs], feed-in premiums [FIPs], and tax exemptions) and quantity-based support (quotas with tradable certificates). Measuring the total value of these support schemes and tracking this information would be useful to provide an overview of the level of policy support that is currently needed to help deploy the technology.

Wind technology is still advancing, and markets must continue to develop to help lower non-economic barriers and trade barriers to deployment. These include grid integration charges and the time it takes for permitting and siting processes to be completed. Grid integration charges may include grid upgrade costs, which are higher in populated areas.

Onshore and offshore wind power will each present a different set of issues and solutions, as shown by the increased role that governments play in planning of offshore wind farms compared to onshore wind farms. This is in addition to the suite of technical issues that differ between the two. Particularly for offshore wind technologies, coherent strategies and robust funding for R&D will be needed in the future.

Wind Energy Discussion

Progress of Wind Power Development and Deployment

Wind power is among the more mature renewable energy technologies and has been deployed in both onshore and offshore applications around the world. It appears likely (60%–90%) that wind power will deploy as described in the BLUE Map scenario (see Appendix G).

Metrics for Monitoring Progress

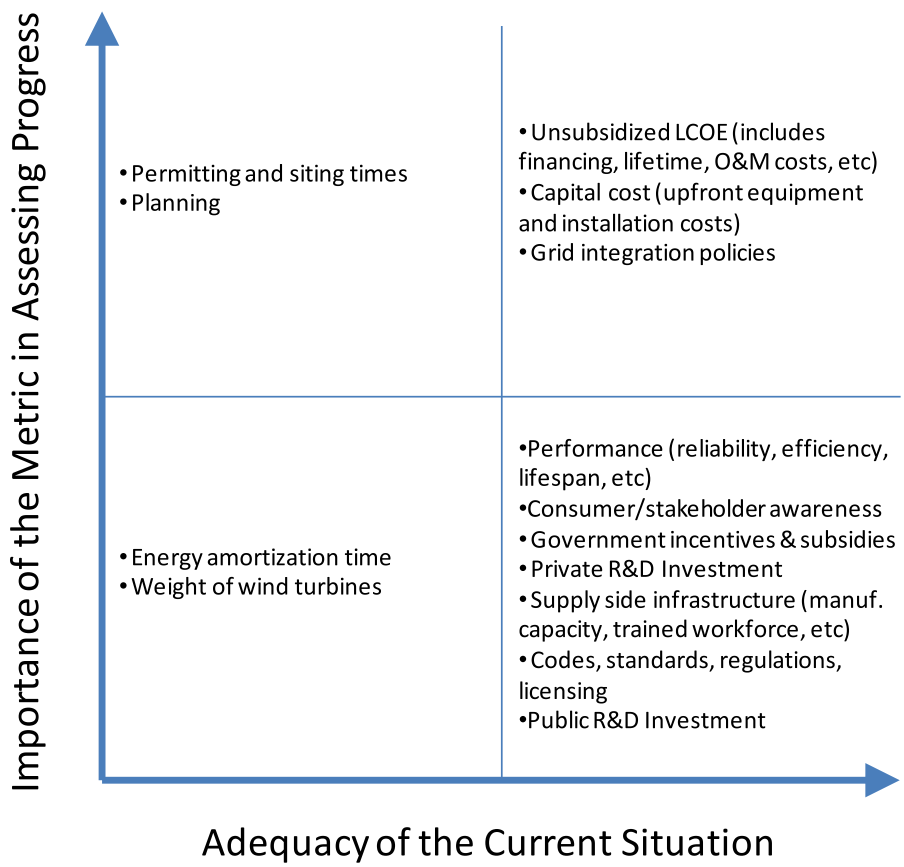
Important areas for expanded deployment of wind power technologies, and areas to track progress of wind technologies, include the following:

- Unsubsidised LCOE
- Capital costs
- Grid integration policies

- Permitting and siting times (application to generation)
- Planning policies

The upper two quadrants of Figure 9 show the metric areas of highest importance.[19] An estimate of the adequacy of the current situation for each area is also provided. The current situation for most of the metrics areas are considered adequate. Of these, unsubsidised LCOE, capital cost, and grid integration policies are the most important measurement areas. Permitting and siting times and planning policies are among the least adequate and are considered important areas for measuring the technology's progress. These represent potential areas of focus for driving further progress.

Figure 9: Importance and Adequacy of Potential Metrics for Assessing Progress of Wind Technologies



Key Messages for Leaders

- Account for the price of externalities and region-specific conditions (e.g. wind conditions, grid infrastructures, and public awareness)
- Improve government assistance for offshore projects
- Implement international standardisation and certification schemes

[19] As determined through survey results.

- Further develop coherent energy R&D strategies and establish a stable policy moving forward
- Address grid integration issues for technical (e.g. system stability) and legal (e.g. access and connection charges) challenges

Opportunities for R&D Cooperation

- Conduct basic research into the components and control systems for large-scale turbines and applications
- Increase collaboration and deployment of transnational systems to optimise grid design and generation patterns
- Strengthen international cooperation in R&D of offshore wind energy projects
- Conduct research to identify recycling and retrofitting methods for old installations
- Research advanced methods and materials to improve construction times, costs, weight, and durability

Biofuels and Biomass Power

Josef Spitzer, Member (Austria), Bioenergy Implementing Agreement

- Link to presentation slides

Key Takeaways: Progress continues for biomass heat and power development and deployment, particularly in small-scale heating and large-scale co-firing, which are now cost competitive with fossil technologies. However, challenges to greater deployment of other bioenergy technologies remain–in particular production of transportation fuels–including the need for improved feedstock supply and upgrading, conversion technologies, costs, and sustained government policies and incentives. The biomass feedstock potential may have been overestimated in previous studies.

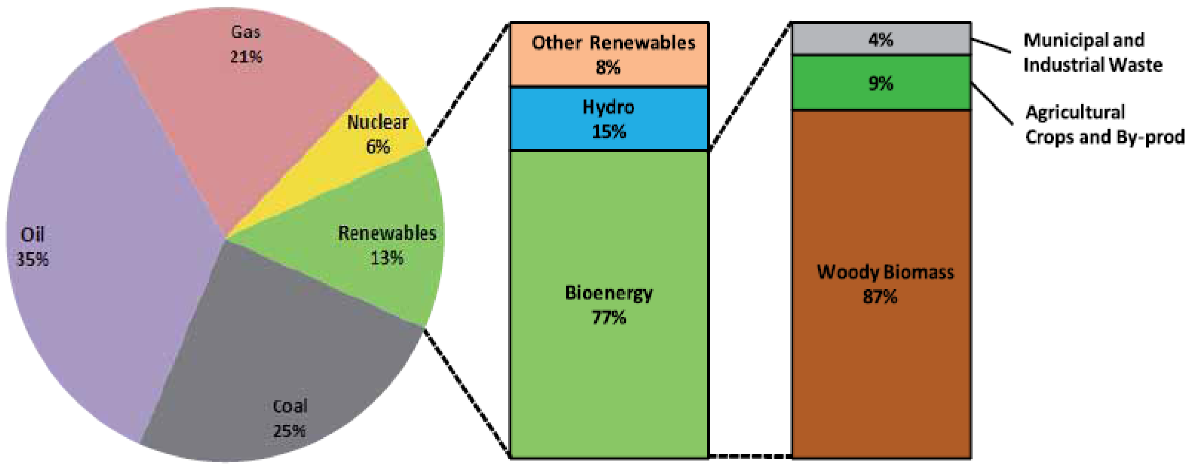
Progress Score:[20]

Very Unlikely	**Unlikely (10 - 40%)**	Maybe	Likely	Very Likely
	✓			

According to IEA and Intergovernmental Panel on Climate Change (IPCC) sources, renewable energy comprises about 13% of the global primary energy mix. Of this 13%, bioenergy accounts for 77%. Within the bioenergy category, municipal solid waste (4%), agricultural crops and residues (9%), and woody biomass (87%) are the main sources of current supply.

[20] The Progress Score is the technology area's estimated likelihood of BLUE Map goal attainment; according to results of a survey among EGRD workshop participants. See Appendix G.

Figure 10. Share of Bioenergy in the World Primary Energy Mix



Source: Based on IEA 2006; and IPCC 2007.

Several promising developments may help increase the share of bioenergy. Gasification as a biomass pre-treatment improves the feedstock's usability for heat, power, and transportation fuel production. Improvements in individual components and whole systems have resulted in more efficient conversion of feedstocks through an "integrated" approach. Feedstock options such as waste biomass and those grown on degraded land avoid the issue of competition with food, feed, and fibre.

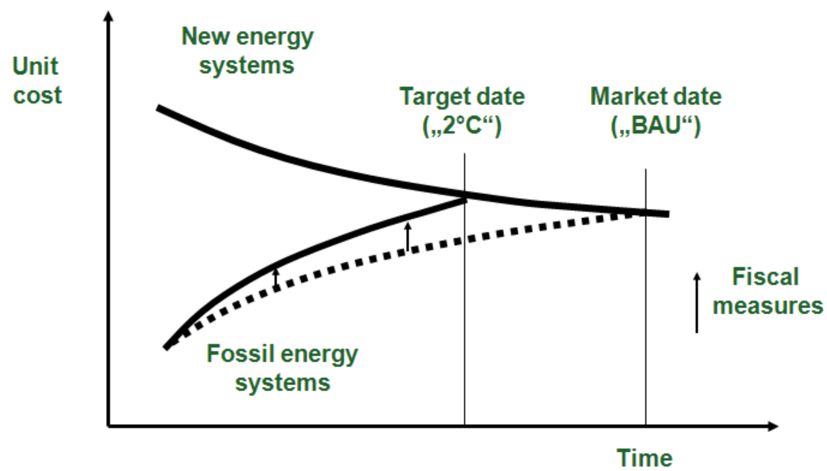
Better metrics and international standardisation have allowed for introduction of "sustainability criteria" and more realistic estimates of global feedstock supply and potential. While these developments give hope for the expansion of heat, electricity, and transportation fuels from biomass, further solutions will be needed to address remaining challenges. For example, the costs of technology remain high, particularly when compared to fossil-based fuels and generation. Costs can be reduced; however, a cost gap will remain for most bioenergy technologies. Ending subsidies for fossil fuels and putting a price on carbon are important policies to bridge that gap (Figure 11).

Technologies developed sufficiently for deployment will need to have well-established basic R&D, proven prototypes, and economic competitiveness. Small-scale heating and large-scale co-firing are the only technology categories that have reached this stage. Many other technologies and applications are still under development, although picking the most worthy for support is challenging.

Supplying both the developed and emerging technologies will be arduous because feedstocks may not be as available as suggested by estimates of regional and global resources and because competition with food, feed, and fibre uses for biomass, as well as other land uses generally reduces available feedstock supply for fuels and energy production. These factors combine to form significant barriers to industrial engagement.

For next generation energy solutions like bioenergy, the difference in costs between the new energy source and the old fossil-based sources reflects the order of magnitude of the costs to address climate change (Figure 11). Increasing the costs of fossil systems through fiscal policy would bring the point of competitiveness for the early-stage technologies closer at hand. Such narrowing of the cost gap may be achieved through a focus on certain barriers to development.

Figure 11: Example for Policy Action for Accelerating the Point of Competitiveness



Source: Implementing Agreement for a Programme of Research, Development and Demonstration on Bioenergy.

Priority areas for continued development of bioenergy are feedstock supply and conversion to end use. Further R&D is required to increase the supply of biomass feedstocks and to render it sustainable. Efficient use and growth in bioenergy production will also lead to international trade requiring pre-treatment to achieve a better energy to volume/weight ratio for the transport of biomass.

With the feedstock supply accounted for, conversion processes for end use need further R&D. While many technology options have shown promise, focusing on fewer of them could support faster implementation (although selecting which option to focus on is not obvious). Component and overall plant optimisation is another priority for improving conversion.

Fundamentally, bioenergy uptake will be driven by lowering costs for bioenergy while increasing the costs of traditional fossil fuels. The lack of a price on carbon and subsidies for fossil energy sources perpetuates reliance on them.

Bioenergy Discussion

Progress of Biopower Development and Deployment

Currently, only a few specific technologies have developed sufficiently for deployment, including small-scale heating and large-scale co-firing. According to survey results, it appears unlikely (10%-40%) that bioenergy will deploy as described in the BLUE Map scenario.

Metrics for Monitoring Progress

Critical areas for expanded deployment of bioenergy technologies, as described above, represent an opportunity to track leading indicators for growth in bioenergy. These include the following:

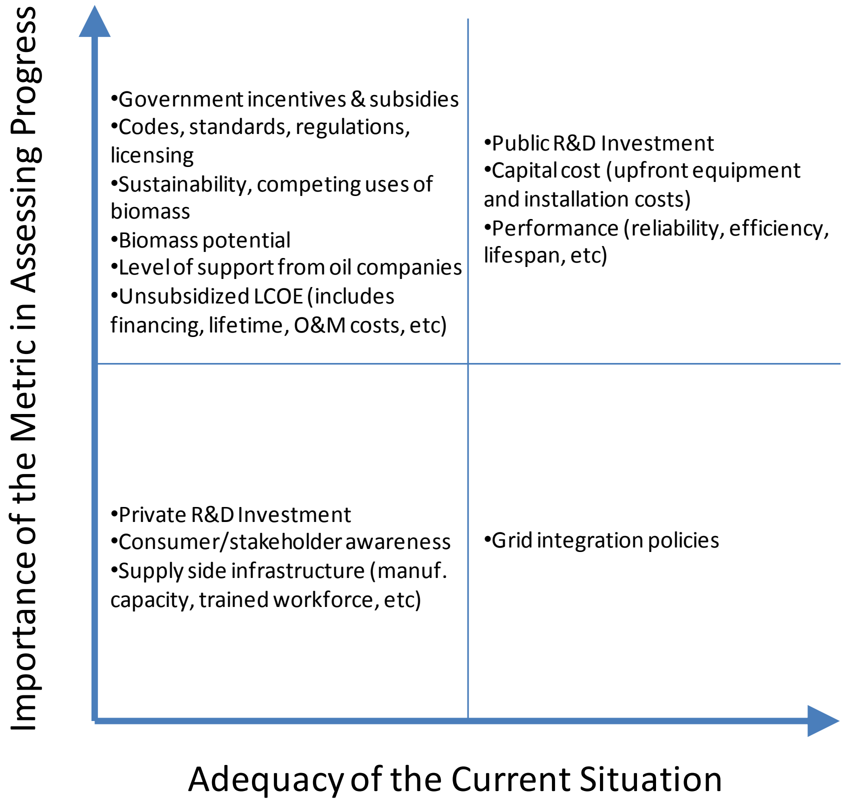
- Public R&D investment
- Capital costs
- Performance
- Unsubsidised LCOE
- Government incentives and subsidies[21]
- Codes, standards, regulations, and licensing
- Sustainability and competing uses of biomass
- Biomass resource potential
- Level of support for bioenergy from legacy oil companies

The areas that are most important for measuring progress in bioenergy are shown in the upper two quadrants of Figure 12.[22] An estimate of the adequacy of the current situation for each potential metric is also provided. The upper left quadrant shows many areas that are considered the most important in measuring progress, yet are currently the least adequate in their progress towards BLUE Map goals. These represent potential areas of focus for driving further progress.

[21] Public incentives and subsidies to decrease consumer cost of bioenergy is considered an important measure of progress in the short term; but in the long term, public subsidies may not be an economically viable solution. In addition, funding that might be available for such actions is likely too limited to bridge the gap shown in Figure 11.

[22] According to a survey of EGRD workshop participants. See Appendix G.

Figure 12: Importance and Adequacy of Potential Metrics for Assessing Progress of Bioenergy Technologies



Key Messages for Leaders

- Instill a coherent pricing policy on CO_2 to greatly expand bioenergy deployment
- Address persistent feedstock supply and sustainability issues through both technology and policy, partly by pushing technologies that do not compete with food/feed/fibre
- Examine use of unutilised resources in agriculture and municipal waste streams
- Evaluate thoroughly the costs and opportunities to determine adequate policy measures to push technology, optimise competitive energy uses (electricity or transport), and apply a balanced portfolio approach among biofuel, combustion (power & heat), and material use

Opportunities for R&D Cooperation

- Conduct system studies on the potential partial reduction of cost through integrated biomass and biofuel facilities (biorefineries)
- Conduct R&D on improved feedstocks able to be cultivated on marginal lands
- Research biomass use as carbon-containing but carbon-neutral feedstock
- Evaluate early-stage, heterogeneous R&D activities to concentrate funding on a promising few technologies for later-stage R&D

CO_2 Capture and Separation: Technology Costs and Progress

Charles Taylor, National Energy Technology Laboratory (NETL), Department of Energy (United States)

- Link to presentation slides

Key Takeaways: Development and deployment of carbon capture and separation technologies continues to lag. Key challenges remain with regard to cost-effective advanced capture technologies; scale-up; varied types and qualities of coal; inadequate workforce skills; and increasing the efficiency of coal plants. Many newer carbon capture technologies are coming in the next two decades.

Progress Score[23]:	Very Unlikely	**Unlikely (10 - 40%)**	Maybe	Likely	Very Likely
		✓			

The BLUE Map Scenario projects that carbon capture and storage (CCS) will be responsible for 19% of emissions reduction by 2050. Meeting this goal will not be without challenges, but the potential for reducing emissions while maintaining slow growth in energy costs is appealing. Using a model to investigate the potential impacts of a possible Clean Energy Standard (CES) for the United States mandating 80% of electricity be generated from clean energy sources (with CCS qualifying as 90% clean) by the year 2035, NETL found that an emissions tax on CO_2 would have to reach USD 23/t CO_2 by 2020 and increase at 5.8% annually. The results of the model indicate that while CCS can play a significant role in a CES by minimising electricity price increases and maintaining baseline electricity generation levels, the cost and performance of CCS must meet the R&D goals of the U.S. Department of Energy in order to meet its full potential.

A number of barriers have been identified that hinder deployment of CCS in new and existing coal plants. Power plants that install CCS systems experience an energy penalty resulting in a 20%-30% loss in power output. The burden of CCS increases the cost of electricity by 80% and adds to capital costs for the plant. While current post-combustion capture technology is capable of separating approximately 200 tons per day, a medium-sized, 550 MWe power plant produces 13 000 tons per day, so scale-up is a significant barrier. The regulatory framework that controls infrastructure development like storage facilities and pipeline networks for transportation forms another barrier to expanded use of CCS. Economies of scale will remain a barrier until the CCS industry can grow sufficiently to take advantage of lower marginal land, power, water use, transportation, and process component costs. One final barrier is the lack of long-term liability structures. The National Risk Assessment Partnership (NRAP) works to develop a defensible, science-based methodology for quantifying such liabilities through integrated assessment modelling.

[23] The Progress Score is the technology area's estimated likelihood of BLUE Map goal attainment, according to results of a survey among EGRD workshop participants. See Appendix G.

HELE Coal Technologies with CCS

Because coal is an inexpensive and abundant resource, usage is projected to more than double by 2050 under baseline scenarios. High-efficiency, low-emissions (HELE) coal-fired power plants with CCS are critical for future use of coal in power generation. There are many technologies to improve efficiency in existing plants, such as waste heat recovery, fuel switching, and co-firing. For new power plants, higher efficiency technologies include supercritical and ultra-supercritical technologies, integrated coal gasification combined cycle (IGCC), and advanced ultra-supercritical technology. Improved efficiency should be developed and deployed along with more efficient CO_2 capture technologies.

However, several barriers specific to HELE CCS plant technologies curtail expanded use. High upfront costs of installation are especially detrimental to CCS technologies, which include solvents, sorbents, oxy-combustion, membrane technologies, chemical looping, and CO_2 compression. More generally, the varying qualities of coal and inadequate operation and maintenance skills form other barriers. Also, deployment is slowed by insufficient information sharing among developers and the lack of appropriate price signals from financial, legal, and regulatory frameworks.

These individual CCS and efficiency technologies have resulted in several different configurations of power plants that are either under development or in operation. Pulverised Coal Power Plant System with post-combustion CO_2 scrubbing using amine solvents has several advantages including relatively low costs and technology proven in petroleum refining and natural gas purification. However, challenges are that the flue gas is quite dilute at 12%-15% CO_2 by volume and that the plant has increased cooling requirements. IGCC Power Plant System with pre-combustion CO_2 scrubbing is advantageous in that it has high chemical potential and low-volume syngas stream. Challenges include the complexity of the power process and the need for additional processes to get high capture rates. Pulverised coal oxyfuel combustion (PCOC) systems have several technology opportunities including using advanced construction materials, such as in compact boiler designs, and using advanced compression of CO_2. A new generation of capture technologies will be developed by 2030.

Carbon Capture and Separation Discussion

Progress of Carbon Capture and Separation Development and Deployment

HELE coal and CCS technologies continue to make progress in R&D, but these technologies need to achieve much larger scale of deployment to make substantial impacts, potentially by being deployed in tandem with other more efficient technologies. It is unlikely (10%-40%) that HELE coal and CCS technologies will deploy as described in the BLUE Map scenario.[24]

Metrics for Monitoring Progress

Important areas to track for HELE coal and CCS progress include:

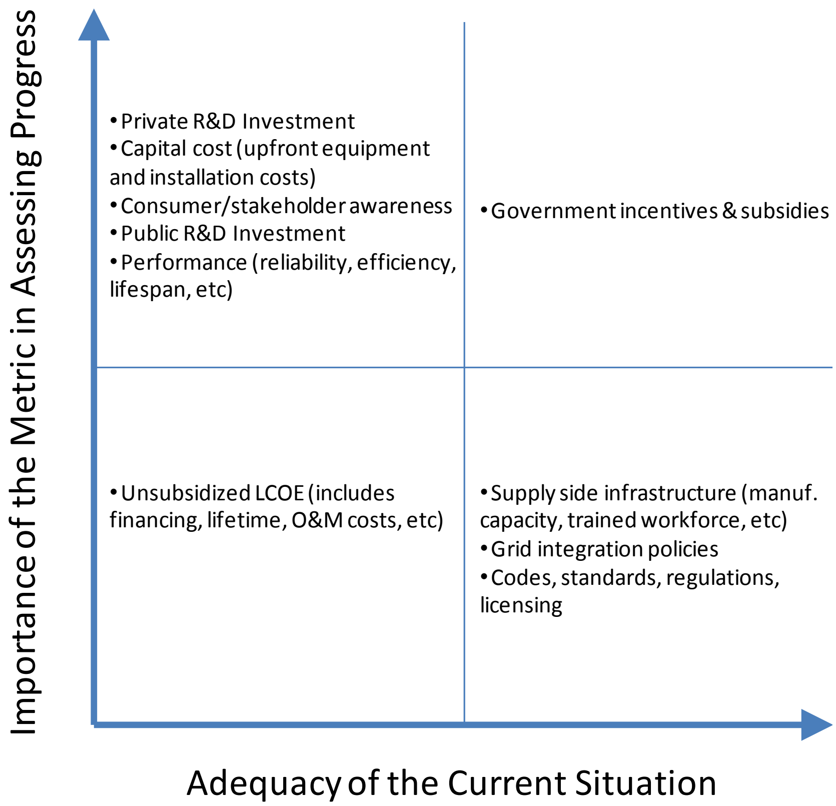
- Private and public R&D investments
- Capital costs
- Consumer awareness of CCS technology
- Performance

[24] According to a survey of EGRD workshop participants. See Appendix G.

- Government incentives

Most of the metric areas for tracking future progress in HELE coal and CCS are considered inadequate in their current situation, as shown in the left-hand quadrants of Figure 13. Of the areas that are the most important measures, only government incentives and subsidies are currently adequate.

Figure 13: Importance and Adequacy of Potential Metrics for Assessing Progress of HELE Coal and CCS Technologies



Key Messages for Leaders

- Address concerns surrounding the lack of a clear and stable policy regarding the price of carbon
- Reinforce the need for significant sustained public investment in R&D and policy development
- Understand that, given slow progress in deployment, the greatest contributions may come more as a supplemental efficiency improvement as part of a greater transformational technology

Opportunities for R&D Cooperation

- Research and demonstrate the potential for CCS technology on larger scales
- Research and demonstration on advanced CO_2 capture technologies to reduce the energy and cost penalties associated with currently available capture technologies
- Address issues concerned with the interplay of internationally distributed intellectual property rights through appropriate initiatives

Geological CO_2 Sequestration: Prognosis as a Clean Energy Strategy

Fedora Quattrocchi, INGV, Functional Unit "Fluid Geochemistry, Geological Storage and Geothermics," and contract professor at University Roma 2, Tor Vergata, Engineering Faculty (Italy)

- Link to presentation slides

Key Takeaways: Progress continues to lag with regard to geological CO_2 storage development and deployment. Key challenges remain with regard to public acceptance, liability, costs, lack of internalisation of CO_2 emission externalities, comparison between numerical modelling and wider monitoring, conflicting uses of underground resources, and tools for dynamic assessment of storage capacity. Monitoring tools already exist and are widespread in Italy, but further development is necessary. Transport of CO_2 is conducted in some countries (e.g. United States) mainly for enhanced oil recovery, and more efforts should be done to plan regional sources-sinks networks.

Progress Score:[25]

Very Unlikely	Unlikely (10 - 40%)	Maybe	Likely	Very Likely
	✓			

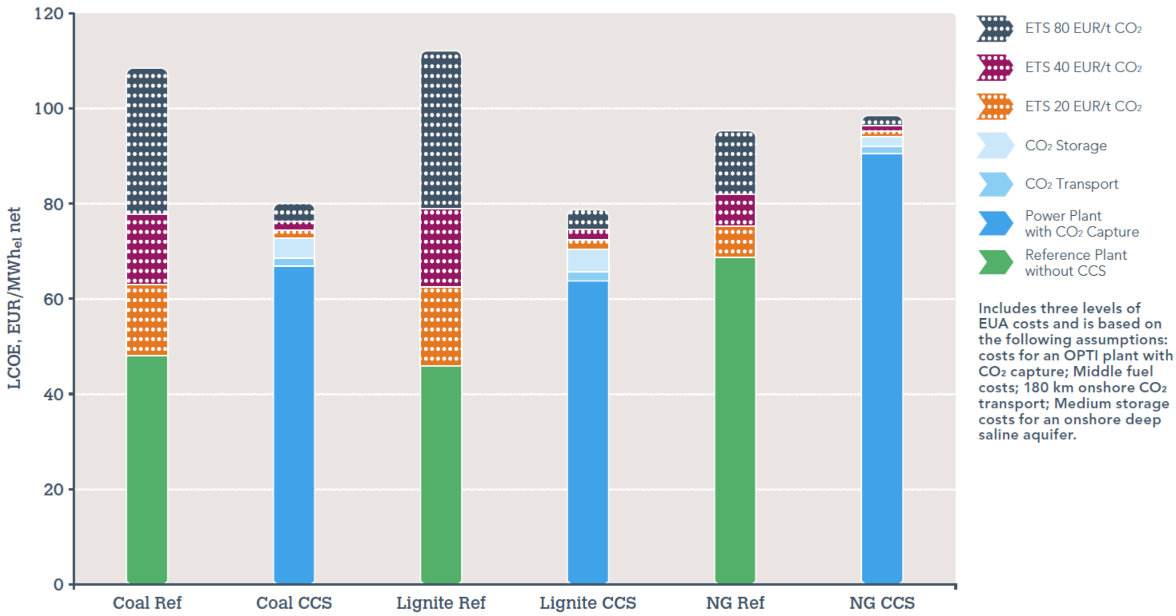
Several different energy technologies require underground resources in different fashions (e.g. storage capacity, resources, and reserves). Besides CCS, spent nuclear fuel, natural gas storage, and geothermics all have vested stakes in geological resources for long- and short-term storage and energy recovery. In the United States, for example, CO_2 is used as a resource injected underground in Enhanced Oil Recovery (EOR) operations. Although EOR is driven by efforts to maximize extraction of underground resources, it is also useful for sequestration of CO_2. In addition, this practice adds to the collective knowledge base of underground CO_2 modelling and monitoring. Building this knowledge is critical for gaining public acceptance of underground CO_2 storage.

Effective planning and coordinated use of the limited underground resources will be progressively more important as demand for prime storage sites increases. Prioritizing storage sites among competing uses may prove difficult and international cooperation may play an important role in addressing this issue. The EU platforms using underground resources – zero emission coal, renewables (geothermics), gen IV nuclear, and biomass – do not currently coordinate regional planning. It is more appropriate to dedicate funds and research efforts to "smart regions" more than "smart cities" alone. Cities are not sustainable without underground regions planning. Neither was such coordination addressed in the EU Seventh Framework Programme (FP7), but high-level coordination should be discussed through FP8 (horizon 2020). One step to improve coordination would be to merge the various governmental underground exploration permits laws into a unique "Underground Exploration/Storage Act," which would be common among regions in terms of liability management.

[25] The Progress Score is the technology area's estimated likelihood of BLUE Map goal attainment, according to results of a survey among EGRD workshop participants. See Appendix G.

For CCS, costs are the greatest barrier. The cost of the technology is not the principal barrier *per se*, but rather the low cost of carbon impedes economic sustainability. Currently, costs associated with CO_2 storage have been estimated from USD 4-USD 20 per tonne CO_2, depending on numerous factors including the type of reservoir, existing infrastructure for the site, onshore versus offshore storage, extent of monitoring required, and regional factors. Active projects have found costs of USD 11-USD 17 per tonne at the Sleipner Fields in the North Sea; USD 20 per tonne at Weyburn, Saskatchewan, Canada; and USD 6 per tonne at the In Salah site in Algeria.

Figure 14: The Levelised Cost of Electricity of Integrated CCS Projects Compared to Reference Plants without CCS



Note: Blue bars indicate integrated CCS projects, while green bars indicate reference plants without CCS.
Source: ZEP, "The Costs of CO2 Capture, Transport and Storage".

Transportation of CO_2 is another significant issue, particularly when the carbon source is distant from the storage site. By 2020, pipeline infrastructure will need to handle four times the amount of CO_2 transported in 2009; by 2030, ten times the amount of CO_2 is projected. For any pipeline system, however, several specific issues must be addressed. Supervisory control and data acquisition (SCADA) is needed to ensure safe operations. Carbonic acid can be generated from ambient moisture in the pipeline and lead to corrosion. Finally, materials for piping, valves, seals, and other aspects must be carefully considered to cut down possible leak paths.

Insurance, liability, and indemnification must be addressed prior to project implementation. In particular, both short-term risks during the construction and operation of the CCS project and the long-term risks of ongoing storage must be managed. In general, the peak risk occurs during the operation (i.e. injecting) and closure phases, so measurement and verification and quantified risk assessment are especially important. Post closure, some risk still exists for the state or nation that has taken stewardship. Furthermore, the transfer of liability implicit in state stewardship post closure must be clearly addressed. The Price Anderson nuclear insurance paradigm is not a good precedent for CCS insurance; this needs to be a state-owned risk, and the risk is different at every site.

Site selection is difficult because of several factors, and general solutions are unavailable because CO_2 storage issues are site-specific. Carbon dioxide outflows differ from one industrial process to another. For example, ammonia production, biofuels production, and natural gas combustion produce relatively pure streams of CO_2, but many flue gas streams may contain significant impurities. Moreover, the different CO_2 sources will require different capture methods, which can affect the costs and CO_2 stream characteristics.

Modelling, while well developed for specific aspects like mass transport, geochemistry, and geo-mechanical actions, is still underdeveloped for generating a complete picture from these discrete analyses. That is, results of the many different models can be difficult to merge into one cohesive picture. Similarly, monitoring capabilities, particularly at the regional scale, are frequently insufficient or underdeveloped.

A lack of sufficient monitoring leads to issues of public acceptance and fosters attitudes of “not under my backyard” (NUMBY). Moreover, a comprehensive monitoring system would act as an alarm for leakage failures and induced seismicity. Unfortunately, low-cost, efficient monitoring systems are only in the research phase and have not reached commercialisation. Remote sensing equipment for inland monitoring is unavailable, and building complex stations for benthic environments is too time-consuming and costly.

The primary concerns of the public focus on leakage and induced seismic activity. Conveying the safety of long-term CO_2 storage is paramount for further development. Primary objectives for CCS projects should be transparency and communication with the public. One essential message to convey is the principle of a natural carbon-dioxide flux–where pockets of CO_2 in geologic formations exist naturally with periodic leakages happening throughout human history. Indeed, in Italy, where CO_2 from 300 natural sources is well monitored and understood, the general public is not worried about such releases. At a maximum, the risks associated with deployment of CCS are similar to those associated with the natural flux.

Demonstrations of CO_2 storage from pilot test sites are needed to increase the public awareness and acceptance of the technology. Such demonstrations also provide learning-by-doing experience and critical data that are needed for monitoring and modelling validation. Pilot demonstrations and full-scale applications should be considered for other technologies with large point source emissions, including cement manufacturing, steel plants, refineries, and biomass plants.

Deployment of CCS will depend largely on only a few important factors. First, the importance of deep geological structures must be conveyed such that the value of underground resources is appreciated. Next, CCS must be implemented widely and quickly, but in cooperation with the other energy technologies utilising subsurface resources. That is, with advance planning, these technologies can coexist underground. Finally, the catalogue of potential sites must be analyzed to quantify associated risk.

Geological CO_2 Storage Discussion

Progress of Geological CO_2 Storage Development and Deployment

The rate of progress of CO_2 storage is lagging. Challenges associated with CO_2 storage, such as lack of a price for carbon emissions, monitoring reliability, liability, public acceptance and policy uncertainty, are among the many factors inhibiting faster development and large-scale deployment. Many storage demonstration projects are behind schedule, or cancelled. This is due to, in part, the lack of public awareness. Information sharing to gain public acceptance is the most important challenge to further deployment. Assuming current policies toward CCS continue, it is considered unlikely (10%-40%) that efficient coal-fired generation with carbon capture and geologic storage will deploy as described in the BLUE Map scenario.[26]

Metrics for Monitoring Progress

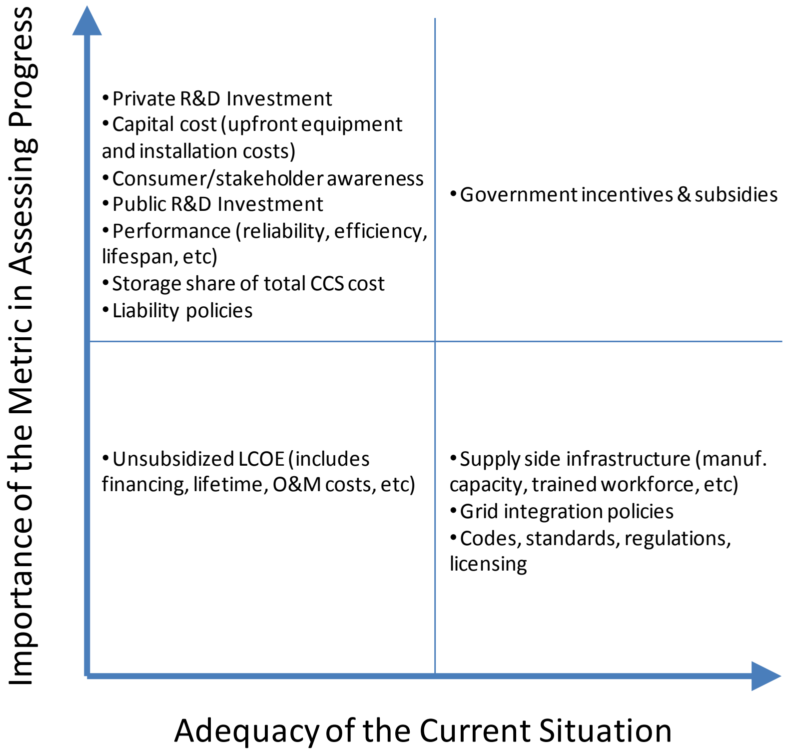
Important areas to track for progress in CO_2 storage include:

- Private and public R&D investments
- Capital costs
- Consumer awareness and social acceptance of CCS technology
- Performance
- Storage share of total CCS project cost
- Liability
- Government incentives

Most of the metric areas for tracking future progress are considered inadequate in their current situation, as shown in Figure 15. Of the areas that are the most important measures, only government incentives and subsidies are currently adequate.

[26] According to a survey of EGRD workshop participants. See Appendix G.

Figure 15: Importance and Adequacy of Potential Metrics for Assessing Progress of CCS Technologies and Geologic CO_2 Storage



Key Messages for Leaders

- Address concerns surrounding the lack of an established price of carbon
- Conduct further research on risk assessments to heighten public acceptance
- Reinforce the need for significant sustained public investment in R&D and policy development
- Explore new approaches and best practices to involve public institutions in addressing site-specific storage issues
- Increase stakeholder involvement–including public outreach and education–in planning and implementing the range of underground applications and addressing liability concerns
- Assess the need for planning to address potential synergic and competition among different uses of underground geological structures including CO_2 storage, natural gas and hydrocarbon storage and recovery, resource extraction from existing and future deep mines, oil and gas upstream, coal resources, geothermal reservoirs, drinking water sources, and geological nuclear spent fuel storage/disposal.

Opportunities for R&D Cooperation

- Conduct underground fate and transport modelling including: mass transport, geochemistry, and geo-mechanics
- Characterize and map storage potential and possible synergic and competing uses
- Research and demonstrate the potential for CCS technology on larger scales

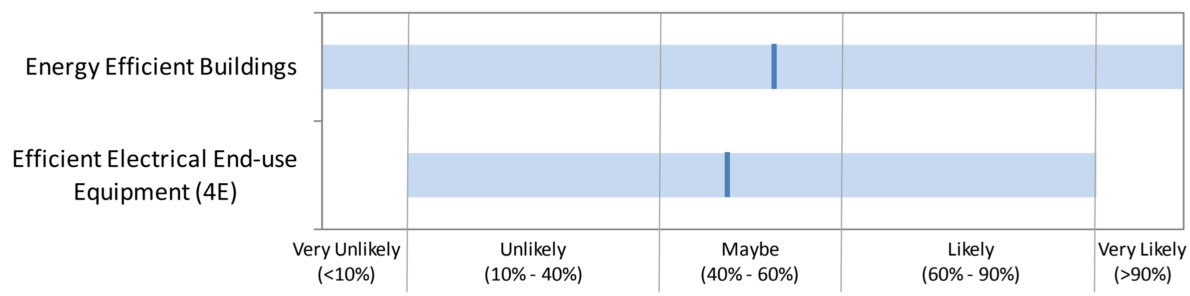
- Investigate potential for increased use of CO_2, including enhanced oil recovery (EOR) applications with CCS-related CO_2 injection
- Merge mass-transport and geochemical modelling efforts to develop a broader scope for monitoring efforts
- Address issues concerned with the interplay of internationally distributed intellectual property rights through appropriate initiatives

Demand-side Technologies

Important end-use energy technologies examined by EGRD include: energy efficient buildings — heating and cooling, and efficient electrical end-use equipment (4E). A discussion of their current status, projected progress, and metrics for monitoring further development in meeting BLUE Map goals is provided.

Energy efficient buildings and end-use equipment are considered to be, on average, about 50% likely to achieve BLUE Map scenario targets. The range of responses for energy efficient buildings, as shown in Figure 16, reflects the collective uncertainty in judging the likelihood that the technology area will meet BLUE Map targets through 2050.

Figure 16: Likelihood that Certain Energy Demand Technologies Will Meet IEA Blue Map Scenario Targets



Note: Bars indicate range of responses from survey of workshop participants; lines show mean response
Source: Workshop survey responses.

Energy Efficient Buildings – Focus on Heating & Cooling Equipment

Rod Janssen, Head, Energy Efficiency of Buildings, European Council for an Energy Efficient Economy

- [Link to presentation slides]

Key Takeaways: Energy efficient heating and cooling equipment exists, but it is not being implemented quickly enough. Challenges and opportunities include effectively addressing new builds and retrofits, focusing on cooling and systems integration approaches, and using standards and codes to address increased upfront costs.

Progress Score:[27]

Very Unlikely	Unlikely	**Maybe (40 - 60%)**	Likely	Very Likely
		✓		

[27] The Progress Score is the technology area's estimated likelihood of BLUE Map goal attainment, according to results of a survey among EGRD workshop participants. See Appendix G.

Current IEA recommendations for advancing energy efficient building technologies include establishing mandatory building energy codes and minimum energy performance standards (MEPS); improving energy efficiency of existing buildings; developing building energy labels or certificates; and improving energy performance of both building components and systems is necessary. Ultimately, buildings should aim to achieve net-zero energy consumption.

The IEA *Clean Energy Progress Report* (2011) projects that energy consumption in the buildings sector will grow to over 4 400 Metric tonnes of oil equivalent (Mtoe) by 2050 compared to 2007 levels of energy consumption of 2 759 Mtoe. More than half of this growth is expected to occur in the residential buildings sector, with significant increases in non-OECD countries. In the BLUE Map Scenario, two-thirds of the energy savings in the buildings sector will come from the residential sector, and the goal is to limit growth in total energy consumption in the buildings sector to a 5% increase from 2007 to 2050.

In order to meet the long-term needs, new buildings will need to be zero-energy and existing buildings will require extensive renovations. The challenge of achieving these goals is putting policies in place that target improvements in technical efficiency of building components, as well as in the design of new buildings and systems (especially heating, ventilation, and cooling). During the last three decades, improvement has been made in the energy performance of insulation materials and windows. For example, double glazing of windows is now becoming standard in buildings. The increase of the sales of high-performing, efficient windows and insulating materials shows the positive steps that are already being taken to ensure improved efficiency of buildings, especially in envelope and shell technologies.

Status

Current heating and cooling technologies are on a good path in terms of being able to meet the projected goals, and the BLUE Map Scenario projects that energy efficient and low or zero carbon technologies for heating and cooling will save 2 Gt of CO_2 by 2050. The IEA Technology Roadmap for Energy Efficient Buildings notes that most of these heating and cooling technologies are commercially available today, although continued R&D efforts should focus on reducing costs, improving the efficiency and integrating components and further developing building materials. The EU and other regions are introducing new R&D strategies with more emphasis on low-carbon economies and the full implications of a low-carbon world.

The key now is policy activity that will contribute to BLUE Map 2050 targets. The EU's revision of the Directive on the energy performance of buildings is taking on a more systems-oriented approach to energy performance with increased focus on cost optimality and near-zero energy buildings. While the EU has the Ecodesign Directive, implementing MEPS for energy consuming products across the EU, there has been a slowdown in approval for boilers. This may not affect on the goals for 2050, but it will affect the goals for 2020. In the United States, there has been significant code development, especially since the 2009 American Recovery and Reinvestment Act (ARRA). A recent study from Pacific Northwest National Lab (PNNL) estimates that by 2030 there will be more than USD 15 billion in annual savings on building energy bills with more targets and programmes for zero-energy buildings on the way. Meanwhile, market transformation has been occurring regionally and globally, as many products are traded on this scale. The implementation of energy labelling programmes and MEPS has also had noticeable effects on market transformation.

Challenges to greater deployment

When considering the goals for 2050, it must be taken into account that a major transformational change is required and that all available options must be considered. Certain areas need urgent attention when looking towards the future. There should be a focus on design and the integration of new solutions and harnessing information and communications technologies (ICT). A systemic approach should be taken, with focus on integration between buildings, grid and heat networks, as well as energy storage systems which can further facilitate integration of renewable energy. Substantial retrofits of existing buildings will also be needed, as the building turnover is only 1% in the EU; however, architects don't like retrofits. Compliance is another issue: mandating higher standards does not guarantee they will be obeyed. High priority should be placed on developing effective policy support tools such as labelling programmes, standardisation, and global harmonisation. There are many market failures in buildings efficiency.

Monitoring progress

Since many of the technologies that are needed to reach the goals for energy efficient buildings are already in use, the key is to focus on policy developments on national, regional, and global levels with an emphasis on the importance of policy targets for GHG emissions reductions. Policies for buildings, such as near zero-energy buildings, will be an important marker towards reaching these goals. Funding from public and private institutions are currently sufficient but must remain consistent, at the very least. The involvement of the private sector in developing markets for advanced building technologies may also play an important role in the future of the global buildings sector.

Energy Efficient Buildings Discussion

Progress of Energy Efficient Building Technology Development and Deployment

Currently, a range of energy efficient building technologies are in use globally. Policy actions will be critical to whether this technology area will deploy to the extent outlined by the BLUE Map scenario. Improvements in efficiencies of building components and a greater emphasis in efficiency during the design stage of new buildings and systems would also enable greater market penetration of advanced heating and cooling technologies. Energy efficient building technologies may be (40%-60%) on pace to deploy as described in the BLUE Map scenario.[28]

Less than 1% of the Clean Development Mechanism projects are efficiency-related. There needs to be more discussion of efficiency at forums related to clean energy credits.

Metrics for Monitoring Progress

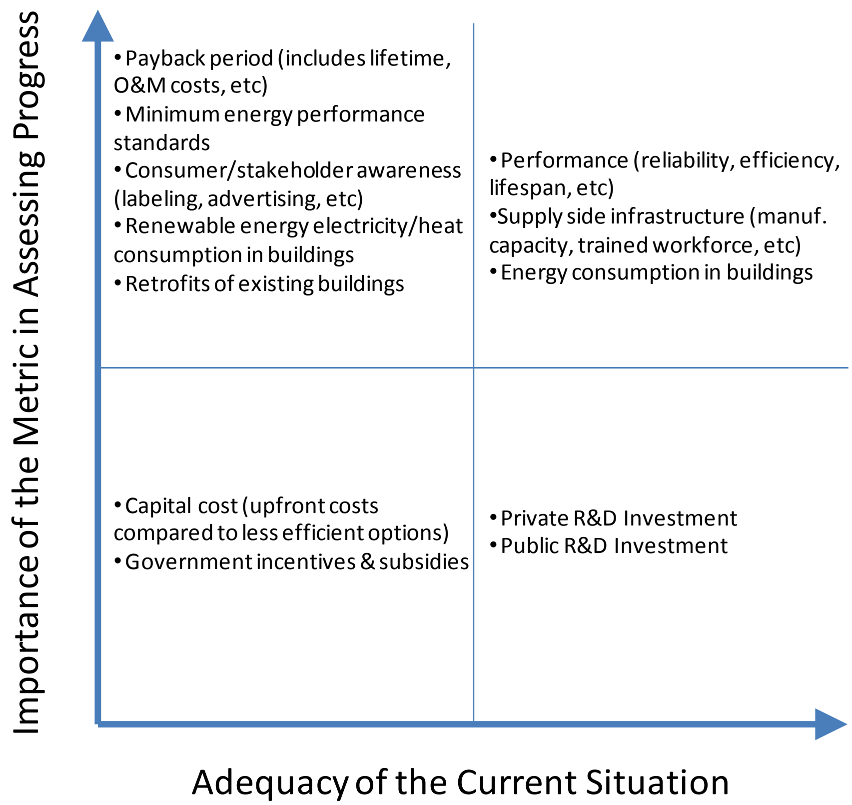
Important areas for expanded deployment of energy efficient building technologies, as described above, represent an opportunity to track leading indicators for continued growth. These include:

[28] According to a survey of EGRD workshop participants. See Appendix G.

- Energy consumption in buildings
- Renewable energy electricity/heat consumption in buildings
- Retrofits of existing buildings

Additional important areas for metrics are shown in the upper two quadrants of Figure 17. Only three of the most important metrics were considered adequate. Government incentives and subsidies, minimum energy performance standards, and consumer and stakeholder awareness are considered the least adequate in their current situation.

Figure 17: Importance and Adequacy of Potential Metrics for Assessing Progress of Energy Efficient Building Technologies



Key Messages for Leaders

- Deploy ambitious and compulsory energy performance standards, upgrades, and retrofit policies for existing buildings
- Emphasise end-use efficiency policies for residential and commercial buildings
- Address the need for robust legal framework that is needed to enable and incentivise deployment of efficient building technologies, many of which already exist
- Reward energy efficient buildings to provide additional impetus to pick the low-hanging fruit

Opportunities for R&D Cooperation

- Research advanced building technologies with applications at a systems level, including integrated building concepts (i.e. efficient buildings with on-site generation)
- Investigate methods of integrating building efficiency, fuel, and technology enhancements into policy schemes through policy tools or codes and standards
- Conduct advanced modelling of energy savings for existing buildings
- Develop flexible design concepts for low/zero-energy buildings (new and existing)

Energy Efficient Residential Appliances

Frank Klinckenberg, Klinckenberg Consultants (Netherlands)

- Link to presentation slides

Key Takeaways: Progress with regard to energy efficient residential appliances is not nearly fast enough to meet 450 ppm goals. Challenges include the need for expanding the coverage and increasing the stringency of standards and labelling, taking a systems approach to integrating appliances with the buildings and systems they serve, identifying the most important appliances in developing countries, and developing advanced efficiency appliances. EU standards have a worldwide impact, representing a key opportunity to broadly influence appliance efficiency.

Progress Score:[29]

Very Unlikely	Unlikely	**Maybe (40 - 60%)**	Likely	Very Likely
		✓		

The World Economic Outlook 2011 450 ppm scenario calls for a 40% improvement in energy efficiency by 2030. Policies adopted recently or likely to be adopted soon put us on a glide path to achieve 1%-1.5% improvement per year starting about 2020. This is less than half the rate needed to achieve the 2030 target. However, there are opportunities to catch up to the BLUE Map target rate by, for example, expanding to areas not currently covered by standards and labelling programmes.

Residential appliances constitute a market of great potential for the application of standards and labelling programmes. Such programmes can serve as an important tool for effecting increased energy efficiency among a range of categories of residential appliances. This is evidenced if we look at the experiences of the United States, Australia, and the European Union for refrigerators. All three nations have experienced significant reductions, nearly halving the average energy consumption of refrigerators (in kWh per litre) from 1990 to 2009. Despite any differences that might exist in the average size of refrigerators in these countries, the progress that has been demonstrated is clear and substantial.

[29] The Progress Score is the technology area's estimated likelihood of BLUE Map goal attainment, according to results of a survey among EGRD workshop participants. See Appendix G.

In the United States alone, there has been a consistent reduction in the price of refrigerators which drops exponentially as cumulative shipments have increased over time. Results indicate a learning rate of 41% for refrigerators in the United States. The EU provides a similar positive outlook in terms of cost reductions and the learning rates for different key residential appliances. An analysis of pre- and post-regulation reductions in cost clearly demonstrates a significant impact from regulations for a range of key household appliances, most notably in laundry dryers, dishwashers, refrigerators, and freezers. The technology learning rate was roughly less than 20% before regulation but close to 40% after the regulation was implemented. The average reduction in cost per doubling of cumulative production increases by a factor of two to nearly four from laundry dryers to freezers. The cost reductions were greatest for refrigerators, and freezers.

Coverage of S&L Programmes

The coverage of standards and labelling (S&L) programmes may be a useful measure of the remaining potential for realising energy efficiency savings. Findings from a study by the Collaborative Labelling and Appliance Standards Program (CLASP) show that in the EU and China, a substantial share — nearly half — of these nations' 2010 energy consumption in all sectors of the economy was subject to Minimum Energy Performance Standards (MEPS). The results of the analysis demonstrate that substantial energy savings potential exists in the commercial and industrial sectors as well, but that the residential sector also represents a significant opportunity for achieving energy savings through standards and labelling programmes. It is clear from this study that such policies may need to be tailored to a nation's economic make-up when it comes to targeting efforts in the residential versus the commercial and industrial sectors. Standards coverage of specific technologies, energy systems, and fuels represent the different policy options that are available for such a program. Standards and labels can be extended to more appliances and to more economies.

Approximately 40% of appliance energy is not covered by efficiency policies (e.g. large electric motors). In these areas, no progress is being made, and there is no tracking. Motors are 95% efficient already, so the opportunity for additional progress may seem slight. However, substantial savings are possible when considering the entire system and adjusting the motor to the power that is actually required. More progress can also be made by setting higher efficiency standards and setting the deadlines sooner.

It is also important to concentrate on the right appliances. The developing world has many more televisions than washers and dryers. Phone chargers are also in widespread use. However, refrigerators/freezers and lighting are the top end-use users of electricity, and space heating is the top fuel end-use. These top users are prime targets for standards and labelling, but the prime targets for cooperative R&D would be appliances that have commonality across borders, such as air conditioners and electric motors.

European standards tend to affect appliance manufacturers worldwide, thereby increasing efficiency outside the region.

Useful Metrics & Indicators

The *coverage* of standards and labelling programmes is an important factor, more so than the *number* of standards and labels programmes. It is important to consider the share of energy consumption in each sector that is covered as well as the share of energy savings potential that still exists. The ideal measure would track the level of savings sufficient to meet a given target, as this could be expressed as a percentage of efficiency improvement needed across all energy demand.

There are other suggested measures to track progress towards clean energy goals that include learning rates; the typical or average cost of advanced appliances, or average for retrofitting existing lighting, heating, or cooling systems with energy efficiency systems or improvements; and average efficiency of installed technologies. In addition, when considering improvements in energy efficiency for a category of equipment subject to standards, accounting for the change in market coverage of the standard provides a better indicator of progress. Metrics should be categorically defined so as not to skew results by making broad statements about energy efficiency improvements and technological progress.

Energy Efficient Residential Appliances Discussion

Progress of Energy Efficient Residential Appliances Development and Deployment

Currently, energy efficient residential appliances are available in global markets, though some appliances have improved energy efficiency more than others in recent years. Appliance technologies may be (40%-60%) on track to deploy as described in the BLUE Map scenario.

Metrics for Monitoring Progress

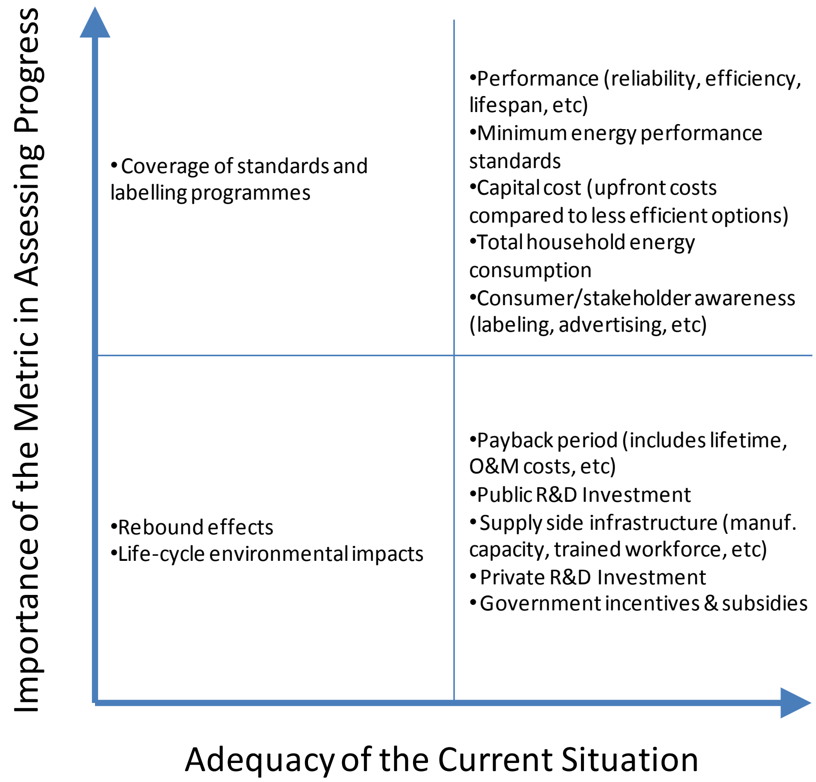
The most important areas for tracking leading indicators of energy efficient appliances deployment include:

- Performance of the technology (e.g. efficiency)
- Minimum energy performance standards
- Consumer awareness
- Coverage of standards and labelling programmes
- Household energy consumption
- Cost of the technology

A diagram of metrics areas and their current adequacy are shown in Figure 18.[30] Standards and labelling are components of three metrics areas considered to be among the most important: MEPS, consumer awareness (e.g. via labelling), and coverage of S&L programmes.

[30] According to a survey of EGRD workshop participants. See Appendix G.

Figure 18: Importance and Adequacy of Potential Metrics for Assessing Progress of Energy Efficient Residential Appliances Technologies



Key Messages for Leaders

- Reinforce the benefits of public awareness and ensure financial policy tools are available
- Emphasize the potential for rebound effects and the need to develop the proper metrics and policy mechanisms (i.e. tax incentives or penalties) to address such effects
- Introduce more aggressive legislation, which may include energy labelling and standards programmes, to ensure continued progress
- Implement policies to regulate and measure improvements in end-use energy consumption and efficiency
- Prioritize product categories with the greatest global impact (i.e. refrigerators, televisions)

Opportunities for R&D Cooperation

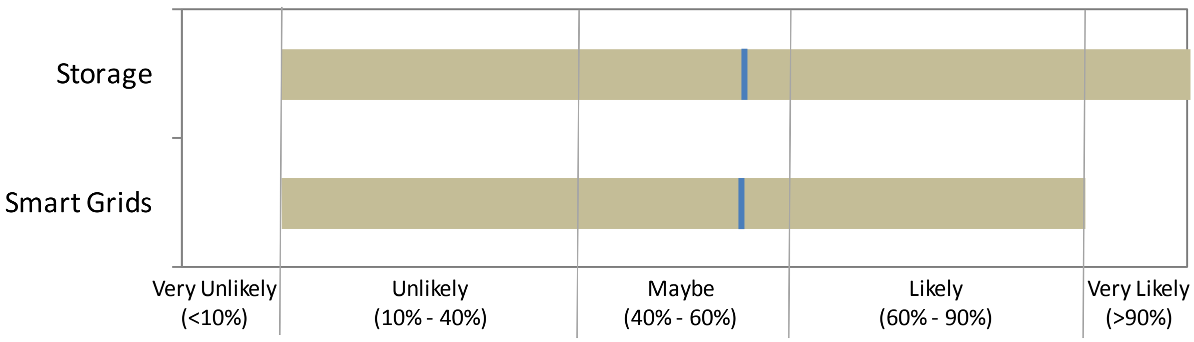
- Develop metrics and data collection information necessary to quantify rebound effect with a macroeconomic scope
- Commission research focused on systems, rather than the components, of advanced appliances
- Conduct detailed analysis of standards and labelling programmes to address national, regional, and community-level needs
- Investigate consumer behaviour as it relates to the use of residential appliances, including willingness to buy energy efficient appliances, as well as trends toward increased numbers of appliances per capita

Cross-cutting Technologies

Important cross-cutting and enabling energy technologies examined by EGRD include energy storage–vehicle batteries, and smart grids. Their current status, projected progress, and metrics for monitoring further development in meeting BLUE Map goals are discussed below.

Energy storage and smart grids are considered, on average, that they "maybe" will achieve BLUE Map scenario targets, as shown in Figure 19

Figure 19: Likelihood that Certain Cross-cutting Technologies will Meet IEA Blue Map Scenario Targets



Note: Bars indicate range of responses from survey of workshop participants; lines show mean response.
Source: workshop survey responses.

Energy Storage – Vehicle Batteries

Andy Chu, Vice President, Marketing and Communications, A123 Systems

- Link to presentation slides

Key Takeaways: Sales of electric vehicles are less than projections, but higher than initial sales of hybrid electric vehicles at their introduction. The cost reductions necessary for broader commercial adoption are achievable, partly because batteries benefit from use in many consumer products, which increases volume and economies of scale. Opportunities include development of fast charge systems for batteries and charging infrastructure, grid energy storage, and better compensation to owners of EV batteries providing ancillary services to the grid.

Progress Score:[31]

Very Unlikely	Unlikely	Maybe (40 - 60%)	Likely	Very Likely
		✓		

Potential for Energy Storage

Energy storage can impact several key technologies to help reduce global GHG emissions. Specifically, energy storage can enhance the impacts of renewable energy, power generation efficiency, and end-use fuel and electricity efficiencies. Applications of grid energy storage include: chemical storage (e.g. batteries), thermal storage (e.g. ice storage), mechanical storage (e.g. high-speed flywheels), bulk mechanical storage (e.g. compressed air energy storage, or CAES), and bulk gravitational storage (e.g. pumped hydroelectricity). In general, energy storage is transforming how energy is generated and used in both the transportation and grid sectors, and will be essential to meeting BLUE Map emissions reduction goals. Energy storage for electric vehicles is the focus for EGRD; although electric vehicle (EV) and plug-in hybrid electric vehicle (PHEV) car batteries will become an important source of grid storage. Grid storage allows ancillary services[32] for utilities, which are currently commercially deployed without government subsidies or support. Fairer compensation for ancillary services will assist the penetration of this technology.

While initial sales of EVs and PHEVs have been lower than expected in the United States, sales of the Nissan Leaf (approximately 8 000) and the Chevy Volt (approximately 4 000) as of October 2011 were still higher than the first year sales of the Toyota Prius (roughly 3 000). Development activity has been strong and there is growing interest in commercial fleet EVs and PHEVs.

[31] The Progress Score is the technology area's estimated likelihood of BLUE Map goal attainment; according to results of a survey among EGRD workshop participants. See Appendix G.

[32] Ancillary services provide resources to system operators who need to maintain the instantaneous and continuous balance between generation and load. These include load regulation; spinning reserve; supplemental reserve; replacement reserve; voltage control; and better integration of intermittent sources.

Micro-hybrid applications are another option that can provide fuel economy gains for a limited incremental cost. Upgrading a conventional vehicle's battery, starter, and alternator enables around 10% fuel savings for limited cost and development effort. According to Pike Research, annual micro-hybrid sales are expected to increase significantly between 2011 and 2017, most notably in western Europe, Asia Pacific, and North America.

Major Barriers to Grid Energy Storage and EV/PHEV Deployment

Barriers to grid energy storage include the cost of storage components and systems, market design and regulatory barriers, and insufficient data and lack of information that leads to conservatism among utility customers. Cost considerations are important. The main battery technologies are lithium ion (Li-ion), nickel metal hydride (NiMH), sodium sulphur, and lead acid batteries. HEVs are expected to use both NiMH and Li-ion for the next several years, but the industry expectation is that Li-ion will gradually replace NiMH over time. Most battery technologies cost around USD 300 to USD 1 000 per kWh; they need to drop to below USD 200 per kWh with over a 10-year lifetime. Despite these barriers, Li-ion-based grid energy storage is currently benefitting from usage of Li-ion in consumer electronics and transportation today — some usages are economically attractive today and more applications will become attractive as battery prices drop.

For EVs and PHEVs, consumer barriers include the initial investment cost of the vehicle, uncertainty about the range of EV/PHEVs, lack of awareness and official information, lack of choice given the limited options available, and limited charging infrastructure. Automakers face a different set of barriers that include costs of production and inputs, technology integration and manufacturing issues, and regulatory uncertainty. Despite these barriers, battery costs are dropping rapidly. Current costs are roughly USD 500 to USD 700 per kWh and industry analysts expect these prices to drop to less than USD 400 per kWh within five years. Suggested metrics for tracking progress of battery technology include the *usable* (not total) energy of the battery, and the total or life-cycle cost of ownership, as opposed to just the initial cost of the battery.

Other barriers to deployment of energy storage technologies include the legal restrictions that may impede full storage asset utilization. At the state and federal levels, an asset is usually categorized as generation, transmission, or distribution. Regulated utilities which use ratepayer funds are not allowed to compete with generation assets that sell services on the open market. This is to prevent the regulated utility from exerting their financial advantage in a market-based service (cross-subsidization). This hinders the use of grid energy storage, which could potentially offer services in all three areas simultaneously, but is prevented from doing so (to avoid cross-subsidization).

Important Messages

Policy support must be consistent and sustained. Regulations drive action in this industry, but there is a lack of clarity in how energy storage services will be compensated, which is slowing deployment by utilities. This is an even larger factor when considering that deployment of today's applications will help accelerate the deployment of future applications beyond ancillary services. Renewable technologies such as wind and PV will depend on energy storage capabilities to achieve high levels of market penetration. Similarly, it is important to consider the perspective that vehicles are mobile energy storage resources. EVs and PHEVs have several useful properties within this scope, considering they work synergistically with other technologies; they are the only vehicles that get cleaner the longer they are on the road (as the grid gets cleaner); and PHEVs are neutral regarding liquid fuels (PHEV technology can run on gasoline, diesel, and biofuels). This is an opportunity to "future-proof" the transportation sector.

Key Actions to Address Barriers

Key solutions to address general energy storage barriers include improving the design of energy markets to compensate energy storage for its services to the grid, which would remove the uncertainty surrounding asset recovery. More robust regulatory structure is needed as well, along with funding for more large-scale deployment. The Federal Energy Regulatory Commission (FERC) Pay-for-Performance Rule is an example of a regulatory solution.[33] Market barriers for EV/PHEVs can be addressed by implementing progressive fleet fuel economy or emissions rules that favour EV/PHEV adoption and both financial incentives for EV/PHEV owners (e.g. point-of-sale rebates, tax credits, reduced registration fees, and reduced electricity prices for off-peak charging) and non-financial incentives (e.g. High Occupancy Vehicle [HOV] lane use, parking, and access to city centres). Addressing broader barriers to deployment of energy storage for other applications may require removing restrictions or creating mechanisms to facilitate full utilisation of these assets, potentially including contractual, competitive solicitations for grid functions, or transparent accounting of new storage assets.

Opportunities for Enhanced R&D Cooperation

Certain R&D opportunities are better suited for government to undertake. These may include systems-level approaches to create the proper environment for the technology to thrive, such as infrastructure, standards and protocols. However, more general opportunities exist for development of fast charge systems both for battery technology and charging infrastructure, and potential investigation of alternative vehicle architectures and/or business models. Given the limited use of vehicles during the day, if they offered another service while plugged in it would improve economics and accelerate adoption. The opportunities for broader applications of energy storage include R&D into new materials and energy storage architectures to reduce cost and improve reliability and lifetime. Demonstration projects that employ grid storage to solve specific local challenges may help the technology gain traction, but additional studies are necessary to quantify and demonstrate the benefits of grid energy storage to help identify structures for assets to be properly compensated. Studies must also focus on EV/PHEVs and the potential to offer grid services such as frequency regulation, renewable integration, and spinning reserves.

Benefits of Grid Energy Storage

The benefits are varied, and they provide a number of perspectives and potential measures for evaluating the progress of the technology. Benefits include allowing for the greater use of renewables; increased efficiency of fuel-burning plants in the form of reduced emissions; increased reliability and reductions in the need for backup generation; enabling of micro-generation; and maximisation of utilisation of other technologies and grid assets through synergies. Grid battery systems (GBS) also

[33] The Pay-for-Performance Rule will be implemented in 2012 and will provide higher payments to fast-responding assets to help reduce the amount of frequency regulation that is procured; thus reducing emissions.

essentially hybridize a power plant — GBS provides power as it discharges, and as the average output of the power plant is produced the GBS is charged by the power plant.

Energy Storage Discussion

Progress of Energy Storage Development and Deployment

Currently, energy storage technology is being deployed globally as batteries for EVs, PHEVs, and hybrid electric vehicles (HEVs). Non-vehicle applications of energy storage still need further efforts to advance the technology and increase deployment

Metrics for Monitoring Progress

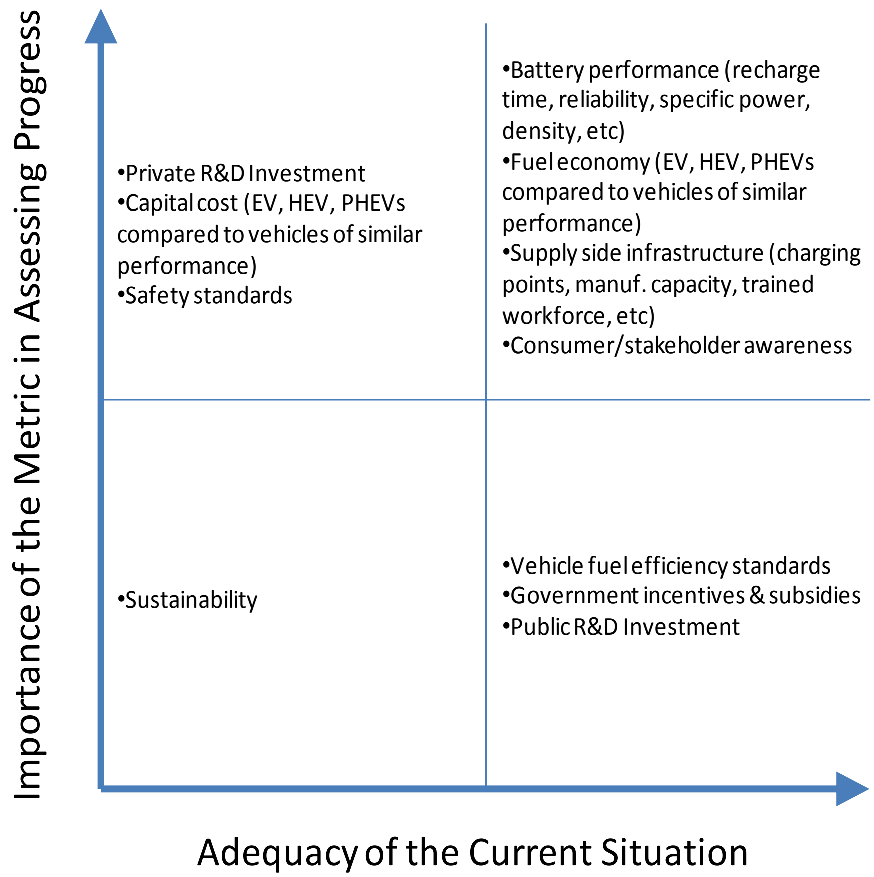
Important areas for expanded deployment of energy storage technologies, as described above, represent an opportunity to track leading indicators for energy storage technology deployment. These include the following:

- Sustainability of energy storage systems and components
- Weight of energy storage system or battery, which can be calculated from the performance metrics chosen as opportunities: specific energy, specific power, energy density, and power density
- Usable energy of the battery
- Life-cycle cost of ownership

Additional important areas for metrics are shown in the upper two quadrants of Figure 20, below.[34] The upper left quadrant shows the areas that are considered the most important in measuring progress, yet are currently the least adequate in their progress towards BLUE Map goals. These represent potential areas of focus for driving further progress. Private R&D investment in vehicle battery storage technologies is among the most important metric area for assessing progress, and one the least adequate. Conversely, public R&D investment is considered the least important area for assessing progress, and it is among the most adequate in its current situation. Public education (i.e. consumer/stakeholder awareness) is an important component in advancing energy storage technology, especially for passenger vehicles. Understanding the difference between conventional vehicles and hybrid, plug-in hybrid, and battery electric vehicle and the relative advantages or benefits of each is important in increasing adoption.

[34] Based on input received from a survey of EGRD workshop participants. See Appendix G.

Figure 20: Importance and Adequacy of Potential Metrics for Assessing Progress of Vehicle Battery Storage Technologies



Key Messages for Leaders

- Strengthen regulations and establish long-term policies that address emissions intensity (CO_2 per km) and tax incentives for vehicles and other applications
- Ensure sustained high levels of public and private funding for battery and energy storage system technology R&D
- Investigate the flexibility of energy consuming equipment in buildings (e.g. air conditioners, heat pumps, etc.) to ease the burden on energy storage to meet consumer and commercial needs

Opportunities for R&D Cooperation

- Develop fast charge systems
- Investigate the potential for EVs and PHEVs to offer auxiliary grid services such as frequency regulation, renewable integration, and spinning reserve
- Research systems-level issues surrounding the implementation of infrastructure, standards, protocols, and financial mechanisms for asset recovery
- Conduct basic research of new materials and energy storage architectures to improve reliability and longevity and reduce cost

- Conduct research on the effect on consumer behaviour of more stringent regulations promoting energy storage technology

Smart Grids

Russ Conklin, Policy Analyst, Office of Policy and International Affairs, U.S. Department of Energy

- Link to presentation slides

Key Takeaways: Smart grid technologies are developing rapidly, and deployment is underway and will continue. However, full deployment will take decades, the technologies may not be optimised to work together, and significant hurdles remain for greater deployment and optimal use of smart grids. Challenges and opportunities include the complex governance of the grid, acceptance among broad stakeholder groups, the longevity of grid infrastructure, cyber security, data management, and interoperability standards and conformance testing protocols. Smart grids represent a prime opportunity for cooperative R&D because of the requirements for interoperability across national boundaries and wide area monitoring and control.

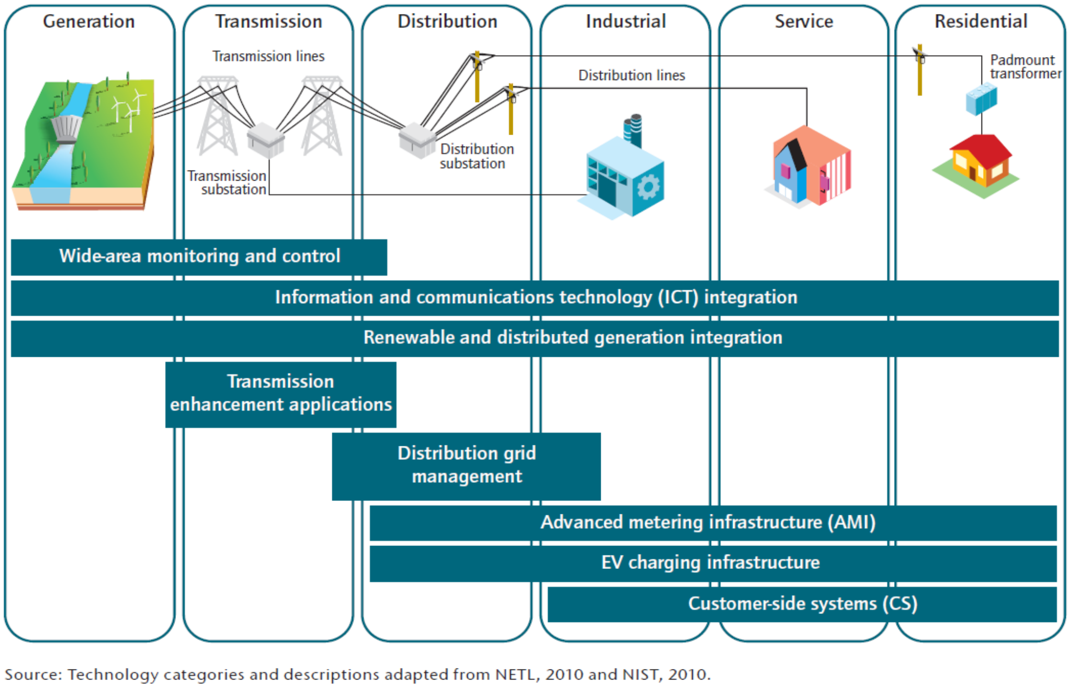
Progress Score:[35]

Very Unlikely	Unlikely	**Maybe (40 - 60%)**	Likely	Very Likely
		✓		

The term "smart grid" has taken on slightly different meanings in different regions. For example, the European Union definition focuses on the ability of an electric network to interact with users' actions and behaviours while the United States definition focuses on the underlying technological characteristics. Despite slight differences in definition, smart grid implementation incorporates a wide range of technologies that individually apply to different parts of the electricity generation and delivery infrastructure. Some developments, such as information and communications technology integration, span the entire range of the system, while others such as transmission enhancement applications, are focused solely on one step in the delivery process (Figure 21).

[35] The Progress Score is the technology area's estimated likelihood of BLUE Map goal attainment; according to results of a survey among EGRD workshop participants. See Appendix G.

Figure 21: Smart Grid Spans a Wide Range of Technologies and Services across the Entire Electricity System



Source: IEA *Technology Roadmap – Smart Grids,* 2011.

The International Smart Grid Action Network (ISGAN), one of the eleven initiatives launched at the 2010 Clean Energy Ministerial, is a mechanism for bringing high-level government attention and action to accelerate the development and deployment of smarter electricity grids around the world. Primarily, ISGAN sponsors activities that build a global understanding of smart grids, address gaps in knowledge and tools, and accelerate smart grid deployment while also building on the momentum of and knowledge created by the substantial smart grid investments already being made globally.

Current Outlook

The technology, as it stands in 2011, is ready for deployment. Indeed, the European Union has mandated 80% installation of advanced metering infrastructure by 2020; Japan and Korea are expected to reach full implementation by 2020; and the United States has reached 11% from near-term investments through the American Reinvestment and Recovery Act (ARRA). Furthermore, new technologies such as distribution automation equipment, phasor measurement units, EV charging infrastructure, and conservation voltage reduction are under development and being deployed. As reported in the IEA Technology Roadmap, development trends in many technology areas indicate fast rates of progress.

Although available technologies hold great promise, many high level challenges hinder expansion. First, the grid itself and the governance structures are complex and multi-layered, often limiting leverage at any one point in the system.

These structures can impact perception and allocation of benefits and costs; that is, vertically integrated structures where the utility can effect changes in generation, transmission, distribution, and retail will have different costs and benefits compared to unbundled structures where only the transmission and distribution activities are regulated. Another challenge is the breadth of the stakeholder group; in developed countries, everyone is affected by the grid. Updates to policy, regulation, and business models often lag technological innovation in part because of the longevity of electric infrastructure compared to the short lifespan of technologies in the ICT sector. Replacing retiring workers with those that have expertise in both power engineering and ICT skills will be a challenge in the next decade. And concerns over cyber security, data privacy, and data security must always be addressed.

With the rapid development and maturation of individual technologies, deployment has frequently progressed without harmonised interoperability standards and conformance testing protocols that would aid continued expansion. Moreover, with the implementation of individual technologies, the combined impact of a suite of technologies is not well understood. The vast amount of data that advanced metering infrastructure (AMI) will produce may help address some of these challenges, but large-scale data management is itself difficult. Lastly, the costs remain too high for many developing countries. For example, the costs of smart meter installation in the United States are not projected to fall below USD 160/meter; India’s target is USD 25/meter.

Opportunities for R&D Cooperation

Given the multifaceted challenges, several areas may be addressed through R&D cooperation. These solutions include testing the technologies, systems, and concepts across a range of technical and policy environments. The development of interoperability standards and conformance testing protocols would be well addressed through cooperation. Another high-potential area of R&D is grid modelling, analytics, and data management. Research is also needed to improve power electronics, materials, and conductors. Finally, as new technologies such as EVs and renewables scale-up, grid integration and system balancing will become more important.

Assessment and Metrics

A preliminary attempt to create metrics for measuring progress of smart grids might focus on monetary resources, technology and market readiness, market transformation, and impacts. However, the current status and growth potential of smart grids suggest that settling on one set of metrics now would be premature. Instead, countries and regions are determining their own metrics. In the European Union, 56 key performance indicators (KPI) have been developed around a rubric of “services” and “benefits” to define an ideal smart grid. That is, each benefit has associated KPIs (e.g. benefit: increased sustainability; KPI: quantified reduction of carbon emissions, environmental impacts of grid infrastructure, etc.), and each service is scored with respect to each KPI. In this manner, a total is determined not only for each service, but also for each benefit. In the United States, on the other hand, the ideal is defined in terms of “characteristics” and 20 metrics, classified as either “build” or “value” metrics, were laid out in the U.S. Department of Energy Smart Grid System Report. These build/value metrics are divided over four spaces: area coordination, distributed energy resources, delivery infrastructure, and information and finance. However, the metrics within each space measure deployment progress as opposed to something more comprehensive. An ongoing challenge for ISGAN, which is analyzing the relationships between core features of smart grids and enabling assets and technologies, is to develop a framework that applies to both developed and emerging economies.

Conclusions

Although the current progress is significant, and government projections expect large uptake by 2020, smart grid transformation is a multi-decade enterprise that will require much experimentation and "learning by doing." In general, one technology solution will not cover every need, so countries and regions will have to implement what works to address their priorities. That said, policy decisions will be better informed by shared (rigorously tested) frameworks, methodologies, and tools. The development of these shared resources has only just begun at the international level.

Smart Grids Discussion

Progress of Smart Grids Development and Deployment

Currently, some technologies are being widely deployed (i.e. smart meters), other technologies (i.e. distribution automation, and electric vehicle charging infrastructures) are ready for deployment, and nations around the world are implementing policies to accelerate market penetration.

Metrics for Monitoring Progress

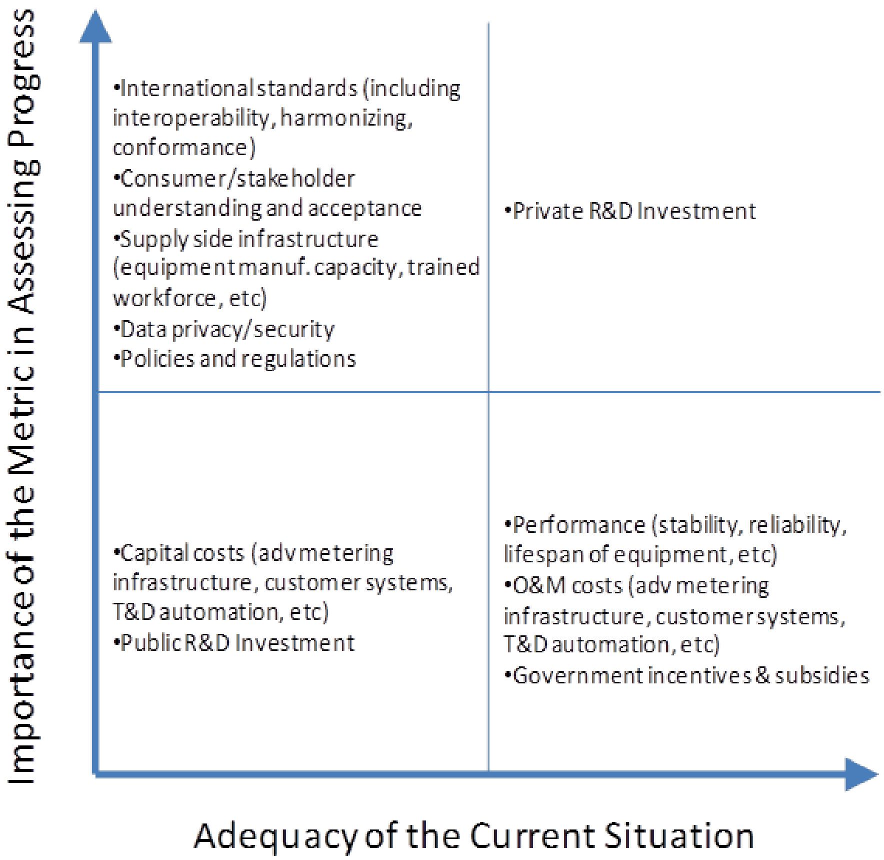
Important areas for tracking leading indicators for smart grid technology deployment include the following:[36]

- Private R&D
- International standards
- Capital costs
- Consumer awareness
- Data security and privacy
- Policies and regulations

A diagram of metrics areas and their current adequacy are shown in Figure 22. Only one of the most important metrics areas, private R&D investment, is considered adequate. International standards and supply side infrastructure are considered the least adequate in their current situation.

[36] Based on input received from a survey of EGRD workshop participants. See Appendix G.

Figure 22: Importance and Adequacy of Potential Metrics for Assessing Progress of Smart Grid Technologies



Key Messages for Leaders

- Focus efforts on developing regulations and assessing the benefits of harmonising international standards to accelerate smart grid deployment
- Estimate potential impacts of deploying a range of technologies based on national and regional priorities, instead of focusing on benefits from implementing technologies individually
- Emphasize the need for long-term policies and appropriate support, given the long time horizon for deployment and market transformation

Opportunities for R&D Cooperation

Smart grid technologies involve many interoperability issues, some of which will cross national boundaries. For this reason, R&D cooperation is especially important for smart grid.

- Developing interoperability standards and conformance testing protocols
- Test technologies, systems, and concepts across a range of technical and policy environments
- Conduct research on grid models, analytics, and data management, including research on optimal grid integration and system balancing

- Improve power electronics, materials, and conductors, including research on the longevity of electronic components and systems
- Develop and implement methods for sharing information and lessons learned from experiences in built environments and integration of electric vehicles

Metrics Frameworks for Measuring Progress

The BLUE Map scenarios perform a critical service by showing paths by which long-term environmental goals may be met. It is imperative to measure progress along those paths so that corrective measures can be implemented when a particular technology falls behind the progress necessary to meet those goals. There are many ways to assess progress; some are relatively easy, and others difficult. Some are very strong, reliable indicators, and others are relatively weak. Some enable us to forecast progress years into the future (leading indicators), and others look back into the past (lagging indicators). The third CEM is approaching, and it is a good time to take a long-term view and consider the universe of possible metrics that could be used to measure progress.

A metrics framework enables a long-term discussion of the different classes and attributes of metrics, so that the best possible sets of metrics are used to measure progress, and so that the sets of metrics may be continuously improved. It encourages systematic thinking about how to measure progress, and allows issues to be surfaced and debated. It forms the basis for progressively better definitions, data collection methods, and data analysis, and builds upon existing efforts of IEA and others.

Performance Metrics Framework: Synthesis and Opportunities to Add Value to the IEA Monitoring and Evaluation Process

John Peterson, Program Analysis and Evaluation, Department of Energy (United States)

- Link to presentation slides

Key Takeaways: Important criteria for performance metrics include understandable, relevant, complete, consistent, quantitative, accurate, timely, and feasible. Additional criteria for high priority metrics opportunities include strength as well as ability to forecast (leading vs. lagging).

Additional Performance Metrics Opportunities: Private R&D investment by technology, cost data by technology, performance data by technology, investor attractiveness data, (e.g. Ernst and Young country attractiveness indices).

Metrics Successes

The IEA regularly collects data that includes: public investment in R&D; deployment, generation, and production progress; end-use efficiency, deployment, and intensity; and data for several additional metrics from member countries and other nations when possible. This year has seen a significant expansion of countries and metrics for which data is being gathered. However, there are many differences between the countries' approaches to metrics and fostering energy technology progress and some metrics are difficult to collect. In addition, some metrics may require multiple years in order to improve the collection methodology and data availability.

Objectives for this meeting include providing informed input to ETP2012 and the chapter on Technology Progress that will be previewed at the next CEM in London in April 2012. Long-term objectives from this meeting will focus on contributing to an enhanced framework of metrics for routine monitoring and measurement of technology progress towards ETP BLUE Map goals. The Performance Measurement Framework (PMF) specifically is meant to enable a discussion of optimal metrics strategy to work towards a long-term integrated set of metrics that will foster improvements in clean energy technology progress monitoring. We will begin by identifying high-priority metrics based on specific criteria, investigate the background, definitions, and limitations of these metrics, and discuss possible initiatives for improving metrics.

Performance Metrics Framework (PMF)

The PMF currently has initial metrics outlined for 14 technology areas grouped into five classes. This initial metrics selection included high priority metrics as well as additional target metrics. Further efforts are needed to refine the metrics and priorities and formulate a proposal to the Secretariat. The criteria for framework metrics assess the quality of a metric based on several key characteristics (e.g. completeness, relevancy, accuracy, quantitative, etc.). From these metrics, high opportunity metrics were selected based primarily on three criteria:

1. The degree to which a metric accurately/reliably indicates technology progress (strength)
2. The degree to which a metric forecasts technology progress into the future (leading vs. lagging)
3. The degree to which IEA does not already collect and analyze the metric.

Other factors considered include the data availability, potential for comparison with BLUE Map, and accuracy and precision. Excluded from consideration at this stage was the difficulty of collecting the data, because this is a long-term process, and we may discover new ways to obtain some high opportunity metrics.

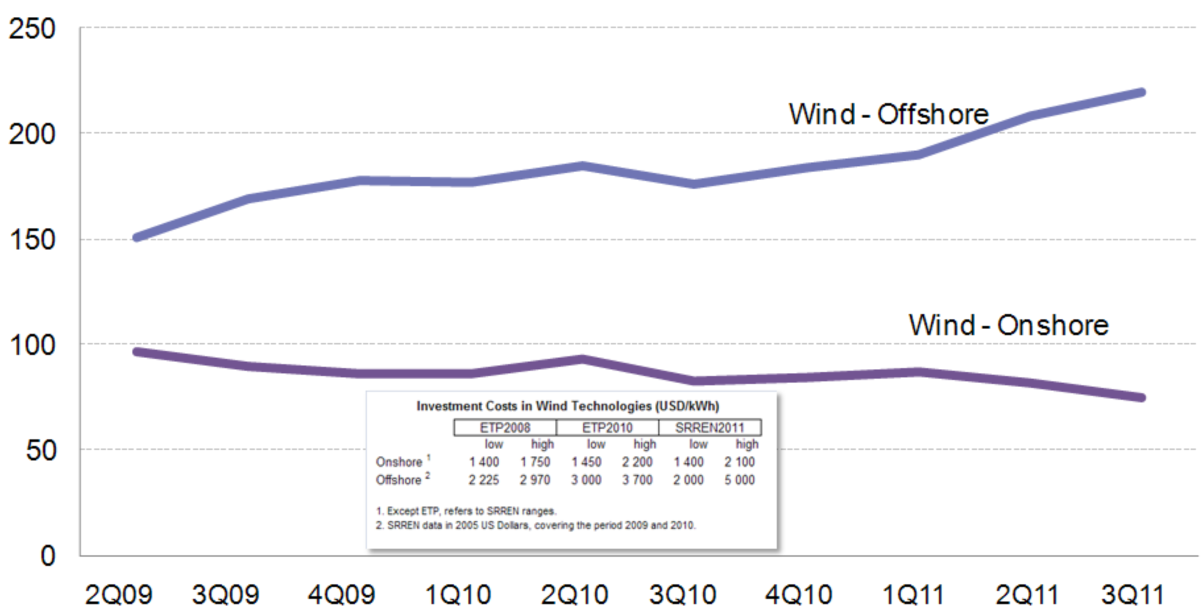
The PMF classes aim to capture the progress of the technology through various stages of development. The classes are: Resources, Technology Readiness, Market Readiness, Market Transformation, and Impacts. Each class relies upon a number of metrics that measure progress toward the goal of reducing CO_2 emissions through increased adoption of clean energy technologies. A metric may be a leading or lagging indicator of progress. For example, leading metrics identify trends that indicate future progress towards the goal, such as Resources metrics (i.e. R&D funding), while others measure progress that will yield more medium-term progress towards the goal, such as Technology Readiness metrics (i.e. cost and performance improvements) and Market Readiness metrics (i.e. policy support and market infrastructure). Market Transformation and Impacts include lagging metrics, which measure progress in the past. Sometimes lagging metrics have the most accurate, easiest-to-obtain data.

Important Considerations

Some metrics are especially difficult to obtain and interpret. Private investment in R&D is one of the most difficult to obtain, for reasons that are well documented. Publicly-owned companies and private companies report a limited amount of information about R&D expenditures, if reporting anything at all, and tend to report a single aggregate estimate of R&D expenses without the level of granularity that is needed to track data for each technology in the various stages of development. Many private companies consider their R&D expenditures to be proprietary information that competitors must not be allowed to know. The limited information on R&D contrasts with the more widely available, publicly reported information on demonstration and deployment. However, this metric is extremely important, as private R&D investment rivals public R&D investment in size, may be more effective, and even partial insight would greatly help governments better prioritize scarce public R&D funds. An interesting recent development was the partnership of UNEP with Bloomberg to obtain private R&D investment numbers. Public-private partnerships may help reassure companies that their data will be held in confidence, and only released in summary form, combined with many other companies.

Technology cost data is another difficult area. Climate/technology models typically assume gradually-declining costs, frequently determined using learning curves. However, actual costs sometimes rise, as shown by historical cost estimates for Wet FGD and SCR scrubbers. The actual costs for most generation technologies appear to have risen or stayed the same over the last several years, based on LCOE estimates from Bloomberg, and comparisons of capital costs from ETP2008, ETP2010, and SRREN studies. This may be influenced by the increases in steel and cement prices of 2-8% during this period. The price rise was especially high for offshore wind and CCS-related technologies (Figure 23).

Figure 23: Levelised Cost of Electricity (LCOE) for Wind Technologies (nominal USD/MWh), 2009-2011



	ETP2008		ETP2010		SRREN2011	
	low	high	low	high	low	high
Onshore [1]	1 400	1 750	1 450	2 200	1 400	2 100
Offshore [2]	2 225	2 970	3 000	3 700	2 000	5 000

Source: Bloomberg New Energy Finance.

Most data comes with uncertainty. There are ways of dealing with uncertainty/variability in data, and we need to acknowledge the uncertainty and factor that into our analysis, even if we start with simple ways.

Innovative metrics should also be considered, such as indices used for private investment decisions. An example of this is the Ernst and Young Country Attractiveness Indices. There is an index for each major generation technology, including separate indices for solar PV and solar CSP. The indices take into account a number of factors, including Power Off-take Attractiveness (includes cost of generation), Tax Climate, Market Growth Potential, Resource Quality, etc. There are explanations on the web site of the main considerations leading to specific scores. Investors can use them to select a set of countries to investigate for possible generation projects. These metrics do not fit well into the Performance Metric Framework because they are a rollup of many other metrics; however, they may be useful to spur countries to improve their clean energy attractiveness by pointing out the specific factors that discourage investors.

The highest priority metrics opportunities include private R&D investment by technology, cost measures, especially for non-generation technologies (i.e. HVAC costs and efficiency; hybrid and electric vehicle cost and savings metrics), and technology performance metrics, such as the battery technology metrics identified in the Vehicle Batteries Table. Forward-looking efforts would benefit from identifying a small set of high-priority metrics; clearly documenting methodology, assumptions, and definitions; developing a strategy for data collection; and presenting these to the IEA to help future data collection efforts and high-level analyses.

The most effective Performance Metrics Framework will be based on a comprehensive set of strong progress metrics that give insight into R&D progress and probable future deployment. The PMF should make use of public and private data, along with IEA research, to bring the maximum amount of insight to the progress report in a way that effects changes in investments and helps achieve greater global deployment of clean energy technologies.

European Union SET-Plan -- Monitoring and Review Framework

Estathios Peteves, Joint Research Centre Institute for Energy, European Commission

- Link to presentation slides

The European Strategic Energy Technology Plan (SET-Plan) is the technology pillar of the EU Energy & Climate Change policy and is a priority for the EU 2020 Energy Strategy. The objective of the SET-Plan is to accelerate the development of low-carbon technologies, leading to their market uptake, while maintaining a firm commitment to position the European industry in a leading role in the transition to a low-carbon economy. The SET-Plan envisions joint strategic planning (between the EU Member States and the EC facilitated by a Steering Group and assisted by the SET-Plan Information System [SETIS]), effective implementation of key initiatives (i.e. European Industrial Initiatives, European Energy Research Alliance, and Trans-European Energy Networks and Systems of the Future), increasing the availability of financial and human resources, and reinforcing international cooperation. The goals of SETIS are the following: to provide a robust, technology-neutral planning tool which reflects the technologies' current state of the art, anticipated technological development, and market potential; to monitor the progress of SET-Plan activities towards their objectives, and to assess performance and cost-effectiveness of SET-Plan activities. The European Industrial Initiatives (EII) implement the SET-Plan in a number of prioritised technology areas that include wind, solar, bioenergy, CCS, the energy grid, fission, smart cities and communities, and fuel cells and hydrogen.

Monitoring and Review

Monitoring and review takes place as a two-stage process consisting of performance assessment of the EII implementation and impact analysis of the implementation state. Monitoring occurs at the EII level, focusing on R&D investments and progress of projects and activities using KPIs, while assessment occurs at the SET-Plan level, focusing on technology progress, and at the EU level, focusing on policy impacts. The monitoring and assessment help to prioritise, identify needs, target revision, and share knowledge. The KPIs represent an essential tool kit for monitoring and reviewing EII progress. Overarching KPIs (i.e. Levelised Cost of Electricity, EUR /MWh or CO_2 avoidance cost EUR /tonne of CO_2) measure the progress of each EII towards meeting its strategic objectives and are calculated based upon second-tier KPIs (i.e. cumulative installed capacity, MW or plant efficiency, percentage, and so on) which measure progress at the project level. KPIs are incorporated into the Implementation Plans (IPs) and have been redefined and quantified (based on joint analytical work) to form the first generation of KPIs that focus on ongoing and future R&D activities. The first-generation KPIs are the result of joint efforts between the EII leads and the Commission (SETIS), and the work has been presented, discussed, and agreed upon with the EII teams. It is important to consider the underlying assumptions of the KPIs that include technology, economic, and other assumptions, as well as the distinction between internal costs of the project (i.e. internal grid integration, construction of the plant, and so on) and costs imposed by external factors (i.e. permitting costs, external grid integration, and other factors).

KPIs for CCS, Wind, and Solar

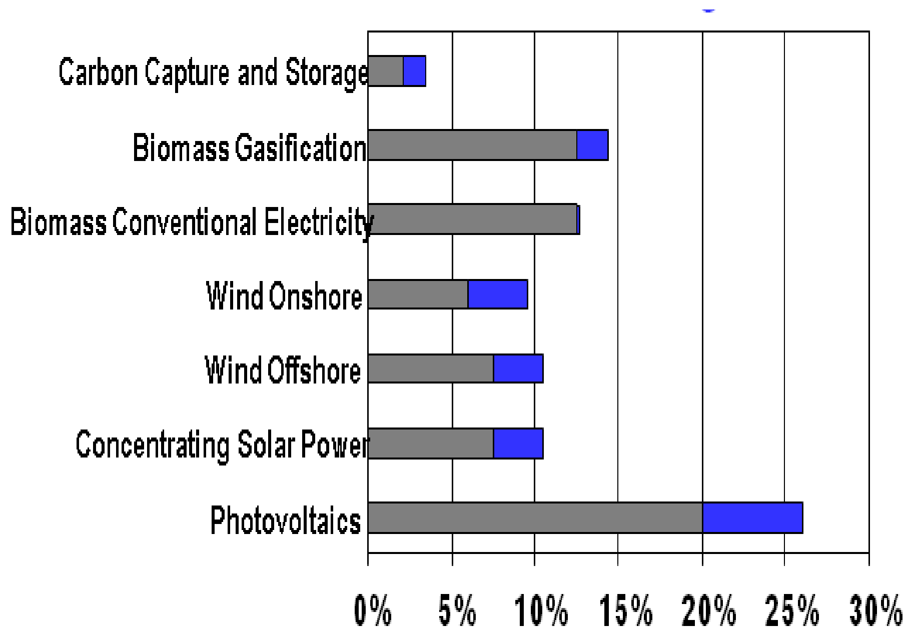
For example, the overarching KPIs for CCS include LCOE or industrial product (EUR /MWh or EUR /t) and CO_2 avoidance cost (EUR /t CO_2). There are numerous second-tier KPIs under various categories that include annual CO_2 avoided (percentage), cumulative CO_2 stored (Mt), instances of CO_2 moved out of designated volume, and quantity of CO_2 moved out of designated volume. These are examples of useful metrics that can provide valuable information concerning the technical and deployment progress of a particular technology.

Detailed information about how the KPIs were calculated, and other second-tier KPIs, can be found on the SETIS website (http://setis.ec.EUR opa.eu/activities/eii-key-performance-indicators).

Assessment/Quantitative Impact of SET-Plan

A model-base impact assessment is used to estimate the change in technology investment costs of SET-Plan priority technologies after accelerated R&D efforts are implemented, and the ability of SET-Plan-driven increases in R&D investments to help the reduce costs of achieving European energy and climate targets and spur deployment of new technologies into the market. The benefits of the SET-Plan can be seen from the significantly accelerated technology learning as seen in Figure 24. Also, the net benefits of the SET-Plan show a 15% internal rate of return over the 2010-2030 period. KPIs for the other areas of EII, including fuel cells and H_2, will be concluded by the end of 2011. EU-funded projects will be required to demonstrate their link with the KPIs and to report progress, while ongoing efforts will work to advance the monitoring framework.

Figure 24: SET-Plan Effect: Increased Learning Rates



Synthesis and Conclusions

The rate of progress of clean energy technology development and deployment varies across technologies, but overall, progress is not keeping pace with the BLUE Map scenario goals. Additional progress is needed — and achievable — across the spectrum of clean energy technologies. The types of efforts underway are on the right track, including technological and policy advances which are reducing costs and increasing deployment for certain technologies, but progress must be accelerated. Solar PV and wind technologies, for example, are considered two of the most likely technologies for meeting the BLUE Map targets, though a great deal of uncertainty remains as to whether even these technologies will ultimately achieve the BLUE Map goals. In addition, while renewables are expanding, the deployment of fossil based energy technologies continues to outpace renewables. Sustained, predictable, and even enhanced policy drivers (e.g. regulations, mandates, and subsidies) and significant sustained investment, both public and private is needed to accelerate progress and to achieve the goals envisioned by the BLUE Map targets for renewables, as well as, other clean energy technologies, such as high efficiency- low emission coal and CCS.

In many countries, some degree of policy retrenchments appears to be underway. This is attributable, in part, to poor economic conditions, changing governments, and unrealistic earlier forecasts of clean energy progress. As a result, recent increases in the rates of progress may potentially be impacted. For example, while policies and incentives are attributed to the growth in renewables, the possibility of phasing out subsidies that encouraged these investments and the adoption of certain clean energy technologies such as solar and wind may be jeopardised.

Of the many challenges facing accelerated deployment, a major factor is the increased cost associated with clean energy technologies. As long as there are subsidies for traditional fossil fuel technologies or a lack of a price on carbon, clean energy technologies will not be cost competitive. Costs are not declining as rapidly as assumed by the BLUE Map scenario; in fact they are increasing for many clean energy technologies. While many technologies' costs increased slightly, some technologies, such as offshore wind, had large increases in cost. The adoption of renewables, as well as other clean energy technologies such as CCS, will incur increased cost, and will not progress without clear policy assistance that the private sector can rely upon when making investment decisions. This should include considerations of transitioning subsidies away from traditional fossil fuels technologies and towards supporting renewable and high efficiency- low emission coal and carbon capture and storage (CCS), as well as considerations of setting carbon prices at a level reflecting the costs to address climate change. For all clean energy technologies, clarity and predictability could be enhanced by including insight into how policy support will change over time (i.e. decrease or be phased out).

Opportunities for R&D Cooperation

There are several cross-cutting opportunities for enhanced clean energy technology research and development (R&D) efforts to address areas projected to fall short of the BLUE Map scenarios, including the need to: (1) drive down cost (e.g. the cost of materials, CO_2 capture); (2) improve efficiency (e.g. PV solar, battery storage); and (3) enhance system integration (e.g. buildings; intermittent renewable energy into the grid). Specific areas for R&D cooperation include the following:

- Solar PV: low-cost sustainable materials, grid integration at systems level, and advanced storage
- Wind: offshore wind technologies, advanced materials (e.g. foundations, turbines), storage, and grid design and integration
- Bioenergy: feedstock supply and upgrading, and integrated biorefineries
- CCS: cost-effective advanced capture technologies, transport and underground storage modelling, characterisation of storage potential and competing uses, monitoring tools, scale-up, CO_2 usage, and sharing intellectual property
- Buildings: systems integration approaches, and standards and codes
- Appliances: rebound effect, coverage of standards and labelling, and advanced appliances systems
- Energy Storage–Vehicle Batteries: fast charge systems integration of EVs with grid energy services, new materials and energy storage architectures, and studies establishing the benefits of ancillary services that could be provided by vehicle batteries
- Smart Grids: interoperability standards and conformance testing protocols, cyber security, common frameworks, tools, and methodologies, and the advancement of many individual technologies

Smart grids present a special opportunity for international cooperative R&D. There will be a host of cross-border issues and required standards, including wide area monitoring and control standards. Smart grids would benefit from common tools, frameworks, and methods.

Progress will also benefit from the sharing of implementation tool kits for siting and winning local acquiescence. Such a targeted action item is not currently addressed by coordinated international technology initiatives under the Clean Energy Ministerial. Other opportunities could include initiatives to develop a better understanding of alternative technology deployment scenarios as compared to the BLUE Map scenario. These would reflect an array of intermediate paths, would be linked to IPCC-based consequences, and would begin to articulate the costs and benefits of various courses of action and/or inaction. Another opportunity for progress is to conduct coordinated reviews of existing barriers for each technology with associated actions to address priority cost-reduction and policy enhancement options (e.g. via technology push, market pull, and non-technical policy solutions).

Public outreach and education remains a key issue for enhanced deployment of clean energy technologies. Understanding the risks, costs and benefits of adopting clean energy technologies is fundamental to enhanced deployment, whether the issue is related to the siting and permitting of a new power generation facility onshore or offshore, a carbon storage facility, or the adoption of energy efficient buildings, appliances, or vehicles.

In addition, several common policy issues could accelerate progress if successfully addressed. Policy actions could be pursued to reconcile the cost differential between clean energy technologies and fossil technologies. Possible actions include sustained, predictable, and enhanced policies and incentives to facilitate the uptake of clean energy technologies into energy systems, establishing an explicit price on CO_2 emissions, and phasing out subsidies for traditional fossil fuel technologies. However, these approaches face real implementation challenges. Perhaps the most effective approach to addressing the cost differential and reducing the cost of clean energy technologies is for enhanced investment and international collaboration in energy technology research, development, and demonstration. As mentioned earlier, these efforts have proven successful in dramatically improving performance and lowering the cost of technologies.

Further analysis is needed to adequately measure progress, characterise consequences, and identify alternative scenarios to increase use of technologies that are making progress, and compensate for those that are not.

Contributions towards Developing an Enhanced Framework of Metrics

IEA already collects and analyses a large set of the most important metrics. However, some metrics are difficult to capture and may require multi-year efforts to improve methodologies and mechanisms in order to enable successful collection. Other metrics may require additional resources or care, but may be worth those resources due to a combination of reliability, ability to forecast into the future, and other characteristics. Private R&D expenditures, technology cost data, and technology performance data are broad areas of opportunity to develop meaningful progress metrics. These areas exhibit favourable characteristics for performance metrics, to the degree that the metric area:

1. Accurately forecasts progress
2. Represents a leading indicator (measurement of future impact)
3. Is not already being measured and analyzed by IEA

Appendix E provides a detailed summary of selected areas of opportunity in three tables — one each for generation technologies, end use technologies, and cross-cutting technologies. These opportunities can be applied across all technology areas examined.

Private R&D expenditures are one of the most leading indicators, forecasting impacts several years into the future, and sometimes as far as 10-15 years into the future. The timeframe varies with the nature of the R&D expenditure, with basic research taking the longest to have an impact and late-stage development or demonstration being much shorter. Private R&D spending is classified as somewhat less leading than public R&D expenditures because public R&D expenditures tend to have a greater component of basic research. Not all R&D investments pay off, but higher investment will tend to bring greater and more certain benefits. In addition, this data would be very useful to countries when setting priorities for public R&D investment. Even partial data on private R&D can bring significant benefits if its scope is defined properly. Private R&D expenditures are not routinely measured due to the difficulty of obtaining the data; however, there are multiple possible methodologies from which to choose, and public-private partnerships, such as the recent UNEP/Bloomberg study, are a promising development. One of the roadblocks to getting data on private R&D is the reluctance of private companies to disclose data they consider proprietary and do not want their competitors to know. Public-private partnerships allow added flexibility to assure companies that their data will be held in confidence.

Cost metrics are another area of opportunity, and they are a very strong indicator of technology progress. IEA frequently gathers these metrics, but not necessarily for all technologies, especially for non-generation technologies.

Technology performance metrics, including efficiency for solar panels and energy and power density for batteries, are beneficial in that higher performance can justify a corresponding cost premium. These metrics accurately forecast progress, as they measure the most important aspects of a technology's suitability. They are also more leading than generation or installed capacity, forecasting the likelihood of additional capacity being installed several years into the future. They can be more leading than cost metrics, depending on whether the performance is measured for current commercial products or for test models. IEA gathers some technology performance metrics; EGRD recommends a small set of performance metrics for each technology.

Surveys filled out by workshop participants support these priorities. According to the survey results, the most useful solar PV metrics would be technology performance, capital cost, and private R&D expenditures. The most useful wind metrics were deemed to be grid integration (of particular importance for wind), capital cost and LCOE, and technology performance.

Another area of opportunity is data used by private investors to identify energy investment opportunities, such as the Ernst and Young Country Attractiveness Indices. This type of data analyses the policy, resource quality, public support, and other areas to rate the attractiveness of each of more than 30 countries for each energy technology. Detailed write-ups could point out the reasons for the scores, which would motivate countries to remove barriers to deployment.

Data for private R&D expenditures are particularly difficult and time-consuming to collect. Additional resources beyond those currently available to IEA for ongoing data collection efforts may be necessary to collect and analyse these additional metrics. Public-private partnerships may prove useful in pursuing metrics that are difficult to obtain.

Conclusion

While overall progress in the development and deployment of clean energy technologies to avoid the serious consequences of climate change and meet expanding global energy needs, as defined by the IEA 2010 ETP BLUE Map Scenario to 2050, is not being met under current domestic and international policies and market conditions, a number of actions can be taken to accelerate progress. The current monitoring framework is useful, but can be made more comprehensive, more indicative of future trends, and augmented by meaningful additions of data, particularly from the private sector.

These workshop findings are presented for further consideration by the IEA Committee on Energy Research and Technology (CERT), the IEA Secretariat working on ETP2012, and the member countries of the Clean Energy Ministerial for possible action, individually or collectively, as a means for being better informed of progress and accelerating pace of clean energy development and deployment.

Appendix A: Agenda and Meeting Rationale

AGENDA

Day 1

9:00		Welcome - Introductions - Meeting Objectives	*Rob Kool, Chair, Expert's Group; Manager, International Sustainable Development, NL Agency (Netherlands)*
9:15		Opening Remarks	*Amb. Richard Jones, Deputy Executive Director International Energy Agency*
MONITORING MILESTONES AND PROGRESS			
9:30	1	IEA Tools and Analysis to Accelerate the Clean Energy Technology Revolution: *Energy Technology Perspectives* 2012	*Lew Fulton, Head, Energy Technology Policy International Energy Agency*
10:00	2	Monitoring and Evaluating Progress in Developing and Deploying Low-Carbon Technologies: *Energy Technology Perspectives* 2012 Progress Tracking	*Antonia Gawel, Analyst, Energy Technology Policy International Energy Agency*
10:30		Break	
11:00	3	Developing a Framework For Monitoring Progress: Challenges and Opportunities	*Robert Marlay, Director, Climate Change Policy and Technology, Department of Energy (United States)*
11:45	4	Energy Technology Perspectives, BLUE Map Scenario: Goals, Targets, and Assumptions	*Uwe Remme, Analyst, Energy Technology Policy International Energy Agency*
12:30		Lunch	
ENERGY SUPPLY TECHNOLOGIES			
Moderator: Birte Holst-Jorgensen			
14:00	5	Solar PV and Concentrating Solar Power	*Wim Sinke , Programme & Strategy Solar Energy, Energy Research Centre of the Netherlands*
14:45	6	Wind Power	*Birte Holst-Jorgensen and Sascha Schroeder, Systems Analysis, Risø DTU National Laboratory for Sustainable Energy (Denmark)*
15:30		Break	
16:00	7	Biofuels and Biomass Power	*Josef Spitzer, Professor, Graz University of Technology, Member (Austria). Bioenergy*
16:45	8	a) Geological CO2 Sequestration: Prognosis as a Clean Energy Strategy b) CO2 Capture and Separation: Technology Costs and Progress	*Fedora Quattrocchi , Geological Storage & Geothermics, INGV University Tor Vergata* *Charles Taylor, National Energy Technology Laboratory, Department of Energy (United States)*
17:30		Close Day 1	

AGENDA
Day 2

DEMAND SIDE TECHNOLOGIES			
Moderator: Herbert Greisberger, Austrian Energy Institute			
9:00	9	Energy Efficient Buildings -- Focus on Heating & Cooling Equipment	*Rod Janssen, Head, Buildings, European Council for an Energy Efficient Economy (France)*
9:45	10	Energy Efficient Residential Appliances	*Frank Klinckenberg, Klinckenberg Consultants (Netherlands)*
10:30		Break	
CROSS CUTTING TECHOLOGIES			
Moderator: Ugo Farinelli, Italian Association of Energy Economics			
11:00	11	Energy Storage - Batteries	*Dr. Andy Chu, Vice President, Marketing and Communications, A123 Systems*
11:45	12	Smart Grids	*Russ Conklin, Policy Analyst, Office of Policy and Intl. Affairs, Department of Energy (United States)*
12:30		Lunch	
EFFECTIVE ROLLUP, BENCHMARKING AND COMMUNICATINGTHE RESULTS: CHALLENGES AND OPPORTUNUTIES: Reflection, Discussion and Next Steps			
Moderator: Bob Marlay, U.S. Department of Energy			
13:30	13	Performance Metrics Framework: Synthesis and Opportunities to Add Value to the IEA Monitoring and Evaluation	*John Peterson, Program Analysis and Evaluation, Department of Energy (United States)*
14:15	14	European Union SET-Plan -- Monitoring and Review Framework	*Estathios Peteves, Joint Research Centre Institute for Energy, European Commission*
15:00		Break	
15:15	15	Open Discussion – With the goal of providing a *Workshop Report* and timely input to IEA, first, for the CEM Progress Report and, second, for a longer-term framework of enhanced progress monitoring metrics, what have we learned regarding the Questions shown in the Meeting Rationale (below).	*Moderator, with Members of the EGRD and Guests*
17:00	16	Wrap-Up, Summary, and Next Steps	*Moderator, and Craig Zamuda, Office of Policy and International Affairs, Department of Energy (U.S.)*
17:15	17	Workshop Conclusion	*Rob Kool, Manager, International Sustainable Development, NL Agency (Netherlands)*
17:30		Close	

MEETING RATIONALE

IEA member countries agree that future global energy systems must meet rapidly expanding energy needs. They also agree that the community of nations, collectively, must avoid the most serious consequences of climate change by significantly reducing future greenhouse gas (GHG) emissions.

Meeting these goals is not just daunting from a technology perspective, but an urgent matter of timing. Visualization of this urgency may be realized by examining a range of GHG-constrained scenarios by the International Energy Agency's report on Energy Technology Perspectives (ETP). The ETP Blue Map scenarios to 2050 outline the scope and pace of the energy technology transformation required -- how much and by when. Such scenarios may be useful as comparative benchmarks for measuring and evaluating progress toward clean energy technology development and deployment goals.

In April 2011, the IEA released its first Progress Report as input to the 2011 Clean Energy Ministerial. Building on this work, the IEA is enhancing this analysis as part of its ETP2012 publication. An early release of this work will serve as input to the next Clean Energy Ministerial (CEM3) meeting, to be held in London in April 2012. The Report will discuss, in part, the extent to which technologies are matching the scope and pace of clean energy development and deployment, as suggested by IEA's Energy Technology Perspectives 2010 (soon to be updated to ETP2012).

It is envisioned that the Report will include an integrated framework of metrics on key technologies that, when juxtaposed with scenarios and underlying modelling assumptions, could serve as a set of leading indicators for R&D planners. The metrics could document technology status and trends in readiness improvement. Comparisons to baselines, such as the ETP Blue Map scenarios, could indicate areas needing attention. When combined with expert opinion and technical foresight, they could suggest opportunities for IEA and CEM member countries' actions, individually or collectively. The IEA's Expert Group on Energy R&D and Priority Setting (EGRD) hopes to contribute to this IEA effort.

Scope

On 16-17 November 2011, EGRD will convene a workshop of invited experts to facilitate the development of a set of metrics for monitoring, evaluating and effectively communicating historical and recent progress on technologies important to the success of the Blue Map scenarios. Technologies will be selected from a list of 14 found among CEM and IEA interests, and include supply, demand, and cross-cutting and/or enabling technologies.

Using metrics, and comparing them to ETP Blue Map scenario output data and underlying modelling assumptions, experts on specific technologies will be asked to assess progress, estimate the likelihood of meeting Blue Map deployment goals by 2050, identify barriers to progress, and suggest opportunities for action.

As an Experts Group on R&D Priority Setting, particular emphasis will be given to opportunities for accelerating technical progress and cost reductions. The workshop would build on previous work of the IEA and EGRD and involve, if possible, selected experts from the IEA energy technology network (Working Parties, Experts' Groups, and Implementing Agreements). Outputs from the workshop will be presented to IEA in a timely manner, leading up to the April 2012 Clean Energy Ministerial.

For the longer-term, the EGRD will synthesize outputs from the workshop and propose a systematic, integrated framework of metrics and leading indicators for use in the future by IEA and member country R&D planners.

For each of the technology areas examined, questions to be addressed by each technology expert include:

Objective 1 -- Input to Progress Report:

Compared to ETP BLUE Map scenarios, from present day to 2050, which technologies appear to be making progress as expected, and which are not?

What are the major barriers to inhibiting greater development and deployment? Can these be characterized by categories, such as: (a) policy; (b) socio-economic; and (c) technical and/or cost?

What would be the most important messages for the audience (IEA Member Countries, Clean Energy Ministers, etc.)?

What are the most important actions that IEA Member Countries might take to address barriers?

For technical and cost-reduction barriers, what are the most fruitful areas or opportunities for enhanced R&D cooperation to address technologies that are not progressing as expected?

Objective 2 – Enhanced Metrics Framework

What metrics are most meaningful and indicative of progress, and can they form a real-time set of leading indicators that would signal need for action.

What are the elements of an effective, integrated framework for monitoring, evaluating and communicating progress on key technologies?

What lessons can be learned from the private sector, or from public-private partnerships in monitoring progress on technology development and commercialization?

What approaches are most effective in communicating results to inform decision-making, feed into the prioritization or restructuring of research investments and related policies, and achieve desired outcome?

Target Audience

In addition to EGRD national experts, we are seeking input from RD&D decision-makers, strategic planners, and programme managers concerned with global progress on clean energy technology development and deployment.

Appendix B: Workshop Participant List

First Name	Last Name	Affiliation
Makoto	Akai	National Institute of Adv. Industrial Science and Technology (Japan)
Vanda	Caetano	National Laboratory for Energy and Geology - LNEG (Portugal)
Andrew	Chu	A123 Systems
Russell	Conklin	Department of Energy (United States)
Ugo	Farinelli	Italian Association of Energy Economics
Lewis	Fulton	IEA
Antonia	Gawel	IEA
Herbert	Greisberger	Austrian Energy Institute
Sylvain	Hercberg	EDF (France)
Birte	Holst	Risø DTU (Denmark)
Rod	Janssen	Independent consultant
Richard	Jones	IEA
Frank	Klinckenberg	Independent consultant
Rob	Kool	NL Agency (Netherlands)
Teresa	Leao	National Laboratory for Energy and Geology - LNEG (Portugal)
Jun	Li	International Research Center on Environment and Development
Robert	Marlay	Department of Energy (United States)
Jesús García	Martín	Iberdrola Distribution
John	Peterson	Department of Energy (United States)
Stathis	Peteves	European Commission Joint Research Centre
Carrie	Pottinger	IEA
Fedora	Quattrocchi	National Institute of Technology (Italy)
Uwe	Remme	IEA
Sascha	Schroeder	Risø DTU (Denmark)
Wim	Sinke	Utrecht University
Peter	Slobodian	Dept. of Resources, Energy and Tourism (Australia)
Benjamin	Smith	Nordic Energy
Josef	Spitzer	Graz University of Technology (Austria)
Charles	Taylor	U.S. National Energy Technology Laboratory
Ludwig	Vandermaelen	Federal Public Service Economy (Belgium)
Mike	Walker	Dept. for Environment, Food and Rural Affairs (United Kingdom)
Craig	Zamuda	Department of Energy (United States)

Appendix C: BLUE Map Scenario Data

Introduction

In preparation for the EGRD meeting, the U.S. Department of Energy compiled a data package for the EGRD meeting speakers so they would have quantifiable metrics against which they could judge technology progress. The data are drawn from several sources, but mainly from IEA's Energy Technologies Perspectives (ETP) work for 2010 and the BLUE Map scenario used in that work. The BLUE Map scenario focuses on a number of key technologies and illuminates the kind of progress necessary for each to meet global goals for greenhouse gas reduction by 2050.

The data was interspersed with questions to the speakers regarding technology progress. This appendix provides an explanation of the BLUE Map scenario and contains the data that was provided to the EGRD meeting speakers. No ETP2012 data was available at the time; all the data in this appendix is ETP2010 data, or unofficial estimates based on ETP2010 data.

The BLUE Map scenario assumes certain policy and technology advancements that result in worldwide reduction of CO_2 emissions by 2050 to half the 2005 levels. Under the BLUE Map scenario, global final energy demand (all forms of energy) grows to about 10,000 MTOe/year, or about 25% higher than that of 2007. Global electricity demand grows to a total of about 37 PWh per year; the average annual growth rate is 1.8%. These demands are respectively about 4 500 MTOe/year and 6 PWh/year lower than ETP's Baseline case in 2050, due to various efficiency improvements.

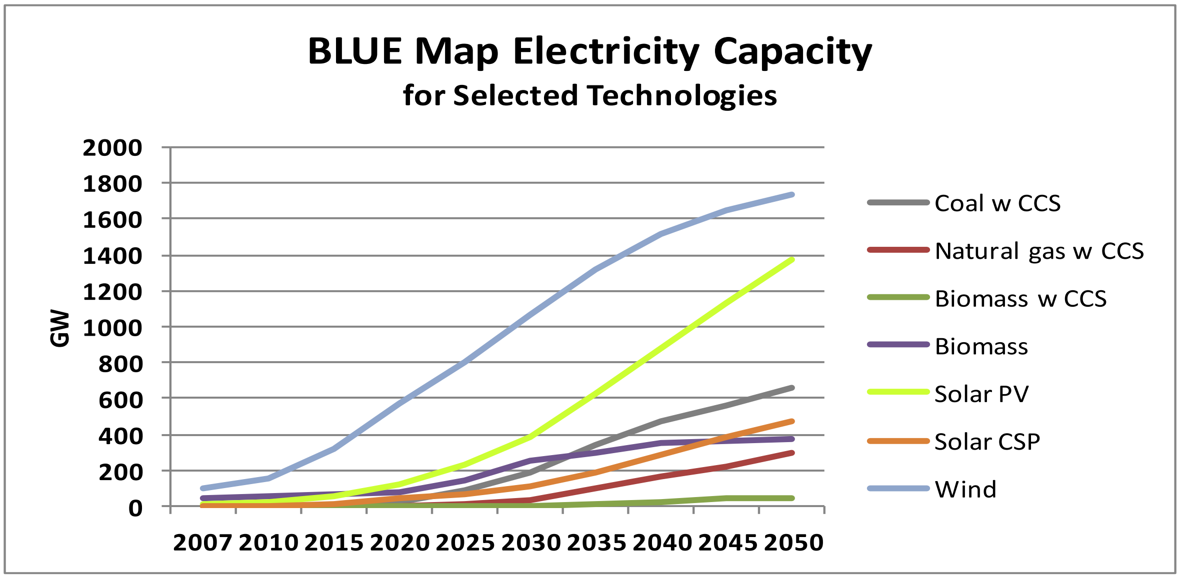
The composition of electricity generation, however, changes radically. Renewable generation increases to nearly half of total generation. Nuclear generation increases to 24%. Coal-fired generation is reduced from 42% to 12% of total; 90+% of that captures its carbon. The GHG-intensity of the power sector falls from 507 grams of CO_2 per kWh in 2007 to 67 in 2050, with OECD countries much lower than that. There are also significant changes to the transportation and other end-use sectors, with bio-fuels and electricity playing significantly expanded roles in the future. These kinds of changes allow worldwide CO_2 emissions to be halved in spite of growing populations and rising standards of living in most of the world.

There are separate sections for each technology. The generation technologies (Solar, Wind, CCS, HELE Coal, etc.) were grouped into one section, so that their data may be compared among technologies.

Generation Technologies

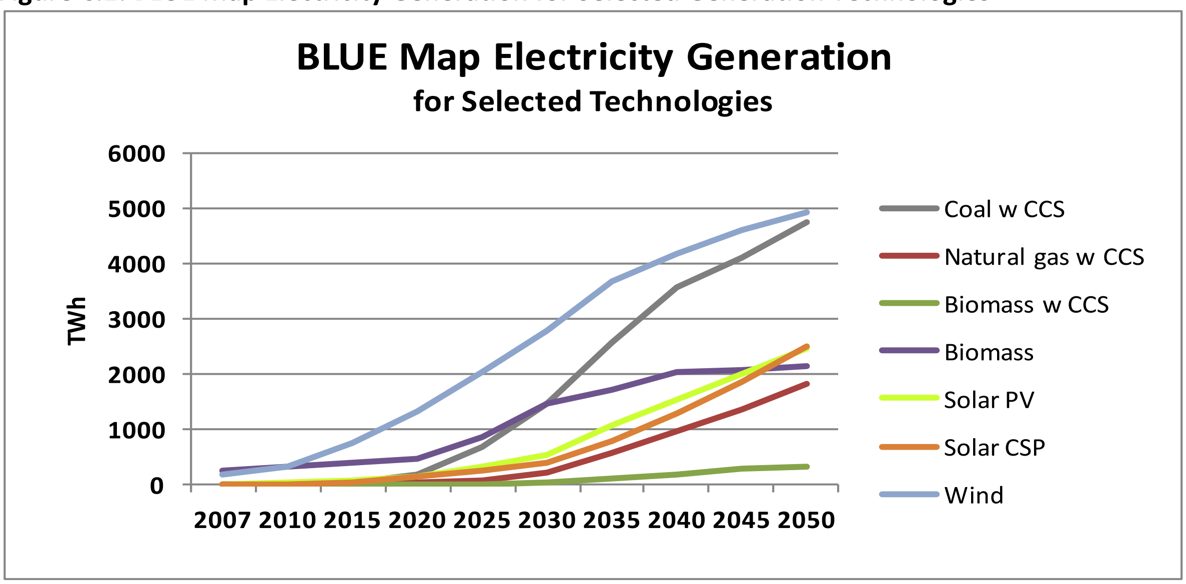
Figures C.1 and C.2 show the electricity capacity and generation worldwide in the BLUE Map scenario for the technologies on the agenda. The actual numbers follow in Tables C.1 and C.2.

Figure C.1: BLUE Map Electricity Capacity for Selected Generation Technologies



Note: Does not include generation from nuclear, hydro, or fossil without CCS.
Source: ETP2010, IEA analysis, data for 2010 through 2050 are estimates.

Figure C.2: BLUE Map Electricity Generation for Selected Generation Technologies



Note: Does not include generation from nuclear, hydro, or fossil without CCS.
Source: ETP2010, IEA analysis, data for 2010 through 2045 are estimates.

Table C.1: BLUE Map Electricity Capacity (GW) for Selected Technologies Worldwide

	2007	2010	2015	2020	2025	2030	2035	2040	2045	2050
Coal w CCS			4	22	85	191	341	476	558	663
Natural gas w CCS			1	5	12	37	98	163	224	298
Biomass w CCS					1	6	16	27	40	50
Biomass	46	53	66	82	149	250	297	352	361	373
Solar PV	8	19	53	126	233	384	630	877	1132	1378
Solar CSP	1	2	8	42	70	107	187	287	382	473
Wind	96	159	322	575	799	1067	1315	1521	1645	1732

Source: ETP2010, IEA analysis, data for 2010 through 2050 are estimates.

Table C.2: BLUE Map Electricity Generation (TWh) for Selected Technologies Worldwide

	2007	2010	2015	2020	2025	2030	2035	2040	2045	2050
Coal w CCS	0	0	29	164	653	1447	2578	3566	4117	4746
Natural gas w CCS	0	0	2	28	64	207	570	955	1337	1815
Biomass w CCS	0	0	0	0	6	33	83	167	265	311
Biomass	259	304	379	469	855	1448	1709	2025	2079	2149
Solar PV	4	17	63	144	306	525	1050	1514	1981	2469
Solar CSP	1	3	22	131	235	395	765	1287	1849	2489
Wind	173	326	755	1323	2045	2779	3682	4190	4617	4916

Source: ETP2010, IEA analysis, data for 2010 through 2045 are estimates.

Capacity and generation data are trailing indicators of technology success. Cost improvements are leading indicators, influencing decision makers to build more capacity using a particular technology. Below are the cost improvements assumed in the BLUE Map scenario in the *Energy Technology Perspectives* (ETP) 2010 edition.

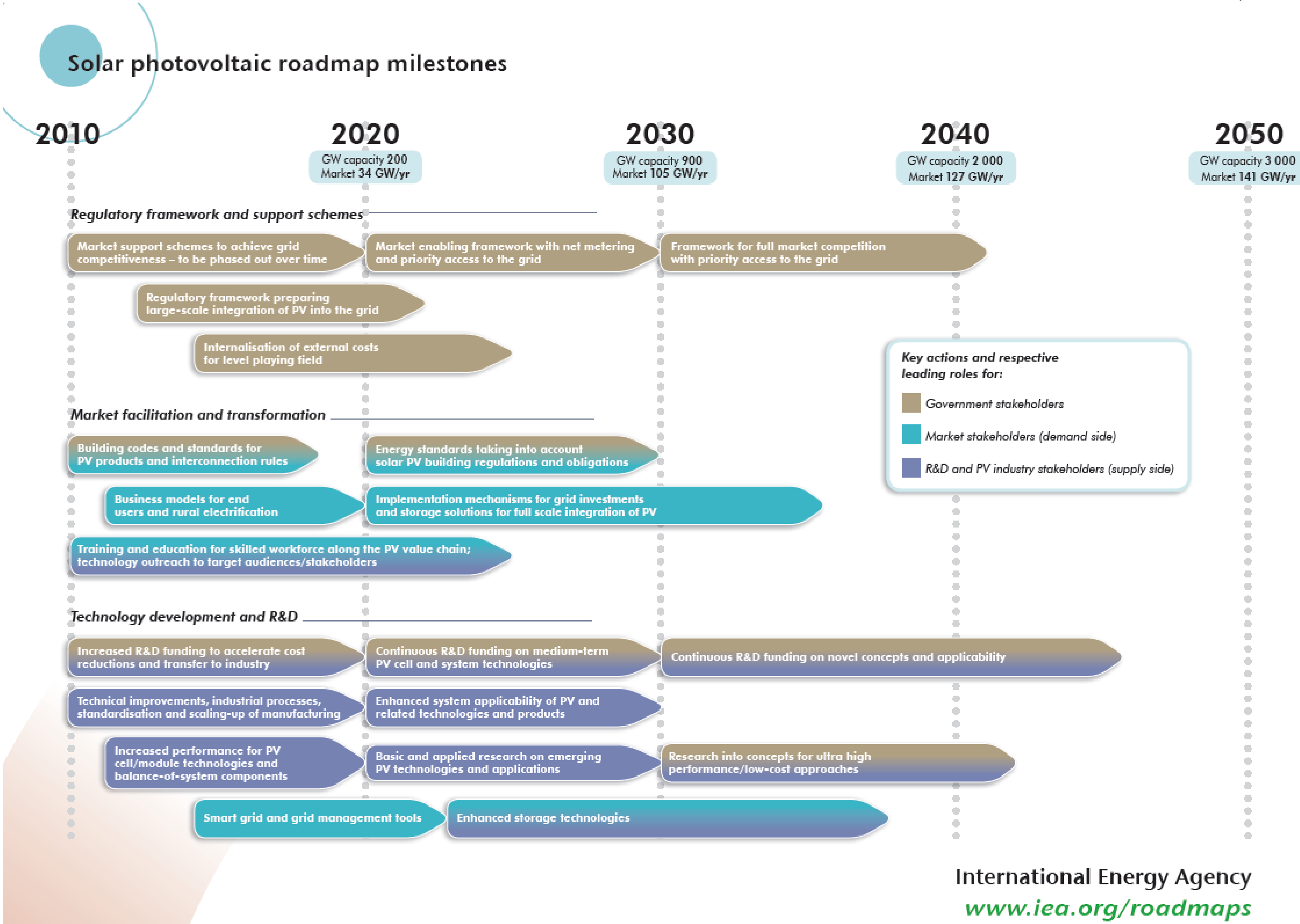
Note that there are min/max ranges of costs for several technologies. The annual improvement is the annual percentage reduction in cost/kW comparing the minimum cost in 2010 to the minimum cost in the target year, or comparing the maximum cost in 2010 to the maximum cost in the target year. Where the two percentages are different, both are given.

Table C.3: BLUE Map Cost Assumptions for Generation Technologies

	Investment costs (USD 2008/kW)			Annual Improvement to		Assumed Learning Rates
Year	*2010*	*2020*	*2050*	*2020*	*2050*	
Coal supercritical (SC)	2100	2000	1650	0.5%	0.6%	NA
Coal ultra-supercritical (USC)	2200	2100	1700	0.5%	0.6%	NA
Coal IGCC	2400	2250	1850	0.6%	0.6%	NA
Natural gas combined cycle (NGCC)	900	850	750	0.6%	0.5%	NA
USC+post-combustion capture	3400	3300	2500	0.3%	0.8%	6%*
USC + oxy-fuelling	3700	3600	2700	0.3%	0.8%	6%*
IGCC + pre-combustion capture	3200	3100	2450	0.3%	0.7%	6%*
Biomass	3000	2500	2200	1.8%	0.8%	5%**
Solar PV	3500-5600	2200-3500	1000-1600	4.5-4.6%	3.1%	18%
Solar CSP	4500-7000	3400-5000	1950-3000	2.8-3.3%	2.1%	10%
Wind onshore	1450-2200	1300-1900	1200-1600	1.1-1.5%	0.5-0.8%	7%
Wind offshore	3000-3700	2300-3000	2100-2600	2.1-2.6%	0.9%	9%

Source: ETP2010, assumed learning rates and data for 2020 are estimates.
Cost assumptions for fossil technologies without carbon capture are based on literature and expert review, not learning rates.
*The 6% learning rate applies only to the additional capture equipment added for CCS.
**For Biomass IGCC

Below are the milestone diagrams from the IEA roadmaps applicable to electricity generation. They specify some nearer term goals that may be helpful in assessing progress. All the roadmaps and milestone fold-outs are available at www.iea.org/roadmaps.


Solar photovoltaic roadmap milestones
2010
2020
GW capacity 200
Market 34 GW/yr
2030
GW capacity 900
Market 105 GW/yr
2040
GW capacity 2 000
Market 127 GW/yr
2050
GW capacity 3 000
Market 141 GW/yr
Regulatory framework and support schemes
Market support schemes to achieve grid competitiveness – to be phased out over time
Market enabling framework with net metering and priority access to the grid
Framework for full market competition with priority access to the grid
Regulatory framework preparing large-scale integration of PV into the grid
Internalisation of external costs for level playing field
Market facilitation and transformation
Building codes and standards for PV products and interconnection rules
Energy standards taking into account solar PV building regulations and obligations
Business models for end users and rural electrification
Implementation mechanisms for grid investments and storage solutions for full scale integration of PV
Training and education for skilled workforce along the PV value chain; technology outreach to target audiences/stakeholders
Technology development and R&D
Increased R&D funding to accelerate cost reductions and transfer to industry
Continuous R&D funding on medium-term PV cell and system technologies
Continuous R&D funding on novel concepts and applicability
Technical improvements, industrial processes, standardisation and scaling-up of manufacturing
Enhanced system applicability of PV and related technologies and products
Increased performance for PV cell/module technologies and balance-of-system components
Basic and applied research on emerging PV technologies and applications
Research into concepts for ultra high performance/low-cost approaches
Smart grid and grid management tools
Enhanced storage technologies
Key actions and respective leading roles for:
Government stakeholders
Market stakeholders (demand side)
R&D and PV industry stakeholders (supply side)
International Energy Agency
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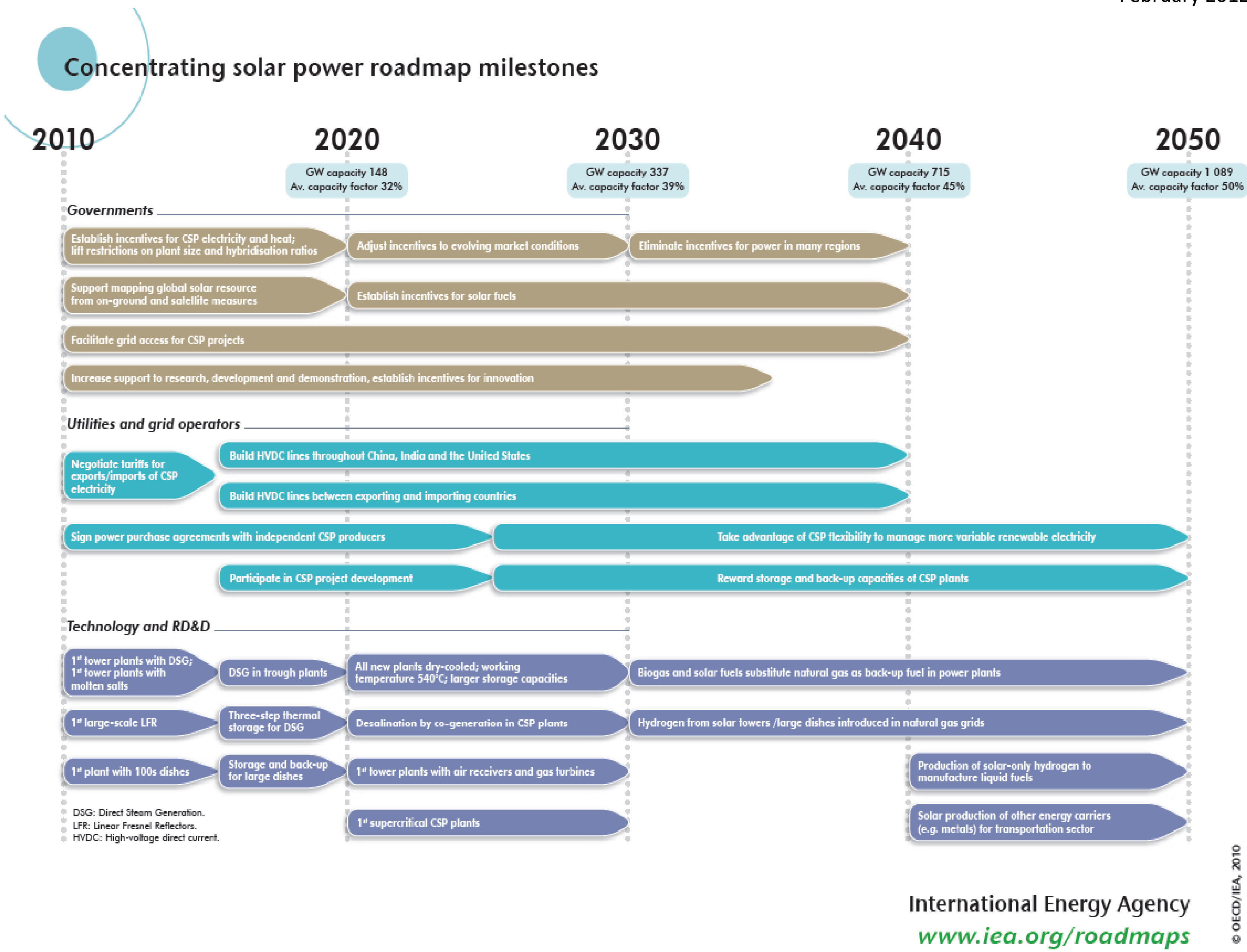
Concentrating solar power roadmap milestones
2010
2020
2030
2040
2050
GW capacity 148
Av. capacity factor 32%
GW capacity 337
Av. capacity factor 39%
GW capacity 715
Av. capacity factor 45%
GW capacity 1 089
Av. capacity factor 50%
Governments
Establish incentives for CSP electricity and heat; lift restrictions on plant size and hybridisation ratios
Adjust incentives to evolving market conditions
Eliminate incentives for power in many regions
Support mapping global solar resource from on-ground and satellite measures
Establish incentives for solar fuels
Facilitate grid access for CSP projects
Increase support to research, development and demonstration, establish incentives for innovation
Utilities and grid operators
Negotiate tariffs for exports/imports of CSP electricity
Build HVDC lines throughout China, India and the United States
Build HVDC lines between exporting and importing countries
Sign power purchase agreements with independent CSP producers
Take advantage of CSP flexibility to manage more variable renewable electricity
Participate in CSP project development
Reward storage and back-up capacities of CSP plants
Technology and RD&D
1st tower plants with DSG; 1st tower plants with molten salts
DSG in trough plants
All new plants dry-cooled; working temperature 540°C; larger storage capacities
Biogas and solar fuels substitute natural gas as back-up fuel in power plants
1st large-scale LFR
Three-step thermal storage for DSG
Desalination by co-generation in CSP plants
Hydrogen from solar towers /large dishes introduced in natural gas grids
1st plant with 100s dishes
Storage and back-up for large dishes
1st tower plants with air receivers and gas turbines
Production of solar-only hydrogen to manufacture liquid fuels
1st supercritical CSP plants
Solar production of other energy carriers (e.g. metals) for transportation sector
DSG: Direct Steam Generation.
LFR: Linear Fresnel Reflectors.
HVDC: High-voltage direct current.
International Energy Agency
www.iea.org/roadmaps
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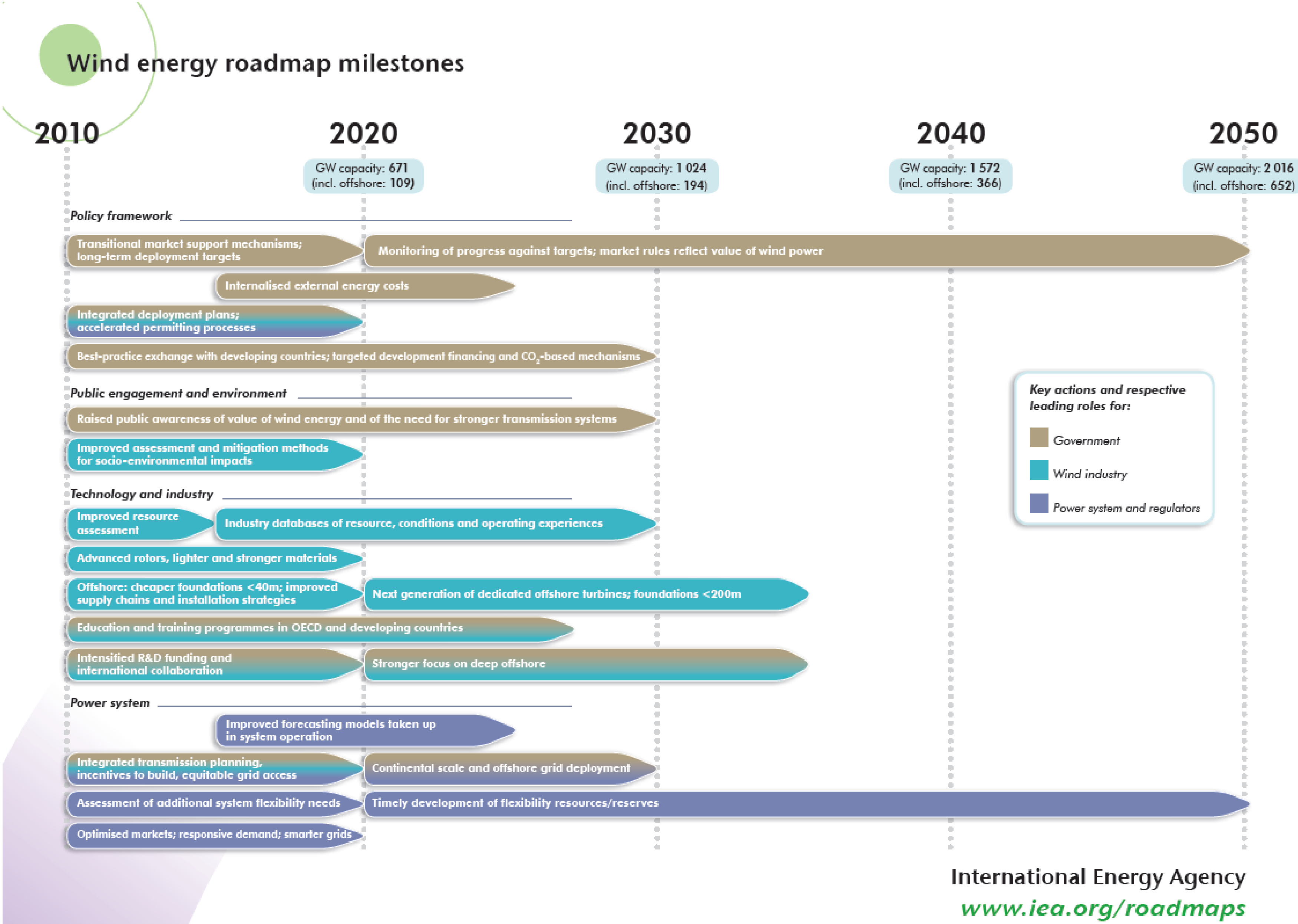
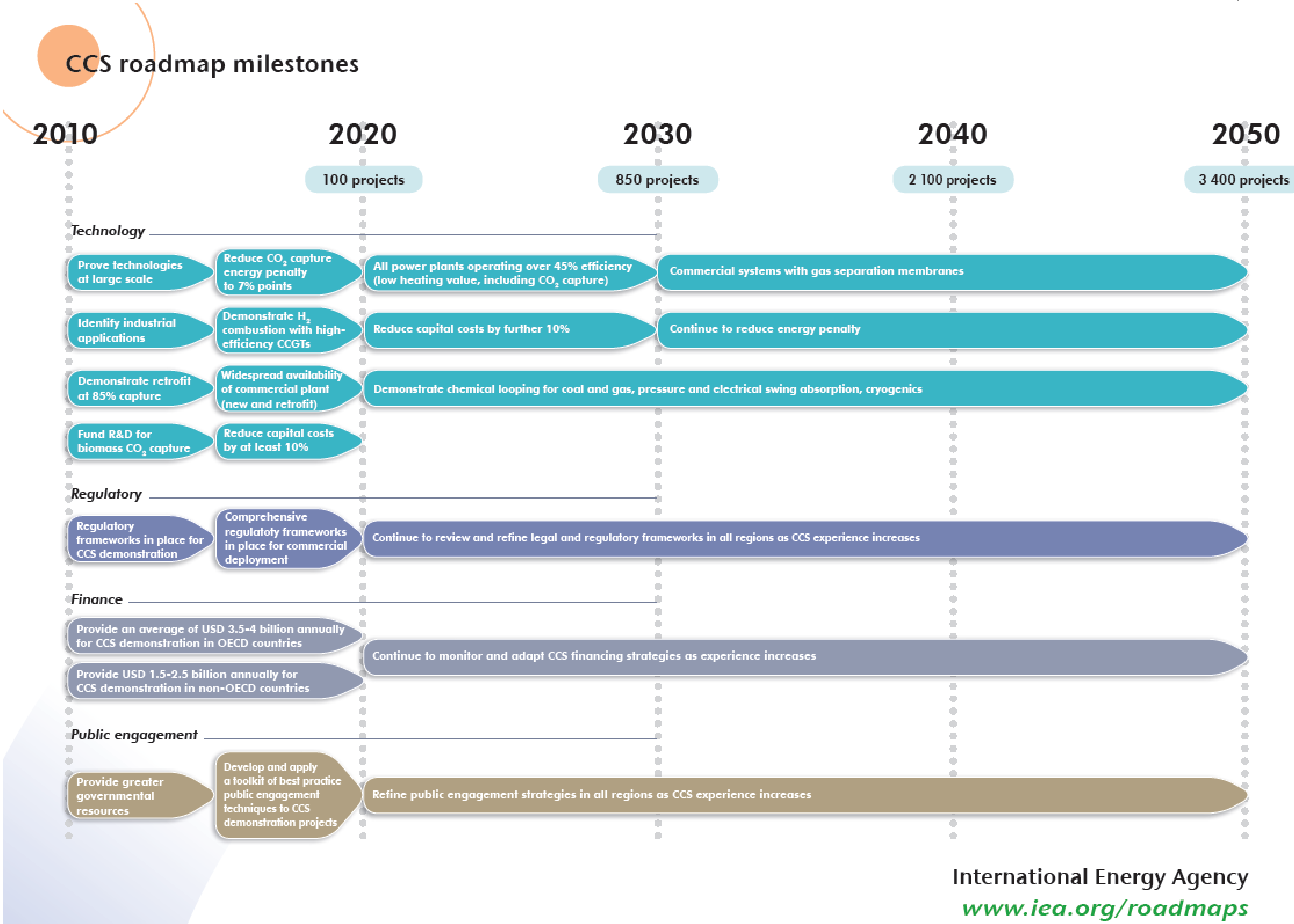

Wind energy roadmap milestones
2010
2020
2030
2040
2050
GW capacity: 671 (incl. offshore: 109)
GW capacity: 1 024 (incl. offshore: 194)
GW capacity: 1 572 (incl. offshore: 366)
GW capacity: 2 016 (incl. offshore: 652)
Policy framework
Transitional market support mechanisms; long-term deployment targets
Monitoring of progress against targets; market rules reflect value of wind power
Internalised external energy costs
Integrated deployment plans; accelerated permitting processes
Best-practice exchange with developing countries; targeted development financing and CO_2-based mechanisms
Public engagement and environment
Raised public awareness of value of wind energy and of the need for stronger transmission systems
Improved assessment and mitigation methods for socio-environmental impacts
Technology and industry
Improved resource assessment
Industry databases of resource, conditions and operating experiences
Advanced rotors, lighter and stronger materials
Offshore: cheaper foundations <40m; improved supply chains and installation strategies
Next generation of dedicated offshore turbines; foundations <200m
Education and training programmes in OECD and developing countries
Intensified R&D funding and international collaboration
Stronger focus on deep offshore
Power system
Improved forecasting models taken up in system operation
Integrated transmission planning, incentives to build, equitable grid access
Continental scale and offshore grid deployment
Assessment of additional system flexibility needs
Timely development of flexibility resources/reserves
Optimised markets; responsive demand; smarter grids
Key actions and respective leading roles for:
Government
Wind industry
Power system and regulators
International Energy Agency
www.iea.org/roadmaps


CCS roadmap milestones
2010
2020
2030
2040
2050
100 projects
850 projects
2 100 projects
3 400 projects
Technology
Prove technologies at large scale
Reduce CO_2 capture energy penalty to 7% points
All power plants operating over 45% efficiency (low heating value, including CO_2 capture)
Commercial systems with gas separation membranes
Identify industrial applications
Demonstrate H_2 combustion with high-efficiency CCGTs
Reduce capital costs by further 10%
Continue to reduce energy penalty
Demonstrate retrofit at 85% capture
Widespread availability of commercial plant (new and retrofit)
Demonstrate chemical looping for coal and gas, pressure and electrical swing absorption, cryogenics
Fund R&D for biomass CO_2 capture
Reduce capital costs by at least 10%
Regulatory
Regulatory frameworks in place for CCS demonstration
Comprehensive regulatoty frameworks in place for commercial deployment
Continue to review and refine legal and regulatory frameworks in all regions as CCS experience increases
Finance
Provide an average of USD 3.5-4 billion annually for CCS demonstration in OECD countries
Provide USD 1.5-2.5 billion annually for CCS demonstration in non-OECD countries
Continue to monitor and adapt CCS financing strategies as experience increases
Public engagement
Provide greater governmental resources
Develop and apply a toolkit of best practice public engagement techniques to CCS demonstration projects
Refine public engagement strategies in all regions as CCS experience increases
International Energy Agency
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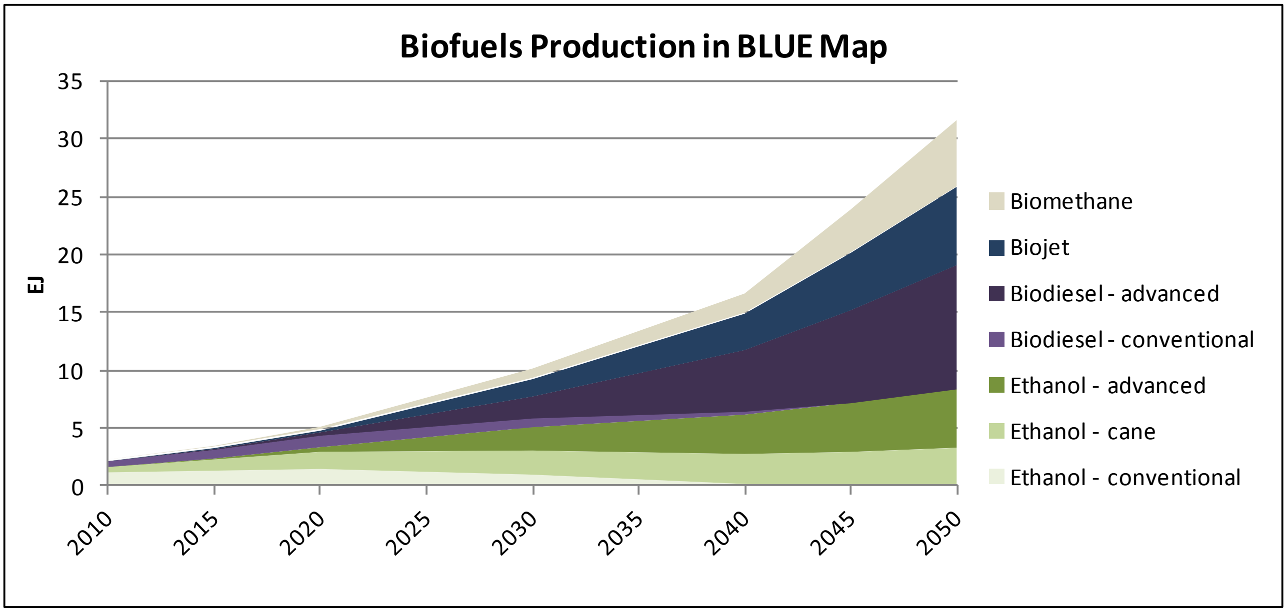
Biofuels

Figure C.3 shows the BLUE Map scenario production of biofuels to 2050.

Figure C.3: BLUE Map Biofuels Production



Source: IEA, *Technology Roadmap – Biofuels for Transport*, 2011.

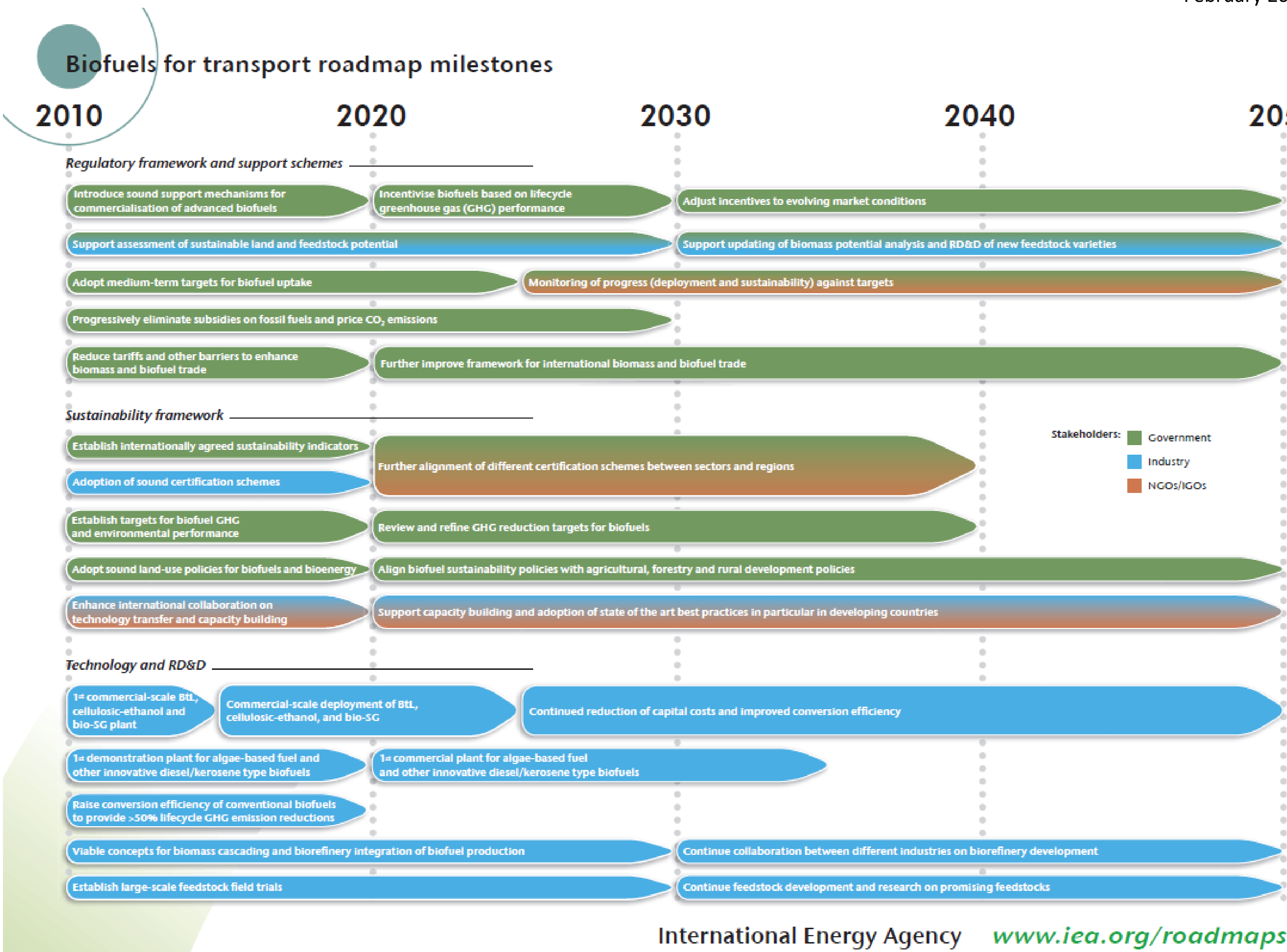
Production is a trailing indicator of technology success. Cost is a leading indicator, influencing the amount of growth in production. Below are cost data for the Low-Cost Biofuels scenario.

Table C.4: BLUE Map Biofuels Cost Assumptions (USD /Lge, Low Cost Scenario)

	2010	2015	2020	Annual Improvement to 2020
Petroleum gasoline	0.54	0.63	0.72	-2.9%
Ethanol - conventional	0.71	0.69	0.68	0.5%
Ethanol - cane	0.62	0.62	0.62	0.0%
Ethanol - cellulosic	1.09	0.97	0.90	1.9%
Biodiesel - conventional	0.98	0.96	0.94	0.4%
Biodiesel - Advanced (BtL)	1.12	0.98	0.92	2.0%
bio-SG	0.90	0.87	0.84	0.7%

Source: IEA, *Technology Roadmap – Biofuels for Transport*, 2011.

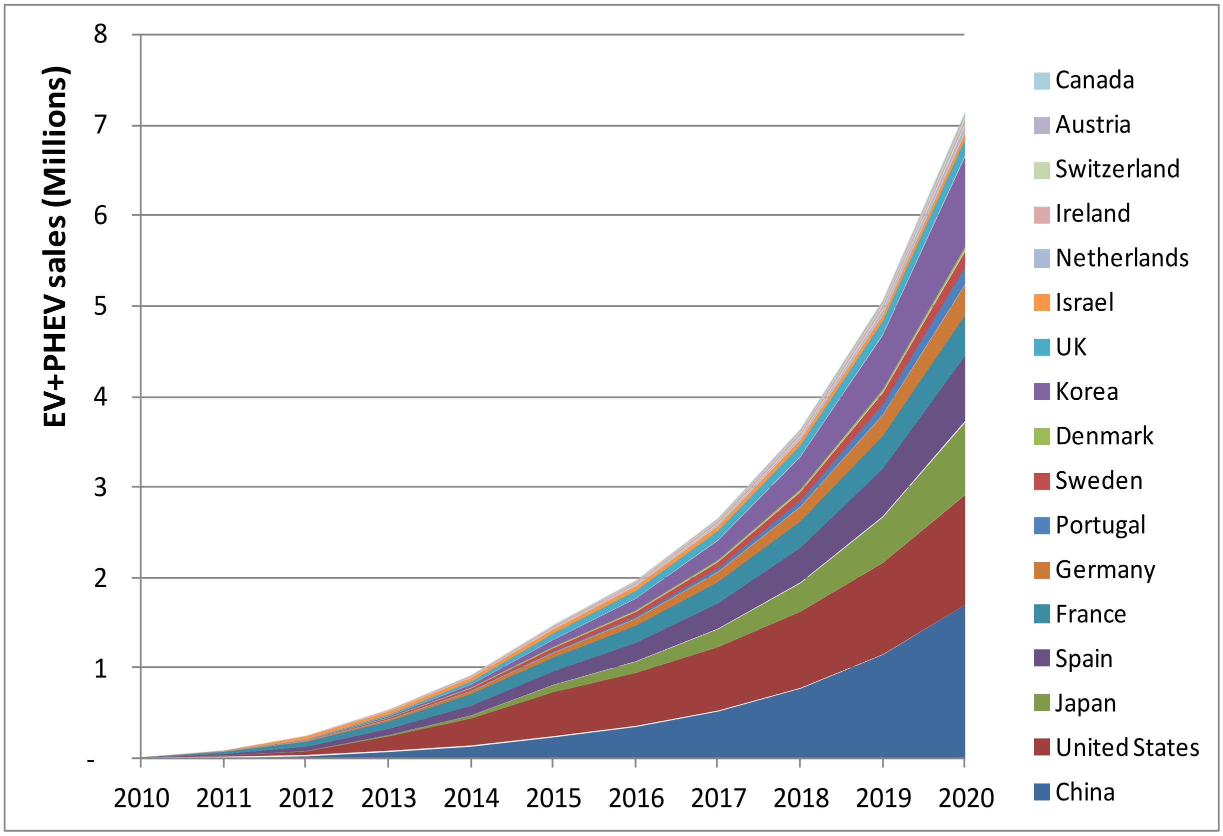
The biofuels milestones from *Technology Roadmap – Biofuels for Transport* are reproduced on the next page. They specify some nearer term goals that may be helpful in assessing progress. All roadmaps and milestone fold-outs available on the IEA website www.iea.org/roadmaps.



Biofuels for transport roadmap milestones
2010
2020
2030
2040
2050
Regulatory framework and support schemes
Introduce sound support mechanisms for commercialisation of advanced biofuels
Incentivise biofuels based on lifecycle greenhouse gas (GHG) performance
Adjust incentives to evolving market conditions
Support assessment of sustainable land and feedstock potential
Support updating of biomass potential analysis and RD&D of new feedstock varieties
Adopt medium-term targets for biofuel uptake
Monitoring of progress (deployment and sustainability) against targets
Progressively eliminate subsidies on fossil fuels and price CO_2 emissions
Reduce tariffs and other barriers to enhance biomass and biofuel trade
Further improve framework for international biomass and biofuel trade
Sustainability framework
Establish internationally agreed sustainability indicators
Adoption of sound certification schemes
Further alignment of different certification schemes between sectors and regions
Stakeholders:
Government
Industry
NGOs/IGOs
Establish targets for biofuel GHG and environmental performance
Review and refine GHG reduction targets for biofuels
Adopt sound land-use policies for biofuels and bioenergy
Align biofuel sustainability policies with agricultural, forestry and rural development policies
Enhance international collaboration on technology transfer and capacity building
Support capacity building and adoption of state of the art best practices in particular in developing countries
Technology and RD&D
1st commercial-scale BtL, cellulosic-ethanol and bio-SG plant
Commercial-scale deployment of BtL, cellulosic-ethanol, and bio-SG
Continued reduction of capital costs and improved conversion efficiency
1st demonstration plant for algae-based fuel and other innovative diesel/kerosene type biofuels
1st commercial plant for algae-based fuel and other innovative diesel/kerosene type biofuels
Raise conversion efficiency of conventional biofuels to provide >50% lifecycle GHG emission reductions
Viable concepts for biomass cascading and biorefinery integration of biofuel production
Continue collaboration between different industries on biorefinery development
Establish large-scale feedstock field trials
Continue feedstock development and research on promising feedstocks
International Energy Agency
www.iea.org/roadmaps

Batteries for Vehicles

Figure C.4 shows the numbers of EV and PHEV vehicle sales projected based on government and industry plans. These statistics do not include HEV vehicles, although they have relatively few batteries per vehicle compared to EV and PHEV vehicles.



Source: estimates based on IEA analysis.

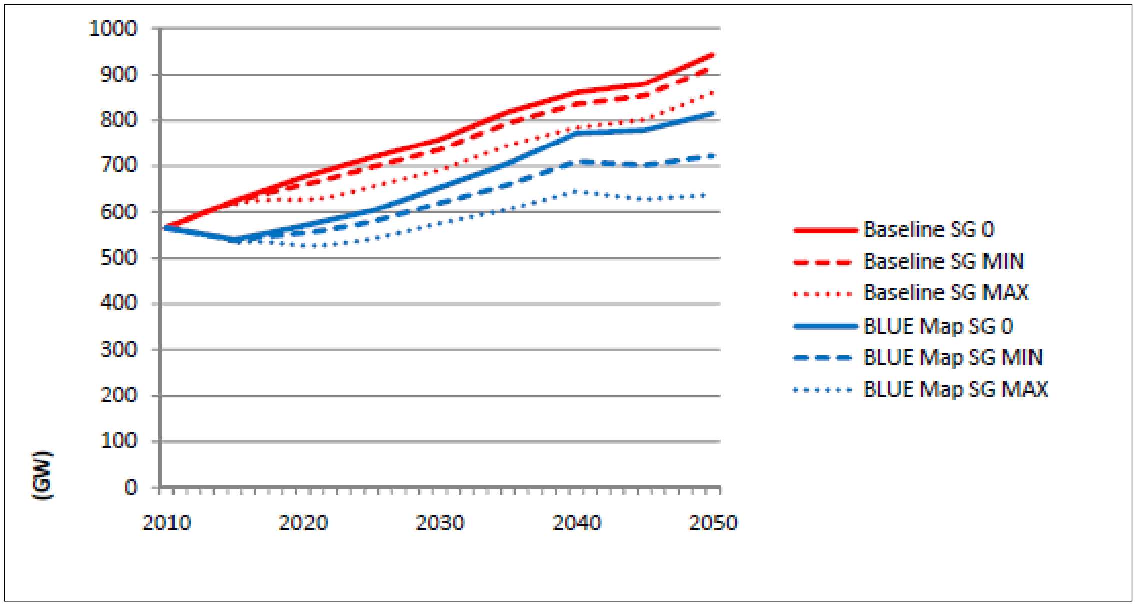
Figure C.4: EV and PHEV Sales Projections

The IEA Electric and *Technology Roadmap — Plug-in Hybrid Vehicles* for battery costs to decline to USD 300/kWh by about 2020. That would translate to a learning rate of about 10% per doubling of batteries manufactured for EV and PHEV vehicles, according to the sales projections above, and about a 9% decline per year from today's estimated cost of about USD 750/kWh.

Smart Grid

ETP2010 BLUE Map made no assumptions regarding smart grid improvements. However, a 2011 study by IEA used the BLUE Map scenario to explore possible declines in peak load due to smart grid. The results for four regions are reproduced below in Figures C.5-C.8. Baseline SG 0 assumes no smart grid deployment at all, while SG MIN assumes minimal deployment, and SG MAX assumes maximal deployment. The declines in peak load from BLUE Map SG MIN to BLUE Map SG MAX were 11-12% in most regions, but 8% in China. A major assumption in the study was the use of EV/PHEV battery storage to reduce peak loading.

Figure C.5: Estimated peak load evolution in OECD Europe, 2010-2050



Source: IEA, *Impact of Smart Grid Technologies on Peak Load to 2050*, 2011.

Figure C.6: Estimated peak load evolution in OECD North America, 2010-2050

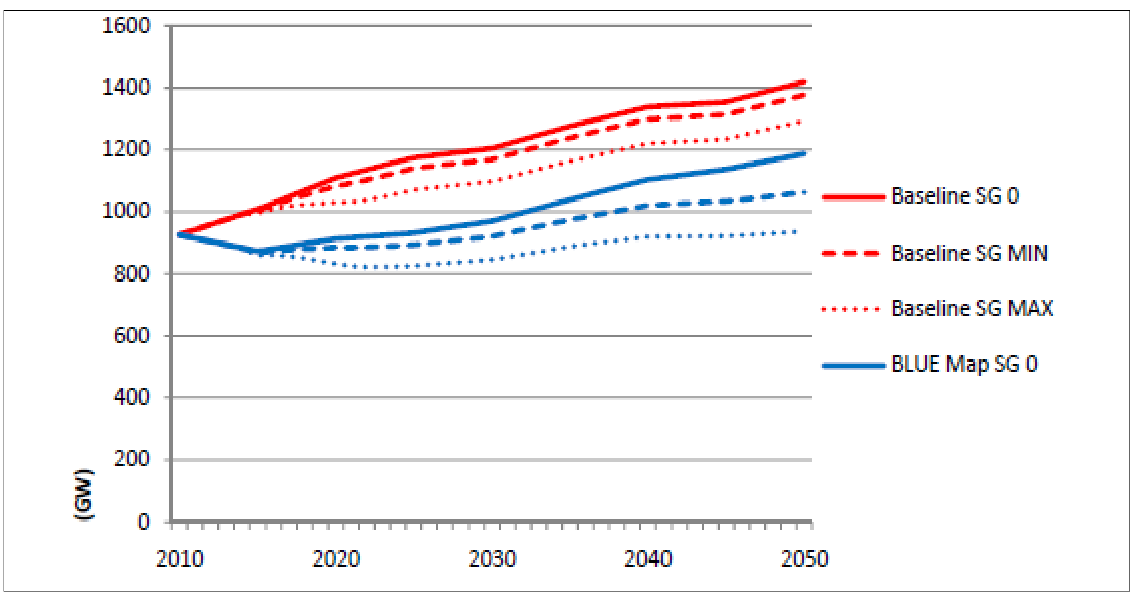


Figure C.7: Estimated peak load evolution in OECD Pacific, 2010-2050

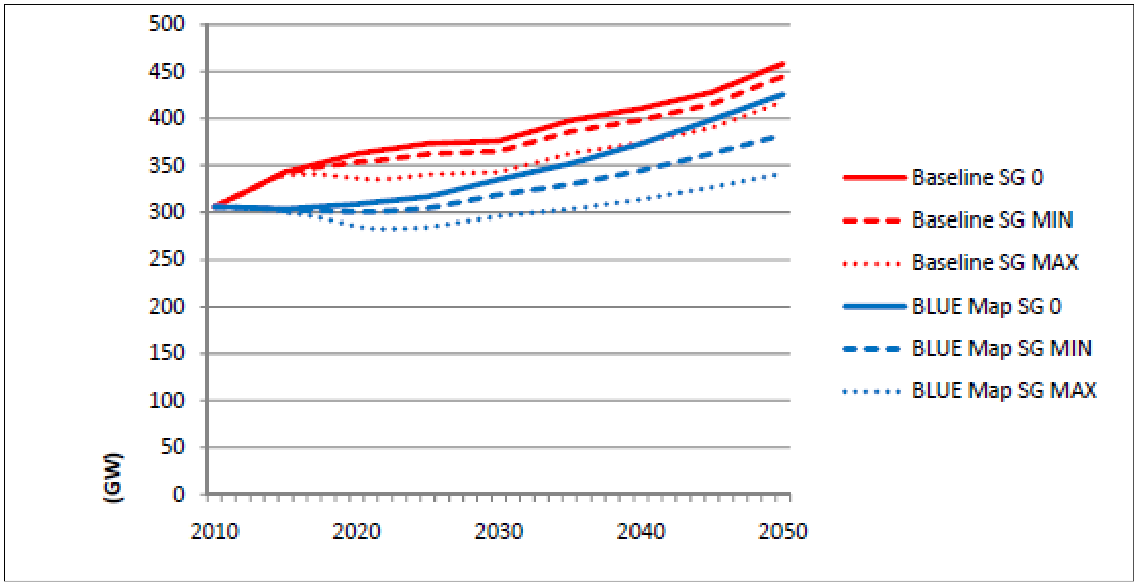
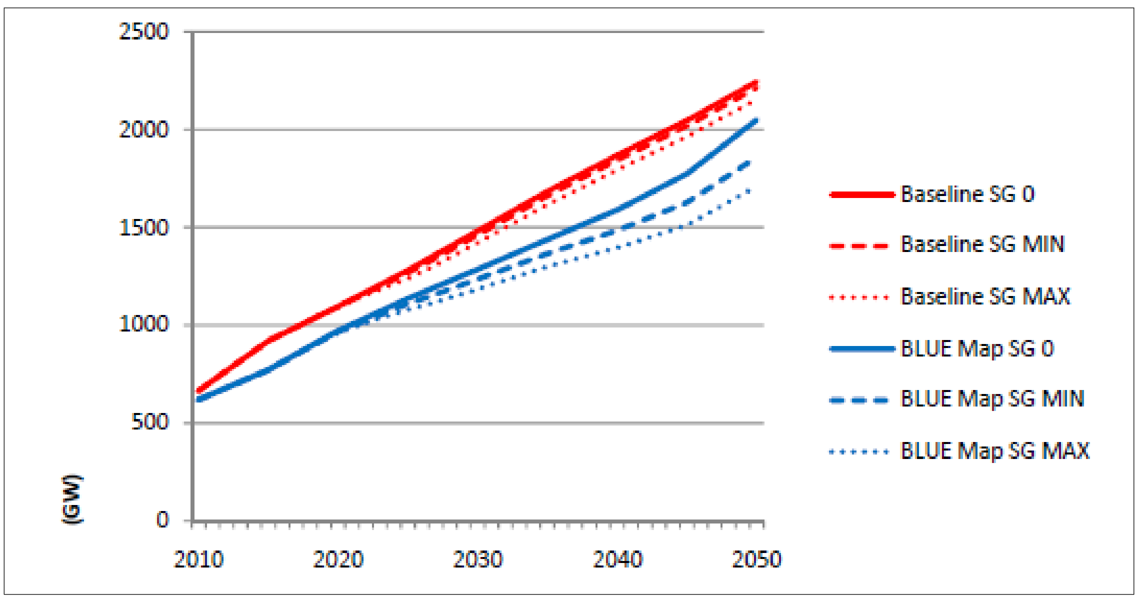


Figure C.8: Estimated peak load evolution in China, 2010-2050



The smart grid milestones from the *Technology Roadmap — Smart Grids* could not be reproduced here due to format issues. They specify some nearer term goals that may be helpful in assessing progress. All roadmaps and milestones fold-outs are available at www.iea.org/roadmaps.

Energy-Efficient Buildings and Energy Efficient Electrical Equipment

Table C.5 shows the energy consumption in buildings by fuels, for both the baseline and BLUE Map scenarios. The Energy Savings (negative numbers represent increases) are simply the difference between the two.

Table C.5: Buildings Sector Energy Consumption by Fuel

MTOE		Baseline			BLUE Map			Energy Savings		
	2007	*2015*	*2030*	*2050*	*2015*	*2030*	*2050*	*2015*	*2030*	*2050*
Coal	96	104	94	88	97	66	44	7	28	44
Oil	336	344	382	439	321	283	182	23	99	257
Gas	608	661	796	958	597	502	366	64	294	592
Electricity	758	914	1270	1837	852	1004	1276	62	266	561
Heat	149	175	186	188	181	208	214	-6	-22	-26
Biomass	799	779	787	816	721	586	491	58	201	325
Solar/other renewables	12	24	49	81	73	184	326	-49	-135	-245
Total	**2758**	**3001**	**3564**	**4407**	**2842**	**2833**	**2899**	**159**	**731**	**1508**

Source: ETP2010.

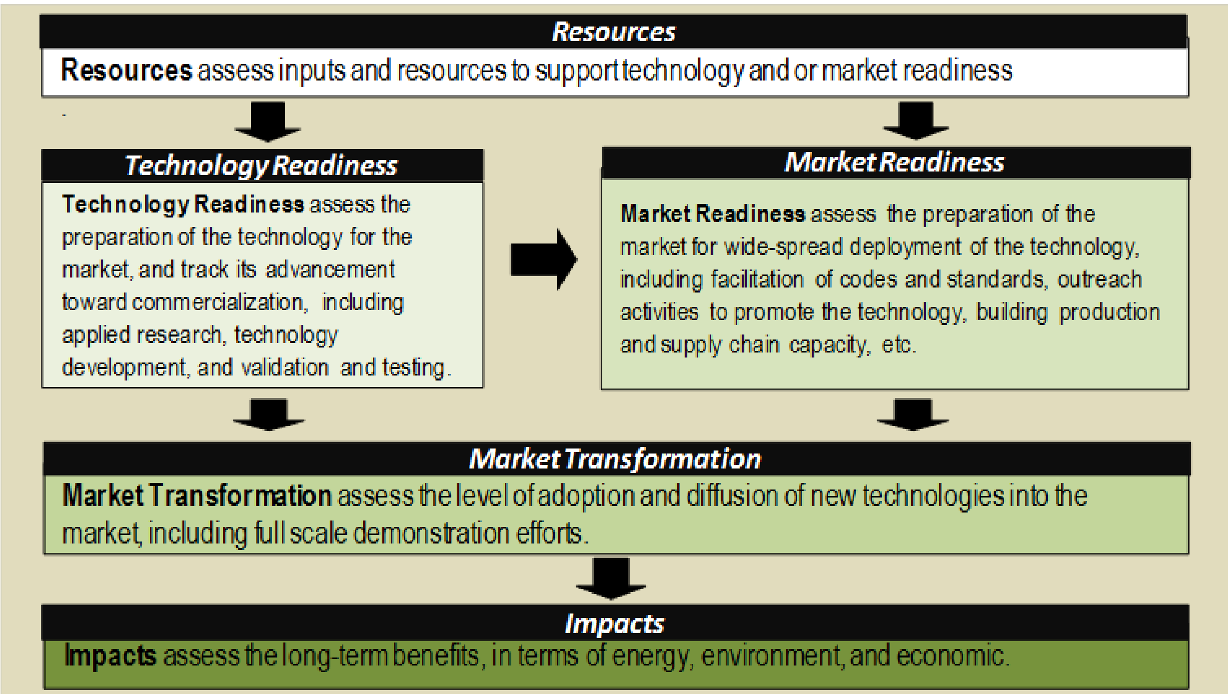
The Buildings milestones from the IEA Biofuels Roadmap brochure could not be reproduced here due to format issues. They specify some nearer term goals that may be helpful in assessing progress. The brochures and the roadmaps themselves are available at www.iea.org/roadmaps .

References

Energy Technology Perspectives 2010 http://www.iea.org/techno/etp/index.asp
IEA Roadmaps http://www.iea.org/roadmaps
Impact of Smart Grid Technologies on Peak Load to 2050
http://www.iea.org/papers/2011/smart_grid_peak_load.pdf

Appendix D: Draft Metrics from 14 Technology Areas

This appendix provides 15-20 critical metrics for each of fourteen energy technology groups, as they are applied to the draft performance metrics framework (see Introduction section and Figure 1 of this report). The metrics were developed by a combination of research efforts prior to the workshop, and revised during presentations and discussions at the workshop. Following the workshop, the metrics were further revised based on input provided by experts through a series of questionnaires (see Appendix G).



The development of the metrics involved a literature search that identified hundreds of metrics related to clean energy technology progress that are an important factor in the deployment of the technology, and/or are currently being tracked. The list of candidate metrics was reduced to about 15-20 for each technology and applied to the framework. Metrics were selected based on eight criteria: relevancy, completeness, consistency, understandability, quantifiability, accuracy, timeliness, and feasibility of collection.

Prior to the workshop, metrics were further refined to bold the highest priority metrics, based primarily on strength (the degree to which a metric forecasts progress accurately), and on the degree to which it is a leading indicator (how far into the future does this metric impact progress?). Accuracy (the degree to which the metric can be accurately measured) was considered to be a relatively minor factor long-term, as new methods of measurement could be instituted. Also, the difficulty or resources required for measurement was not considered for the same reason: this is a long-term perspective on the framework, and the difficulty/resources could change with innovative measurement methodologies.

Fourteen (14) clean energy technologies are seen as important to the longer-term attainment of the IEA BLUE Map Scenario goals for 2050 and within scope for the meeting. Draft metrics are provided for the following clean technology areas:

- Solar PV
- Concentrating Solar Power
- Wind Power
- Biofuels
- Biomass Power
- Electricity Generation with High-Efficiency Lower Emission Coal
- Carbon Capture and Storage
- Energy Efficient Heating and Cooling Technologies
- Energy Efficient Lighting
- Energy Efficient Residential Appliances
- Vehicle Batteries
- Smart Grid
- Geothermal Power
- Intelligent Transportation Systems

Brackets [ ] indicate references for explanation of importance of selected metric and/or sources of data. Metrics in the areas of Resources, Technology Readiness, and Market Readiness are seen as *leading* indicators; metrics in Market Transformation are indicators of the current status, or *coincident* indicators; and those in Impacts are *lagging* indicators.

Solar PV

Draft Metrics for Measuring Progress toward a Global Clean Energy Economy

Resources

- Public RD&D investment in PV technologies($/yr) [1]
- Private RD&D investment in PV technologies ($/yr) [2]

Technology Readiness

- Unsubsidized LCOE ($/kWh) and capital cost ($/kW) from new PV installations in a) utility, b) commercial, and c) residential sectors [3]
- Maximum PV efficiency (%) for next generation technologies achieved in lab and average annual improvement (%) [1]
- Energetic amortization time (yrs)

Market Readiness

- Total value of government support issued for PV deployment ($/yr) [2]
- Time duration from application to grid connection (months) [1]
- Capacity and production of PV component manufacturing plants (MW/yr) [7]
- Funding for training and outreach to create an educated PV workforce among government planners, industry builders, consumers, etc. ($/yr) [1]

Market Transformation

- Installed PV a) capacity (MW) and b) generation (TWh/yr) [1]
- Annual growth rates of PV a) capacity and b) generation (%/yr) [3, 5]
- Learning rate: cost reduction for each doubling of cumulative installed PV capacity (%) [3]
- Market capitalization of PV manufacturers ($)

Impacts

- GHG emissions avoided (MtCO2e/yr) [1]
- Number of employees in PV workforce (#) [1, 2]

Concentrating Solar Thermal Power (CSP)

Draft Metrics for Measuring Progress toward a Global Clean Energy Economy

Resources

- Public RD&D investment in CSP technologies ($/yr) [1]
- Private RD&D investment in CSP technologies ($/yr) [5]

Technology Readiness

- Unsubsidized LCOE from new CSP installations ($/kWh) [3, 7]
- CSP water requirements for cooling and condensing processes (L/MWh) [4]
- Cost of CSP system storage with duration of a) 4hrs, b) 8hrs, c) 18 hrs ($/kW) [2]
- Maximum CSP efficiency achieved in a) new installations and b) laboratory (%) [6]
- Energetic amortization time (yrs)

Market Readiness

- Total value of government support issued for CSP deployment ($/yr) [1]
- Time duration from application to grid connection (months) [9]
- Capacity and production of CSP component manufacturing plants (MW)
- Percent of G20 countries with published codes and standards for CSP (%) [2,8]

Market Transformation

- Installed CSP plants: a) capacity (MW) and b) generation (TWh/yr) [4,7]
- Learning rate: cost reduction for each doubling of cumulative installed CSP capacity (%) [3, 4, 7]
- Annual growth rates of CSP: a) capacity and b) generation (%) [4,7]
- Market capitalization of CSP manufacturers ($)

Impacts

- GHG emissions avoided (MtCO2e/yr) [4]
- Number of employees in CSP workforce (#) [1]

Wind Power

Draft Metrics for Measuring Progress toward a Global Clean Energy Economy

Resources

- Public RD&D investment in wind power technologies ($/yr) [1,3]
- Private RD&D investment in wind power technologies ($/yr) [1,3]

Technology Readiness

- Unsubsidized LCOE ($/kWh) and capital cost ($/kW) for new a) onshore and b) offshore installations [3]
- Annual improvement in capacity factor (%) [2]
- Energetic amortization time (yrs)

Market Readiness

- Total value of government support issued for wind power deployment ($/yr) [2]
- Time duration from application to grid connection (months)
- Manufacturing capacity and production of a) large and b) small (<1 MW) turbines (MW/yr) [6]
- Social acceptability score

Market Transformation

- Installed capacity of a) onshore and b) offshore (GW) [3]
- Generation of a) onshore and b) offshore (TWh/yr) [4]
- Learning rate: cost reduction for each doubling of cumulative installed capacity (%) [1]
- Wind share of electricity mix in G20 markets (%) [1]
- Average annual growth rate in wind power generation (%) [3]
- Market capitalization of wind manufacturers ($)

Impacts

- GHG emissions avoided from use of wind energy (MtCO2e/yr) [6]
- Number of employees in wind energy workforce (#) [1,6]

Biomass Power

Draft Metrics for Measuring Progress toward a Global Clean Energy Economy

Resources

- Public RD&D investment in biomass power ($/yr) [5]
- Private RD&D investment in biomass power ($/yr) [5]
- Energy requirement for biomass cultivation and processing (MJ/MT dry matter) [2]
- Cost of delivered biomass ($/GJ) [3]
- Global availability of sustainably harvested biomass feedstock (MT dry matter) [1]

Technology Readiness

- LCOE from biomass/coal co-fired power plant ($/kWh) [3]
- LCOE from dedicated biomass plants (gasification, combustion, or other) ($/kWh) [3]
- Maximum conversion efficiency (biological, thermochemical, or other) in a) heating applications and b) electricity generation (based on MJ output/MJ feedstock) [2]
- Maximum percentage of biomass content in coal co-fired power generation facilities (%) [3]
- Life cycle water use efficiency (ratio of water input to biopower output) (L/MJ) [2]

Market Readiness

- Total value of government support issued for biomass power deployment, including heating and electric power ($/yr) [5]
- Time duration from application to grid connection (months)
- International standards and certifications (e.g., sustainability) facilitating biomass international trade (#) [3]

Market Transformation

- Global electricity generation from biomass (TWh/yr) [3]
- Sustainability indicator score
- Learning rate: cost reduction of biomass power plant for each doubling of cumulative installed capacity (%) [4,6]
- Global production of biomass for heating applications (MJ/yr) [6]

Impacts

- GHG emissions avoided from biomass power, including land use impacts (MtCO2e/yr) [6]
- Number of employees in biomass workforce (#)

Advanced Biofuels

Draft Metrics for Measuring Progress toward a Global Clean Energy Economy

Resources

- Public RD&D investment in advanced biofuels ($/yr) [5,8]
- Private RD&D investment in advanced biofuels ($/yr) [5,8]
- Cost of biofuel feedstock ($/MT harvested dry matter) [3]
- Global production of sustainable biofuel feedstock (MT harvested dry matter) [1]

Technology Readiness

- Cost of pretreatment of feedstock ($/lge) [6]
- Minimum advanced biofuel conversion cost ($/lge) [7]
- Maximum conversion yield (biochemical, thermochemical, or other) in lab (lge/dry ton) [2]
- Maximum advanced biofuel production yields (lge/ha) [4]
- Capital cost of full scale advanced biofuel facility ($/annual gallon) [2]

Market Readiness

- Total value of government support issued for advanced biofuels deployment ($/yr) [4,8]
- Selling price of advanced biofuels at the pump ($/lge)
- Government procurement requirements for advanced biofuels in G20 countries (million lge) [9]

Market Transformation

- Global production of advanced biofuels (lge/yr) [5]
- Sustainability indicator score
- Learning rate: cost reduction of delivered advanced biofuel for each doubling of cumulative installed production (%) [8]
- Global sustainable production capacity of advanced biofuels (lge/yr)
- Market capitalization of advanced biofuels companies ($)

Impacts

- GHG emissions avoided from advanced biofuels, including land use impacts (MtCO2e/yr) [8]
- Number of employees in advanced biofuels workforce

High Efficiency, Lower Emissions Coal

Draft Metrics for Measuring Progress toward a Global Clean Energy Economy

Resources

- Public RD&D investment in HELE coal technologies ($/yr) [1]
- Private RD&D investment in HELE coal technologies ($/yr) [1]

Technology Readiness

- Unsubsidized LCOE of a) supercritical, b) ultra-supercritical, c) fluidized bed combustion, d) IGCC, and e) advanced ultra-supercritical 500MW power plant ($/kWh) [2]
- Difference in thermal efficiency of average coal-fired plants compared to advanced HELE coal plant (%) [2]

Market Readiness

- Number of emissions control standards published in G20 countries (#) [2,3]
- Value of incentives to accelerate HELE coal deployment beyond the demonstration phase ($) [2]

Market Transformation

- HELE coal plants a) installed capacity (GW) and b) generation (TWh/yr) [2,4]
- Share of HELE coal plant generation as a percentage of all coal-fired power generation in G20 countries (%) [2]
- Capacity of existing coal plants retrofitted with HELE coal technologies (e.g., efficient boilers, waste heat recovery systems/economizers, air pre-heaters) (GW) [2,4]

Impacts

- Reduction in coal consumption compared to Business-As-Usual (tonnes) [2]
- GHG emissions avoided from use of HELE coal technologies (MtCO2e/yr) [3]

Carbon Capture and Storage

Draft Metrics for Measuring Progress toward a Global Clean Energy Economy

Resources

- Public RD&D investment in CCS technologies ($/yr) [4]
- Private RD&D investment in CCS technologies ($/yr) [4]
- Capacity of suitable geologic formations in proximity to large CO2 emissions sources (MtCO2) [2]
- Total investment devoted to a) capture technologies, b) transportation, and c) storage ($/yr) [2, 5]

Technology Readiness

- Cost of CO2 avoided for a) NGCC, b) PC, c) IGCC, and d) oxyfuel and other ($/MtCO2) [6]
- Cost for transport and storage, including monitoring and verification ($/MtCO2)
- Unsubsidized LCOE ($/kWh) cost differential for new facility with CO2 capture compared to new facility without CO2 capture [3]
- Capital costs of retrofitting existing facility to capture 90% of CO2 emissions ($/kW) [3]
- Value of incentives to accelerate CCS R&D ($/yr) [3]

Market Readiness

- Number of G20 countries with legal and regulatory frameworks for CO2 transport, storage site selection, M&V, risk assessment, and indemnification (#) [1]
- Value of incentives to accelerate CCS deployment beyond the demonstration phase ($/yr) [2]
- Funding for CCS education and outreach programs ($) [2]

Market Transformation

- Total electricity capacity (GW) and output (TWh/yr) from plants with CCS [2]
- Capture and storage of emissions from a) power generation and b) industry (MtCO2/yr) [5]
- CO2 emissions from 'CCS retrofit-ready' facilities that are a) installed and b) proposed (MtCO2/yr) [2]
- CO2 emissions captured from large-scale demonstrations (MtCO2/yr) [4]
- Learning rate: cost reduction of CCS plant for each doubling of cumulative capacity of power plants with CCS (%)
- Number of a) projects and b) companies operating plants with CCS (#)

Impacts

- GHG emissions captured and stored from CCS (MtCO2e/yr)

Geothermal Heat and Power

Draft Metrics for Measuring Progress toward a Global Clean Energy Economy

Resources

- Public RD&D investment in geothermal technologies ($/yr) [1]
- Private RD&D investment in geothermal technologies ($/yr) [1, 2]
- Energy potential from developed geothermal resources and projects under way (GJ) [3]

Technology Readiness

- Unsubsidized LCOE ($/kWh) and capital cost ($/kW) for new flash and binary plants [1,2,3,4]
- Unsubsidized LCOE for Enhanced Geothermal Systems (EGS) installations ($/kWh) [3]
- Levelized cost of energy for new Low Temperature (<150 deg C) installations ($/kWh) [6]
- Levelized cost of heat for new a) ground source heat pumps (GSHP) and b) other direct heat installations ($/kWh$_{th}$) [2,3,4]
- Annual improvement in capacity factor (%) [2]

Market Readiness

- Total value of government support for geothermal energy deployment ($/yr) [5]
- Time duration from application to grid connection (months)
- Number of geothermal exploration licenses held by companies (#) [2,4]

Market Transformation

- Installed capacity for a) power generation (GW) and b) heat (GJ) [1,2]
- Geothermal electricity generation (TWh/yr) [4]
- Average annual growth rate in a) power generation and b) heat (%) [1]
- Learning rate for capital costs: cost reduction associated with cumulative doubling in installed capacity (%) [4]
- Market capitalization of geothermal power manufacturers ($)

Impacts

- GHG emissions avoided from use of geothermal energy (MtCO2e/yr) [4]
- Number of employees in geothermal power workforce (#)

Energy Efficient Heating and Cooling Equipment

Draft Metrics for Measuring Progress toward a Global Clean Energy Economy

Resources

- Public RD&D investment in energy efficient heating & cooling technologies ($/yr) [4]
- Private RD&D investment in energy efficient heating & cooling technologies ($/yr) [4]

Technology Readiness

- Typical cost for retrofitting existing heating/cooling system with energy efficient system ($/unit) [4]
- Maximum efficiency of a) electric heat pumps, b) gas-engine heat pumps, c) CHP, d) solar thermal, and e) AC systems(%) [4]
- Average installed efficiency of a) electric heat pumps, b) gas-engine heat pumps, c) CHP, d) solar thermal, and e) AC systems[4]

Market Readiness

- Percent improvement compared to 2000 of mandatory MEPS multiplied by market coverage for heating/cooling equipment sold in G20 countries (%) [1,4]
- Number of G20 countries with labeling programs, split by categorical, endorsement and other for heating and cooling equipment (#, type) [1,4]

Market Transformation

- Global sales of new energy efficient heating and cooling equipment (units/yr) [4,5,6]
- Learning rate: cost reduction associated with cumulative doubling in sales of high efficiency heating and cooling equipment (%) [2]
- Average energy use of new heating and cooling equipment sold (kWh/yr) [1]
- Percent of households with high efficiency heating/cooling system (%) [4]

Impacts

- End-use energy demand and GHG emissions avoided from use of high efficiency heating/cooling equipment (TWh, MtCO2e/yr) [4]

Energy Efficient Lighting

Draft Metrics for Measuring Progress toward a Global Clean Energy Economy

Resources

- Public RD&D investment in energy efficient lighting ($/yr) [1]
- Private RD&D investment in energy efficient lighting ($/yr) [1]

Technology Readiness

- Typical cost of retrofitting existing lighting systems with energy efficiency lighting in a) residential and b) service applications (yr) [3]
- Average installed efficacy of lighting in (a) residential and (b) service applications (lm/W) [2]
- Maximum efficacy of (a) a non-directional light source with lifetime of at least 6,000 hrs and (b) a directional light source with lifetime of at least 20,000 hrs (lm/W) [1]

Market Readiness

- Percent improvement compared to 2000 of mandatory minimum energy performance standards multiplied by market coverage for lamps sold in G20 countries (%) [4]
- Number of G20 countries with labeling programs, split by categorical, endorsement and other for lamps (#, type) [1,4]
- Capacity of manufacturing throughput of high efficacy devices (units/yr) [2]

Market Transformation

- Global sales of energy efficient lamps (units/type/yr) [4,5]
- Learning rate for capital costs: cost reduction associated with cumulative doubling in sales of high efficacy lighting (%) [6]
- Total electricity consumption from lighting by a) households and b) services [5]
- Percent of lighting devices using high efficacy systems (on a per lumen basis) (%) [5]

Impacts

- End-use energy demand and GHG emissions avoided (TWh, MtCO2e/yr) [4]

Energy Efficient Appliances

Draft Metrics for Measuring Progress toward a Global Clean Energy Economy

Resources

- Public RD&D investment in energy efficient appliances ($/yr) [1]
- Private RD&D investment in energy efficient appliances ($/yr) [1]

Technology Readiness

- Typical cost of purchasing an advanced appliance (yr) [2]
- Average installed efficiency of advanced (a) refrigerators, (b) televisions, (c) other electronic devices [2]
- Maximum efficiency achieved for (a) refrigerators (kWh/l/yr), (b) televisions (kWh/sq in/yr), (c) other electronic devices [1]
- Average life cycle energy consumption of advanced appliances, by type (kWh)

Market Readiness

- Percent improvement compared to 2000 of mandatory MEPS multiplied by market coverage for appliances sold in G20 countries (%) [1,5,6]
- Number of G20 countries with labeling programs, split by categorical, endorsement and other, for high efficiency appliances (#, type) [6]

Market Transformation

- Annual sales of high efficiency appliances (units/type/yr) [2,8,11]
- Learning rate for capital costs: cost reduction associated with cumulative doubling in sales of high efficiency appliances (%) [7]
- Average energy consumption for average new appliances, including (a) refrigerators, (b) televisions, (c) other electronic devices (kWh/yr) [5,10,11]
- Percent of installed appliance stock that can be considered high efficiency (% per type) [1]

Impacts

- End-use energy demand and GHG emissions avoided from use of energy efficient appliances (TWh, MtCO2e/yr)

Intelligent Transportation Systems

Sample Metrics for Measuring Progress toward a Global Clean Energy Economy

Resources

- Public RD&D investment in ITS technologies ($/yr) [1]
- Private RD&D investment in ITS technologies ($/yr) [1]

Technology Readiness

- Cost to implement integrated Vehicle-to-Infrastructure system (including ATMS, vehicle-to-vehicle communications, cooperative intersection collision avoidance systems, intelligent speed adaptation, etc) for population area of 1 million $/system [1]
- Cost of telematics device (e.g., GPS, some cell phones) that provides optimal route selection and navigation instructions based on location and real-time road conditions ($/unit) [1]
- Cost to implement Advanced Transportation Management Systems (ATMS) (e.g., traffic signals, ramp meters, message signs, etc.) for population area of 1 million ($/system) [1]

Market Readiness

- Number of G20 countries with ITS-enabled transportation pricing systems (e.g., congestion pricing, VMT fee system) for a) passenger vehicles and b) commercial transport (#) [1,2]
- Number of G20 countries with demonstration projects for vehicle-to-vehicle or vehicle-to-infrastructure integration systems (#) [1]
- Number of international technical standards for ITS technologies (e.g., passenger vehicles and freight/commercial vehicles) (#) [1]
- Funding for training and outreach for ITS among government transportation agencies, city planners, consumers, etc. ($/yr)[1]

Market Transformation

- Number of Vehicle-to-Infrastructure systems in place (#) [2]
- Telematics global market size ($) [1,2]
- Percentage of vehicles in G20 countries carrying some form of telematics device (e.g., GPS, smart phone) (%) [1,2,3]
- Percentage of vehicles in G20 metropolitan areas with population > 1 million that have access to real-time incident and travel time/speed information (%) [2]

Impacts

- Number of vehicle collisions per vehicle mile traveled (#/VMT) [5,6]
- CO2 emissions reductions from fuel savings, compared to 2005 baseline (MtCO2/hr) [1,5]
- Fuel savings from reduced congestion, compared to 2005 baseline (lge) [1,6]
- Average time lost due to traffic congestion (hrs/yr) [4]

Energy Storage – Vehicle Batteries (EV, HEV, PHEV)

Draft Metrics for Measuring Progress toward a Global Clean Energy Economy

Resources

- Public RD&D investment in battery technologies($/yr) [1]
- Private RD&D investment in battery technologies ($/yr) [1]

Technology Readiness

- Incremental capital cost of EV, HEV, PHEVs compared to conventional ICE vehicle of comparable size and performance (%) [4,6,7]
- Average fuel economy difference compared to conventional ICE vehicle of comparable size and performance (light duty) (%) [7]
- Battery specific power (kW/kg) [4]
- Battery power density (kW/L) [4]
- Battery life expectancy (cycles or yrs) [4]
- Average recharging time for EV and PHEVs (hrs/100 km) [4,7,8]
- Estimated cost of recharging infrastructure ($/car) [4]
- Cost of batteries in commercial production ($/kWh) [6,7]

Market Readiness

- Average national fuel efficiency standards in G20 countries (light duty) (km/L) [5,7]
- Value of subsidies per electric drive vehicle (EV, HEV, PHEV) among G20 countries ($/vehicle) [5,6,7,8,10]
- Number of nations with national EV/PHEV sales targets (#) [2,4,11]
- Manufacturing capacity of batteries (units/yr) [6,7]
- Number of electric charging points among G20 countries (#) [7]

Market Transformation

- Annual sales of electric vehicles (EV, HEV, PHEV) (#/yr) [3,4,5,9]
- Learning rate for capital costs: cost reduction associated with cumulative doubling in sales of vehicle batteries (%)
- Share of vehicle fleet that is electric (EV, HEV, PHEV) (%) [3,5,11]

Impacts

- GHG emissions avoided from use of electric vehicles (EV, HEV, PHEV) (MtCO2e/yr) [3]
- Reduction in petroleum consumption for transportation (bbls/yr)
- Number of employees in vehicle energy storage workforce (#) [1]

Smart Grids

Draft Metrics for Measuring Progress toward a Global Clean Energy Economy

Resources

- Public RD&D investment in smart grids ($/yr) [1]
- Private RD&D investment in smart grids ($/yr) [1,2]

Technology Readiness

- Electricity capacity of smart grids demonstrations and pilot tests (MW) [3]
- *Modeled* power system stability and reliability (CAIDI, SAIDI) [5]
- Capital and O&M costs of (a) advanced metering infrastructure, (b) customer systems, (c) distributed automation and monitoring, (d) transmission system monitoring and control, and (e) integrated systems [11,12]
- Expected lifespan of advanced metering infrastructure hardware (yrs) [12]

Market Readiness

- Number of organizations participating in international standards interoperability and/or harmonization activities [12]
- Percentage of products conforming to international smart grid standards [12]
- Number of G20 countries with performance or pricing standards, including tariff structures, for deploying smart grid technologies [3]
- Stakeholder understanding of the relative costs and benefits and acceptance of smart grid technologies (survey) [4]
- Number of G20 countries with protection mechanisms regarding privacy, ownership, and security issues associated with customer usage behavior data [4]
- Number of G20 countries with regulatory mechanisms that encourage markets to demonstrate or deploy smart grid technologies [4]
- Investments in information products and incentives that encourage deployment of consumer-based enabling technologies, such as energy use information ($) [4]

Market Transformation

- Percentage of consumers with access to real-time energy usage information, including dynamic pricing (%) [4]
- Number of networked phasor measurement units deployed (#) [2]
- Change in total capacity of automated demand response available compared to baseline (MW) [4]
- Capacity of electricity storage connected to smart grids at (a) transmission scale and (b) distribution scale (MW) [7]
- Distributed generation to total generation (ratio) [3,8]
- Change in Smart Grid Maturity Model (SGMM) scores [9]

Impacts

- Average ratio of peak power demand to average power demand [3]
- Average outage duration (hrs) [8,10]
- Frequency of power outages (CAIDI, SAIDI) [6]
- GHG emissions avoided from smart grid implementation (MtCO2e/yr)
- Reduction in (a) energy demand and (b) T&D line losses from improved volt/VAR control (%) [3,8]

Endnote references for key metric rationale and/or for data

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Appendix E: Summary Tables of Opportunities for Metrics Data Collection

Draft metrics frameworks were sent to the EGRD meeting participants prior to the meeting in two forms: Excel tables and PowerPoint slides. These are shown in Appendix D; also, refer to the Introduction and John Peterson's presentation summary for additional information.

The presentation reviewed how metrics opportunities were identified using the strength (the degree to which a metric forecasts progress accurately), and on the degree to which it is a leading indicator (how far into the future does this metric impact progress?), along with the degree to which the metric was already being measured and analysed by IEA. Metrics with high strength that were more leading than others were considered opportunities if they were not already being collected routinely. The results of this selection were summarised in three tables for generation technologies, end use technologies, and crosscutting technologies (see Tables 1 through 3 below). This methodology identified several broad areas of opportunity: private R&D expenditures, cost data, and performance data. This is described in more detail in the Conclusions section.

Table 1: Solar PV

Candidate Metric	Unit	Strength	Leading/Lagging	IEA Gathering	Comparison	Precision	Data Availability	Oppor-tunity
Public RD&D investment in PV technologies	**$/yr**	**Med-High**	**Leading-1**	**Yes**	**Trends**	**Medium**	**B**	
Private RD&D investment in PV technologies	**$/yr**	**Med-High**	**Leading-2**	**No**	**Trends**	**Low**	**B**	✓
Technology Readiness								
Unsubsidized LCOE ($/kWh) and capital cost ($/kW) from new PV installations in a) utility, b) commercial, and c) residential sectors	**$/kWh; $/kW**	**High**	**Leading-4**	**Partial**	**BLUE Map**	**Low-Med**	**B**	
Maximum PV efficiency (%) for next generation technologies achieved in lab and average annual improvement (%)	%	Medium	Leading-3	No	Trends	Medium	B	
Market Readiness								
Total value of subsidies issued for PV	**$/yr**	**High**	**Coincident-5**	**Yes**	**Trends**	**Med-High**	**C**	
Percent of G20 countries with grid integration policies for PV deployment	**%**	**Medium**	**Leading-3**	**Partial**	**Roadmap**	**High**	**C**	
Capacity and production of PV component manufacturing plants	MW/yr	Medium	Leading-4	No	BLUE Map	Med-High	C	
Share of PV power generation meeting a quota obligation system	%	Medium	Leading-4	No	Trends	Med-High	B	
Funding for training and outreach to create an educated PV workforce among government planners, industry builders, consumers, etc.	$/yr	Medium	Leading-3	No	Trends	Medium	C	
Market Transformation								
Installed PV a) capacity (MW) and b) generation (TWh/yr)	**MW; TWh/yr**	**High**	**Coincident-5,6**	**Yes**	**BLUE Map**	**High**	**A**	
Annual growth rates of PV a) capacity and b) generation	%/yr	High	Leading-4	Calculated	BLUE Map	High	A	
Learning rate (% cost reduction for each doubling of cumulative installed PV capacity)	%	Medium	Leading-2	No	BLUE Map	Med-High	B	
Market capitalization of PV companies	$	Low	Leading-4	No	Trends	Medium	C	
Impacts								
GHG emissions avoided	MtCO2e/yr	High	Lagging-6	Calculated	BLUE Map	High	C	
Life cycle environmental impact score of PV systems	score	Medium	Leading-4	No	Trends	Med-High	D	
Number of employees in PV workforce	#	Low	Leading-4	No	Trends	Med-High	B	

Table 2: Energy Efficient Heating & Cooling Equipment

Candidate Metric	Unit	Strength	Leading/Lagging	IEA Gathering	Comparison	Precision	Data Availability	Oppor-tunity
Resources								
Public RD&D investment in energy efficient heating and cooling equipment	**$/yr**	**Med-High**	**Leading-1**	**Yes**	**Trends**	**Medium**	**C**	
Private RD&D investment in energy efficient heating and cooling equipment	**$/yr**	**Med-High**	**Leading-2**	**No**	**Trends**	**Low**	**D**	✓
Technology Readiness								
Typical cost for retrofitting existing heating/cooling system with energy efficient system	$/unit	High	Leading-4	No	Trends	Medium	B	
Maximum and average installed efficiency of a) electric heat pumps, b) gas-engine heat pumps, c) CHP, d) solar thermal, and e) AC systems	**%**	**Med-High**	**Leading-3**	**No**	**BLUE Map**	**Medium**	**A**	✓
Installed costs of a) electric heat pumps, b) gas-engine heat pumps, c) CHP, d) solar thermal, and e) AC systems	**$/kW**	**High**	**Leading-4**	**No**	**BLUE Map**	**Medium**	**B**	✓
Market Readiness								
Percent improvement compared to 2000 of mandatory minimum energy performance standards for heating/cooling equipment sold in G20 countries, weighted by market coverage	**%**	**High**	**Leading-3**	**Yes**	**Roadmap**	**High**	**C**	
Number of G20 countries with labeling programs for heating and cooling equipment, split by categorical, endorsement, and other	**#**	**Med-High**	**Leading-3**	**Yes**	**Trends**	**High**	**B**	
Average value of incentives issued per high efficiency heating and cooling unit	$/unit	High	Coincident-5	Yes	Trends	Med-High	C	X
Market Transformation								
Global sales of new energy efficient heating and cooling equipment	**units/yr**	**High**	**Coincident-5**	**Yes**	**BLUE Map**	**High**	**B**	
Learning rate for capital costs (% cost reduction associated with cumulative doubling in sales of high efficiency heating and cooling equipment)	%	Medium	Leading-2	No	Trends	Med-High	B	
Average energy use of new heating and cooling equipment sold	kWh/yr	Medium	Leading-4	Yes	Trends	Medium	C	
Percent of households with high efficiency heating/cooling system	%	Medium	Coincident-5	No	Trends	Medium	C	
Impacts								
End-use energy demand and GHG emissions avoided from use of high efficiency heating and cooling equipment	TWh; MtCO2e/yr	High	Lagging-6	No	BLUE Map	High	C	
Number of employees in energy efficient heating and cooling workforce	#	Low	Leading-4	No	Trends	Med-High	D	X

Table 3: Energy Storage - Vehicle Batteries (EV, HEV, PHEV)

Candidate Metric	Unit	Strength	Leading/ Lagging	IEA Gathering	Comparison	Precision	Data Availability	Oppor-tunity
Resources								
Public RD&D investments in battery technologies	**$/yr**	**Med-High**	**Leading-1**	**Yes**	**Trends**	**Medium**	**B**	
Private RD&D investment in battery technologies	**$/yr**	**Med-High**	**Leading-2**	**No**	**Trends**	**Low**	**D**	✓
Technology Readiness								
Incremental capital cost of EV, HEV, PHEVs compared to conventional ICE vehicle of comparable size and performance (light duty)	**%**	**High**	**Leading-4**	**No**	**BLUE Map**	**Med-High**	**B**	✓
Average fuel economy difference compared to conventional ICE vehicle of comparable size and performance (light duty)	**%**	**Med-High**	**Leading-4**	**No**	**BLUE Map**	**Medium**	**B**	✓
Battery specific power	**kW/kg**	**Med-High**	**Leading-3**	**No**	**Trends**	**High**	**B**	✓
Battery power density	**kW/L**	**Med-High**	**Leading-3**	**No**	**Trends**	**High**	**B**	✓
Battery specific energy	**kWh/kg**	**Med-High**	**Leading-3**	**No**	**Trends**	**High**	**B**	✓
Battery energy density	**kWh/L**	**Med-High**	**Leading-3**	**No**	**Trends**	**High**	**B**	✓
Estimated cost of recharging infrastructure	$/car	Med-High	Leading-3	No	Trends	Medium	B	
Average recharging time for EV and PHEVs	hrs/100 km	Medium	Leading-3	No	Trends	Med-High	B	
Battery life expectancy	cycles; yrs	Medium	Leading-3	No	Trends	Med-High	C	
Cost of batteries in commercial production	$/kWh	Med-High	Leading-3	No	Trends	Medium	A	
Market Readiness								
Average national fuel efficiency standards in G20 countries (light duty)	**km/L**	**Medium**	**Leading-2**	**Yes**	**BLUE Map**	**High**	**B**	
Value of subsidies per electric drive vehicle (EV, HEV, PHEV) among G20 countries	$/vehicle	High	Leading-4	Partial	Trends, BLUE Map	High	B	
Number of nations with national EV/PHEV sales targets	#	Med-Low	Leading-3	Partial	Trends	High	B	
Manufacturing capacity of batteries	units/yr	Medium	Leading-4	No	BLUE Map	Med-High	C	
Number of electric charging points among G20 countries	#	Medium	Leading-4	No	Trends	Med-High	C	
Market Transformation								
Annual sales of electric vehicles (EV, HEV, PHEV)	**#/yr**	**High**	**Coincident-5**	**Yes**	**BLUE Map**	**High**	**B**	
Learning rate (% cost reduction associated with cumulative doubling in capacity)	%	Medium	Leading-2	No	Trends	Med-High	C	
Share of vehicle fleet that is electric (EV, HEV, PHEV)	%	Medium	Coincident-5	Calculated	BLUE Map	High	B	
Impacts								
GHG emissions avoided from use of electric vehicles (EV, HEV, PHEV)	MtCO2/yr	High	Lagging-6	Calculated	BLUE Map	High	A/B	
Reduction in petroleum consumption for transportation compared to BAU	bbls/yr	High	Lagging-6	Calculated	BLUE Map	High	B	
Number of employees in vehicle energy storage workforce	#	Low	Leading-4	No	Trends	Med-High	C	

The initial draft of the performance metrics framework attempted to economise on the number of metrics by combining cost and performance into payback period metrics. However, feedback from the group indicated that cost and performance are important enough to be tracked separately, and volatile factors such as fuel or electricity costs can obscure the trends of a payback period metric.

The group also had many suggestions for refining the definitions of the metrics including using installed costs and efficiencies rather than lab measures, and modifying weightings to reflect technology volumes. These changes have been made in the tables.

The group also recommended dropping some metrics, which are marked in the tables with an X in the Opportunity column.

Appendix F: Sample Questionnaires Provided at Workshop

Example of the questionnaire that was provided for the following technologies:

- Solar PV and Concentrating Solar Power
- Wind Power
- Biofuels and Biomass Power
- Coal Power Generation with CCS and High-Efficiency Low Emissions Coal Technologies

Objective #1: Input to Progress Report

1. *What is the likelihood that the technology will deploy as described in the BLUE Map scenario (select one):*

☐ Very Unlikely (<10%) ☐ Unlikely (10-40%) ☐ Maybe (40-60%) ☐ Likely (60-90%) ☐ Very Likely (>90%)

2. *What is the most important message about advancing this technology to convey to leaders attending the Clean Energy Ministerial in April 2012?*
3. *What opportunities exist for enhanced R&D cooperation to address areas not progressing as described in the BLUE Map scenario?*

Objective #2: Enhanced Metrics Framework

A. What metrics are most useful in assessing progress? Score the relative utility of each metric below, using the scale: [1 = low utility; 2 = moderate utility; or 3 = high utility].
B. Assess the current situation, as represented by the metric's data, regarding progress toward BLUE Map goals: [1 = inadequate; 2 = adequate; or 3 = more than adequate].

Metric		**A. Utility of the Metric as an Input to Assessing Progress (circle one)†**	**B. Adequacy of Current Situation (circle one)††**	**Comments (additional room for comments on back of form)**
Resources	Public R&D Investment	1 2 3	1 2 3	
	Private R&D Investment	1 2 3	1 2 3	
Technology Readiness	Performance (reliability, efficiency, lifespan, etc)	1 2 3	1 2 3	
	Capital cost (upfront equipment and installation costs)	1 2 3	1 2 3	
	Unsubsidized LCOE (includes financing, lifetime, O&M costs, etc)	1 2 3	1 2 3	
Market Readiness	Supply side infrastructure (manuf. capacity, trained workforce, etc)	1 2 3	1 2 3	
	Grid integration policies	1 2 3	1 2 3	
	Codes, standards, regulations, licensing	1 2 3	1 2 3	
	Government incentives & subsidies	1 2 3	1 2 3	
	Consumer/stakeholder awareness	1 2 3	1 2 3	
Other	Other factor, please describe:	1 2 3	1 2 3	
	Other factor, please describe:	1 2 3	1 2 3	

† Relative usefulness of the metric as an indicator of technical progress, or an input to assessing deployment progress.
†† Adequacy of the circumstances (as represented by the metric) to promote progress toward the ETP BLUE Map goals by 2050.

Example of the questionnaire that was provided for the following technologies:

- Energy Efficient Buildings – Heating & Cooling Equipment
- 4E – Efficient Electric End-Use Equipment

Objective #1: Input to Progress Report
1. *What is the likelihood that the technology will deploy as described in the BLUE Map scenario (select one):* ☐ Very Unlikely (<10%) ☐ Unlikely (10-40%) ☐ Maybe (40-60%) ☐ Likely (60-90%) ☐ Very Likely (>90%)
2. *What is the most important message about advancing this technology to convey to leaders attending the Clean Energy Ministerial in April 2012?*
3. *What opportunities exist for enhanced R&D cooperation to address areas not progressing as described in the BLUE Map scenario?*

Objective #2: Enhanced Metrics Framework

A. What metrics are most useful in assessing progress? Score the relative utility of each metric below, using the scale: [1 = low utility; 2 = moderate utility; or 3 = high utility].
B. Assess the current situation, as represented by the metric's data, regarding progress toward BLUE Map goals: [1 = inadequate; 2 = adequate; or 3 = more than adequate].

Metric		A. Utility of the Metric as an Input to Assessing Progress (circle one)†	B. Adequacy of Current Situation (circle one)††	Comments (additional room for comments on back of form)
Resources	Public R&D Investment	1 2 3	1 2 3	
	Private R&D Investment	1 2 3	1 2 3	
Technology Readiness	Performance (reliability, efficiency, lifespan, etc)	1 2 3	1 2 3	
	Capital cost (upfront costs compared to less efficient options)	1 2 3	1 2 3	
	Payback period (includes lifetime, O&M costs, etc)	1 2 3	1 2 3	
Market Readiness	Supply side infrastructure (manuf. capacity, trained workforce, etc)	1 2 3	1 2 3	
	Minimum energy performance standards	1 2 3	1 2 3	
	Government incentives & subsidies	1 2 3	1 2 3	
	Consumer/stakeholder awareness (labelling, advertising, etc)	1 2 3	1 2 3	
Other	Other factor, please describe:	1 2 3	1 2 3	
	Other factor, please describe:	1 2 3	1 2 3	

† Relative usefulness of the metric as an indicator of technical progress, or an input to assessing deployment progress.
†† Adequacy of the circumstances (as represented by the metric) to promote progress toward the ETP BLUE Map goals by 2050.

Example of the questionnaire that was provided for the following technology:

- Energy Storage – Vehicle Batteries

Objective #1: Input to Progress Report
1. *What is the likelihood that the technology will deploy as described in the BLUE Map scenario (select one):* ☐ Very Unlikely (<10%) ☐ Unlikely (10-40%) ☐ Maybe (40-60%) ☐ Likely (60-90%) ☐ Very Likely (>90%)
2. *What is the most important message about advancing this technology to convey to leaders attending the Clean Energy Ministerial in April 2012?*
3. *What opportunities exist for enhanced R&D cooperation to address areas not progressing as described in the BLUE Map scenario?*

Objective #2: Enhanced Metrics Framework

A. What metrics are most useful in assessing progress? Score the relative utility of each metric below, using the scale: [1 = low utility; 2 = moderate utility; or 3 = high utility].
B. Assess the current situation, as represented by the metric's data, regarding progress toward BLUE Map goals: [1 = inadequate; 2 = adequate; or 3 = more than adequate].

	Metric	A. Utility of the Metric as an Input to Assessing Progress (circle one)†	B. Adequacy of Current Situation (circle one)††	Comments (additional room for comments on back of form)
Resources	Public R&D Investment	1 2 3	1 2 3	
	Private R&D Investment	1 2 3	1 2 3	
Technology Readiness	Battery performance (recharge time, reliability, specific power, density, etc)	1 2 3	1 2 3	
	Capital cost (EV, HEV, PHEVs compared to vehicles of similar performance)	1 2 3	1 2 3	
	Fuel economy (EV, HEV, PHEVs compared to vehicles of similar performance)	1 2 3	1 2 3	
Market Readiness	Supply side infrastructure (charging points, manuf. capacity, trained workforce, etc)	1 2 3	1 2 3	
	Vehicle fuel efficiency standards	1 2 3	1 2 3	
	Government incentives & subsidies	1 2 3	1 2 3	
	Consumer/stakeholder awareness	1 2 3	1 2 3	
Other	Other factor, please describe:	1 2 3	1 2 3	
	Other factor, please describe:	1 2 3	1 2 3	

† Relative usefulness of the metric as an indicator of technical progress, or an input to assessing deployment progress.
†† Adequacy of the circumstances (as represented by the metric) to promote progress toward the ETP BLUE Map goals by 2050.

Example of the questionnaire that was provided for the following technology:

- Smart-Grids

Objective #1: Input to Progress Report

1. *What is the likelihood that the technology will deploy as described in the BLUE Map scenario (select one):*

☐ Very Unlikely (<10%) ☐ Unlikely (10-40%) ☐ Maybe (40-60%) ☐ Likely (60-90%) ☐ Very Likely (>90%)

2. *What is the most important message about advancing this technology to convey to leaders attending the Clean Energy Ministerial in April 2012?*

3. *What opportunities exist for enhanced R&D cooperation to address areas not progressing as described in the BLUE Map scenario?*

Objective #2: Enhanced Metrics Framework

A. What metrics are most useful in assessing progress? Score the relative utility of each metric below, using the scale: [1 = low utility; 2 = moderate utility; or 3 = high utility].

B. Assess the current situation, as represented by the metric's data, regarding progress toward BLUE Map goals: [1 = inadequate; 2 = adequate; or 3 = more than adequate].

Metric		A. Utility of the Metric as an Input to Assessing Progress (circle one)†	B. Adequacy of Current Situation (circle one)††	Comments (additional room for comments on back of form)
Resources	Public R&D Investment	1 2 3	1 2 3	
	Private R&D Investment	1 2 3	1 2 3	
Technology Readiness	Performance (stability, reliability, lifespan of equipment, etc)	1 2 3	1 2 3	
	Capital costs (adv metering infrastructure, customer systems, T&D automation, etc)	1 2 3	1 2 3	
	O&M costs (adv metering infrastructure, customer systems, T&D automation, etc)	1 2 3	1 2 3	
Market Readiness	Supply side infrastructure (equipment manuf. capacity, trained workforce, etc)	1 2 3	1 2 3	
	International standards (including interoperability, harmonizing, conformance)	1 2 3	1 2 3	
	Government incentives & subsidies	1 2 3	1 2 3	
	Consumer/stakeholder understanding and acceptance	1 2 3	1 2 3	
Other	Other factor, please describe:	1 2 3	1 2 3	
	Other factor, please describe:	1 2 3	1 2 3	

† Relative usefulness of the metric as an indicator of technical progress, or an input to assessing deployment progress.
†† Adequacy of the circumstances (as represented by the metric) to promote progress toward the ETP BLUE Map goals by 2050.

Appendix G: Summary Results of Meeting Questionnaires

This appendix provides a summary of the input received on the survey questionnaires by expert participants at the workshop.

Immediately following each of the technology-specific presentations and discussions at the workshop, EGRD participants were asked to complete a questionnaire for the respective technology area. (The workshop agenda was provided in Appendix A; also, refer to Appendix F for samples of the questionnaires.)

Table G.1: Tally of Responses to Question 1 "What is the likelihood that the technology will deploy as described in the BLUE Map scenario?"

	Very Unlikely	Unlikely	Maybe	Likely	Very Likely
Solar PV	0	2	5	4	7
Wind	0	0	3	7	4
Biofuels and Biomass	0	6	4	1	0
Coal Power Generation with CCS and HELE Coal Technologies	2	6	1	0	0
Energy Efficient Buildings – Heating & Cooling Equipment	1	1	5	2	1
4E – Efficient Electric End-use Equipment	0	3	4	2	0
Energy Storage – Vehicle Batteries	0	3	1	1	2
Smart Grids	0	2	3	4	0

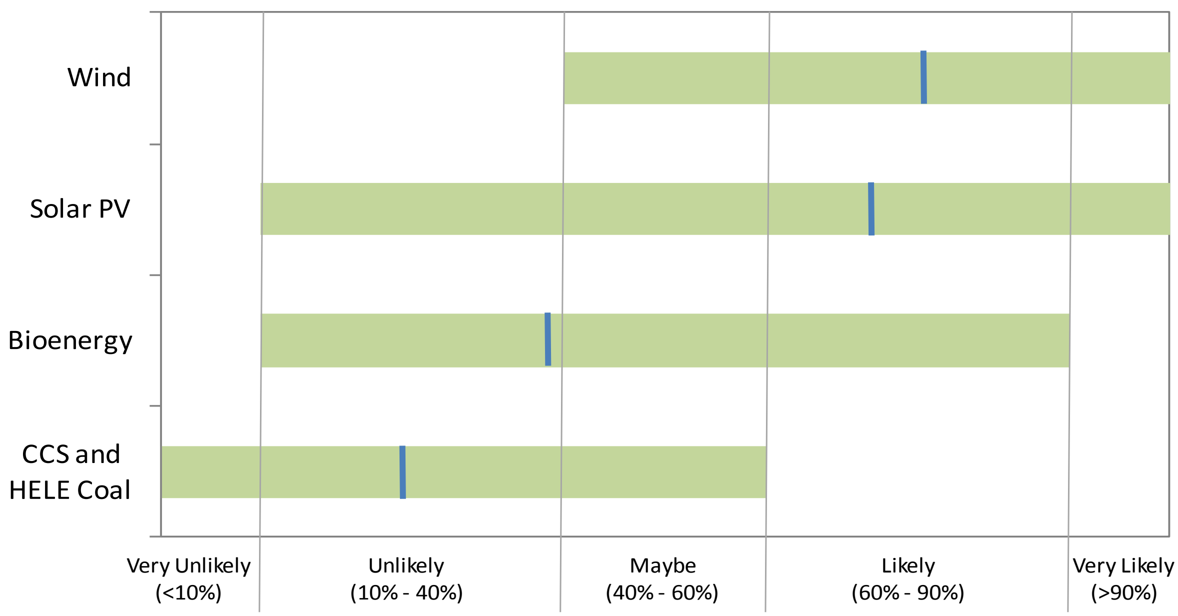
The values in Table G.1 refer to the number of respondents who indicated the given likelihood that the technology will be deployed as described in the BLUE Map scenario. For the purposes of the likelihood assessments, participants assumed that existing policies remained in place through 2050, and that there were no significant new policies implemented (e.g. global price on carbon). The potential impacts of proposed or future legislation, regulations, or standards were not reflected in this likelihood assessment.

The following charts illustrate the range and average (mean) likelihood that the technologies will meet the deployment targets outlined in the ETP2010 BLUE Map scenario. The blue line indicates the average response, and the horizontal bars show the range of responses.

The mean was calculated using a weighted average of all responses. The weighting was based on the average percentage likelihood in each category. For example, Very Likely represents 0-10%, Unlikely is 10-40%, Maybe is 40-60%, Likely is 60-90%, and Very Likely is 90-100%; the average for each category are 5%, 25%, 50%, 75%, and 95%, respectively.

As shown in Figure G.1, wind and solar PV are considered the most likely to achieve BLUE Map scenario targets of the four energy supply technologies examined by EGRD. Less promising is the progress in biomass power/biofuels and low-emission coal technologies. On average, those technologies are considered unlikely to meet the BLUE Map targets.

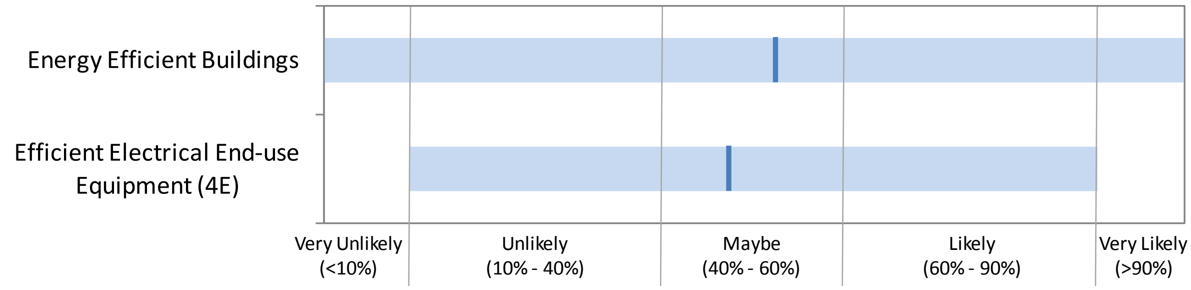
Figure G.1: Likelihood that Certain Energy Supply Technologies Will Meet IEA Blue Map Scenario Targets



Note: Bars indicate range of responses from survey of workshop participants; lines show mean response
Source: workshop survey responses.

Energy efficient buildings and end-use equipment are considered to be, on average, about 50% likely to achieve BLUE Map scenario targets. The range of responses for energy efficient buildings, as shown in Figure G.2, reflects the collective uncertainty in judging the likelihood that the technology area will meet BLUE Map targets through 2050.

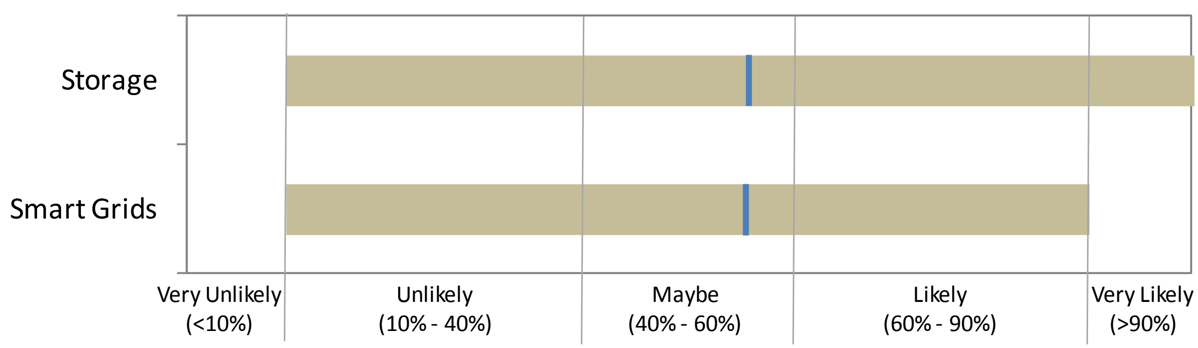
Figure G.2: Likelihood that Certain Energy Demand Technologies Will Meet IEA Blue Map Scenario Targets



Note: Bars indicate range of responses from survey of workshop participants; lines show mean response
Source: workshop survey responses.

Energy storage and smart grids are considered, on average, that they "maybe" will achieve BLUE Map scenario targets, as shown in Figure G.3.

Figure G.3: Likelihood that Certain Crosscutting Technologies Will Meet IEA Blue Map Scenario Targets



Note: Bars indicate range of responses from survey of workshop participants; lines show mean response
Source: workshop survey responses.

The remainder of this section provides a compilation of the results from each of the technology-specific survey questionnaires. The numerical values shown for "Utility of the Metric as an Input to Assessing Progress" and "Adequacy of Current Situation" represent the mean response, and the comments are transcribed from hand-written notes on the survey response forms.

SOLAR PV

A. What metrics are most useful in assessing progress? Score the relative utility of each metric below, using the scale:
[1 = low utility; 2 = moderate utility; or 3 = high utility].

B. Assess the current situation, as represented by the metric's data, regarding progress toward BLUE Map goals:
[1 = inadequate; 2 = adequate; or 3 = more than adequate].

Metric		**A. Utility of the Metric as an Input to Assessing Progress†**	**B. Adequacy of Current Situation††**	**Comments**
Resources	Public R&D Investment	2.3	1.8	- Downward trend is problematic - Balance investment - Area shift
Resources	Private R&D Investment	2.6	1.6	- Address more BOS - Make investment base in sustainable analysis
Technology Readiness	Performance (reliability, efficiency, lifespan, etc)	2.8	2.0	- Not there yet - Initiated, long-term
Technology Readiness	Capital cost (upfront equipment and installation costs)	2.6	1.7	- Not there yet
Technology Readiness	Unsubsidized LCOE (includes financing, lifetime, O&M costs, etc)	2.5	1.8	- Not there yet
Market Readiness	Supply side infrastructure (manuf. capacity, trained workforce, etc)	2.1	1.8	- Adequacy varies greatly by geography - Not addressed - Integrated solution is needed - A total system (cell, storage) would
Market Readiness	Grid integration policies	2.3	1.3	- Not addressed (inadequate) - Integrated solution is needed
Market Readiness	Codes, standards, regulations, licensing	2.3	1.7	- Not addressed (inadequate) - Integrated solution is needed
Market Readiness	Government incentives & subsidies	2.2	1.9	- Change too quickly - More countries need to promote the development - Confused/misguided/need more careful development
Market Readiness	Consumer/stakeholder awareness	2.2	1.9	- Not addressed (inadequate) - Some efforts could be needed In customer awareness in specific areas
Other	Other factors:	• Availability and lifetime metrics • Export metrics (Not adequately defined in international export statistics) • Business concepts (International exchange of experiences) • Generation cost per kWh • Domestic power generation		

† Relative usefulness of the metric as an indicator of technical progress, or an input to assessing deployment progress. Values shown represent average 'utility' score from questionnaire responses.

†† Adequacy of the circumstances (as represented by the metric) to promote progress toward the ETP BLUE Map goals by 2050. Values shown represent average 'adequacy' score from questionnaire responses.

WIND ENERGY				
A. What metrics are most useful in assessing progress? Score the relative utility of each metric below, using the scale: [1 = low utility; 2 = moderate utility; or 3 = high utility]. B. Assess the current situation, as represented by the metric's data, regarding progress toward BLUE Map goals: [1 = inadequate; 2 = adequate; or 3 = more than adequate].				
Metric		**A. Utility of the Metric as an Input to Assessing Progress†**	**B. Adequacy of Current Situation††**	**Comments**
Resources	Public R&D Investment	2.0	1.9	- Some countries need to improve the financing mechanism to keep private confidence -Technology is mature so private RD&D more significant metric
	Private R&D Investment	2.3	1.8	-To be developed -Problem that has to be overcome for new technologies
Technology Readiness	Performance (reliability, efficiency, lifespan, etc)	2.5	2.2	-Is saying windmills will be replaced adequate or desirable?
	Capital cost (upfront equipment and installation costs)	2.6	1.8	- USD 1 500-2 000/kW(2050)
	Unsubsidized LCOE (includes financing, lifetime, O&M costs, etc)	2.7	1.8	-If it requires subsidies it is adequate
Market Readiness	Supply side infrastructure (manuf. capacity, trained workforce, etc)	2.3	1.9	-Varies by geography
	Grid integration policies	2.6	1.6	-Should be measured per country
	Codes, standards, regulations, licensing	2.2	1.7	
	Government incentives & subsidies	2.3	2.0	-To be developed as metrics -Compare to LCoE and grid on a per MW basis
	Consumer/stakeholder awareness	2.3	1.6	-To be developed -New future will need strong effort to reinforce solid acceptance -Research on acceptance drivers needs to be strengthened
Other	Other factors:	• Energy amortization time • Time from application to generation • Weight • Energetic lifetime • RD&D policies, strategies, etc. • Regional planning • Social acceptance policies • Safety and environmental aspects		

† Relative usefulness of the metric as an indicator of technical progress, or an input to assessing deployment progress. Values shown represent average 'utility' score from questionnaire responses.
†† Adequacy of the circumstances (as represented by the metric) to promote progress toward the ETP BLUE Map goals by 2050. Values shown represent average 'adequacy' score from questionnaire responses.

BIOENERGY				
A. What metrics are most useful in assessing progress? Score the relative utility of each metric below, using the scale: [1 = low utility; 2 = moderate utility; or 3 = high utility]. B. Assess the current situation, as represented by the metric's data, regarding progress toward BLUE Map goals: [1 = inadequate; 2 = adequate; or 3 = more than adequate].				
Metric		**A. Utility of the Metric as an Input to Assessing Progress†**	**B. Adequacy of Current Situation††**	**Comments**
Resources	Public R&D Investment	2.5	1.6	-Feedstock cost/competition is a big issue -Needs focus/concentration
	Private R&D Investment	2.4	1.4	-Likely require substantial investment
Technology Readiness	Performance (reliability, efficiency, lifespan, etc)	2.6	1.5	-Adequacy for biomass power is 2 and for biofuels is 1 -Not competitive today-too costly, feedstocks limited
	Capital cost (upfront equipment and installation costs)	2.6	1.6	-Adequacy for biomass power is 2 and for biofuels is 1 -Not competitive today-too costly, feedstocks limited
	Unsubsidized LCOE (includes financing, lifetime, O&M costs, etc)	2.7	1.4	-Adequacy for biomass power is 2 and for biofuels is 1 -Not competitive today-too costly, feedstocks limited -It will be a problem if “cost gap” remains
Market Readiness	Supply side infrastructure (manuf. capacity, trained workforce, etc)	2.2	1.5	-Transportation, pipelines, etc.
	Grid integration policies	1.8	2.0	
	Codes, standards, regulations, licensing	2.5	1.4	-Include sustainability
	Government incentives & subsidies	2.6	1.5	-To be developed -Need level playing field
	Consumer/stakeholder awareness	2.	1.3	-Competition for land is a clear challenge
Other	Other factors:	• Biomass sustainability (Label) indicator • Competing use of biomass • Biomass potential • Vertical integration in countries • Level of support from legacy oil companies		

† Relative usefulness of the metric as an indicator of technical progress, or an input to assessing deployment progress. Values shown represent average ‘utility’ score from questionnaire responses.

†† Adequacy of the circumstances (as represented by the metric) to promote progress toward the ETP BLUE Map goals by 2050. Values shown represent average ‘adequacy’ score from questionnaire responses.

COAL POWER GENERATION WITH CCS AND HELE COAL TECHNOLOGIES				
A. What metrics are most useful in assessing progress? Score the relative utility of each metric below, using the scale: [1 = low utility; 2 = moderate utility; or 3 = high utility]. B. Assess the current situation, as represented by the metric's data, regarding progress toward BLUE Map goals: [1 = inadequate; 2 = adequate; or 3 = more than adequate].				
Metric		**A. Utility of the Metric as an Input to Assessing Progress†**	**B. Adequacy of Current Situation††**	**Comments**
Resources	Public R&D Investment	2.6	1.3	-Public risks/storage liability, no insurances
	Private R&D Investment	2.8	1.1	
Technology Readiness	Performance (reliability, efficiency, lifespan, etc)	2.5	1.4	-We have injected CO_2 underground since 1960, and captured since 1970
	Capital cost (upfront equipment and installation costs)	2.6	1.3	-The problem of CCS is mostly public acceptance, cost
	Unsubsidized LCOE (includes financing, lifetime, O&M costs, etc)	2.4	1.4	-Long-term liability need public efforts to monitor -LCoE does not account for expected generation hours (max 4000-5000 due to renewables)
Market Readiness	Supply side infrastructure (manuf. capacity, trained workforce, etc)	1.6	1.8	-3500 km of pipelines for CO_2 are installed already
	Grid integration policies	1.6	2.0	-Smart cities -> smart regions - CO_2 grid
	Codes, standards, regulations, licensing	1.6	1.5	-Merging software for mass-transport-reactive-geochemical, flue gas contaminants
	Government incentives & subsidies	2.5	1.5	
	Consumer/stakeholder awareness	2.6	1.4	-Only 1-5% of people know what CCS is. Coexistence/conflicting use of underground (i.e. natural gas storage, geothermal), closed lobbies (commercial on CO_2 geonet, network)
Other	Other factors:	• Liabilities • Social acceptance		

† Relative usefulness of the metric as an indicator of technical progress, or an input to assessing deployment progress. Values shown represent average 'utility' score from questionnaire responses.
†† Adequacy of the circumstances (as represented by the metric) to promote progress toward the ETP BLUE Map goals by 2050. Values shown represent average 'adequacy' score from questionnaire responses.

ENERGY EFFICIENT BUILDINGS – HEATING & COOLING TECHNOLOGIES				
A. What metrics are most useful in assessing progress? Score the relative utility of each metric below, using the scale: [1 = low utility; 2 = moderate utility; or 3 = high utility]. B. Assess the current situation, as represented by the metric's data, regarding progress toward BLUE Map goals: [1 = inadequate; 2 = adequate; or 3 = more than adequate].				
Metric		**A. Utility of the Metric as an Input to Assessing Progress†**	**B. Adequacy of Current Situation††**	**Comments**
Resources	Public R&D Investment	1.9	1.7	
	Private R&D Investment	2.1	1.9	
Technology Readiness	Performance (reliability, efficiency, lifespan, etc)	2.8	2.1	-Many exciting technologies, make an integrated system
	Capital cost (upfront costs compared to less efficient options)	2.4	1.4	-Many exciting technologies, make an integrated system
	Payback period (includes lifetime, O&M costs, etc)	2.9	1.4	-Many exciting technologies, make an integrated system
Market Readiness	Supply side infrastructure (manuf. capacity, trained workforce, etc)	2.5	1.6	
	Minimum energy performance standards	2.9	1.4	-Stronger policy needed- mandates
	Government incentives & subsidies	2.3	1.4	-Stronger policy needed- mandates
	Consumer/stakeholder awareness (labelling, advertising, etc)	2.6	1.4	-Stronger policy needed- mandates
Other	Other factors:	• Share of renewable energy in electricity consumption of heat pumps • Financial issues • Market transformation • Annual energy consumption per square meter		

† Relative usefulness of the metric as an indicator of technical progress, or an input to assessing deployment progress. Values shown represent average 'utility' score from questionnaire responses.
†† Adequacy of the circumstances (as represented by the metric) to promote progress toward the ETP BLUE Map goals by 2050. Values shown represent average 'adequacy' score from questionnaire responses.

4E – EFFICIENCT ELECTRIC END-USE EQUIPMENT				
A. What metrics are most useful in assessing progress? Score the relative utility of each metric below, using the scale: [1 = low utility; 2 = moderate utility; or 3 = high utility]. B. Assess the current situation, as represented by the metric's data, regarding progress toward BLUE Map goals: [1 = inadequate; 2 = adequate; or 3 = more than adequate].				
Metric		**A. Utility of the Metric as an Input to Assessing Progress†**	**B. Adequacy of Current Situation††**	**Comments**
Resources	Public R&D Investment	1.6	1.9	
	Private R&D Investment	2.1	1.8	
Technology Readiness	Performance (reliability, efficiency, lifespan, etc)	2.8	1.9	-Learning curve rates for refrigeration is the most important metric
	Capital cost (upfront costs compared to less efficient options)	2.6	1.7	
	Payback period (includes lifetime, O&M costs, etc)	2.4	2.1	-LED learning rates
Market Readiness	Supply side infrastructure (manuf. capacity, trained workforce, etc)	1.6	2.1	-Policies accelerate the rate of learning
	Minimum energy performance standards	2.8	1.7	
	Government incentives & subsidies	2.1	1.7	-Policy coverage is the most important metric
	Consumer/stakeholder awareness (labelling, advertising, etc)	2.8	1.6	-Need wider range of metrics-existing standard protocols measure the wrong things
Other	Other factors:	• Life cycle assessment (to account for production energy consumption) • Top-runner approach for MEPS • Financial facilities • Coverage of S&L • Rebound effects • Total consumption per household		

† Relative usefulness of the metric as an indicator of technical progress, or an input to assessing deployment progress. Values shown represent average 'utility' score from questionnaire responses.
†† Adequacy of the circumstances (as represented by the metric) to promote progress toward the ETP BLUE Map goals by 2050. Values shown represent average 'adequacy' score from questionnaire responses.

ENERGY STORAGE – VEHICLE BATTERIES				
A. What metrics are most useful in assessing progress? Score the relative utility of each metric below, using the scale: [1 = low utility; 2 = moderate utility; or 3 = high utility]. B. Assess the current situation, as represented by the metric's data, regarding progress toward BLUE Map goals: [1 = inadequate; 2 = adequate; or 3 = more than adequate].				
Metric		**A. Utility of the Metric as an Input to Assessing Progress†**	**B. Adequacy of Current Situation††**	**Comments**
Resources	Public R&D Investment	1.7	1.7	
	Private R&D Investment	2.7	1.3	
Technology Readiness	Battery performance (recharge time, reliability, specific power, density, etc)	2.9	1.6	
	Capital cost (EV, HEV, PHEVs compared to vehicles of similar performance)	2.6	1.0	
	Fuel economy (EV, HEV, PHEVs compared to vehicles of similar performance)	2.9	1.7	
Market Readiness	Supply side infrastructure (charging points, manuf. capacity, trained workforce, etc)	2.6	1.6	
	Vehicle fuel efficiency standards	2.1	1.7	
	Government incentives & subsidies	2.1	1.7	-Not governments, but systems operators may be decisive
	Consumer/stakeholder awareness	2.4	1.7	
Other	Other factors:	• Sustainability/weight indicator • Financial facilities • Safety standards		

† Relative usefulness of the metric as an indicator of technical progress, or an input to assessing deployment progress. Values shown represent average 'utility' score from questionnaire responses.
†† Adequacy of the circumstances (as represented by the metric) to promote progress toward the ETP BLUE Map goals by 2050. Values shown represent average 'adequacy' score from questionnaire responses.

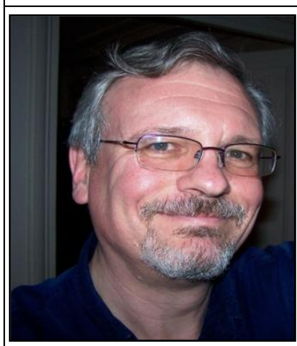
SMART GRIDS				
A. What metrics are most useful in assessing progress? Score the relative utility of each metric below, using the scale: [1 = low utility; 2 = moderate utility; or 3 = high utility]. B. Assess the current situation, as represented by the metric's data, regarding progress toward BLUE Map goals: [1 = inadequate; 2 = adequate; or 3 = more than adequate].				
Metric		**A. Utility of the Metric as an Input to Assessing Progress†**	**B. Adequacy of Current Situation††**	**Comments**
Resources	Public R&D Investment	2.3	1.5	
	Private R&D Investment	2.8	1.6	-Hard to get reliable investment
Technology Readiness	Performance (stability, reliability, lifespan of equipment, etc)	2.3	1.7	-Lifespan of ICT
	Capital costs (adv metering infrastructure, customer systems, T&D automation, etc)	2.4	1.5	-Important for regulation proceeding, varies by developing for emerging
	O&M costs (adv metering infrastructure, customer systems, T&D automation, etc)	2.2	1.6	
Market Readiness	Supply side infrastructure (equipment manuf. capacity, trained workforce, etc)	2.6	1.3	
	International standards (including interoperability, harmonizing, conformance)	2.8	1.3	-Very important -Intent is there, just need policymakers to approve
	Government incentives & subsidies	2.0	1.8	- Subsidies need to start things, but make themselves superfluous.
	Consumer/stakeholder understanding and acceptance	2.6	1.4	-International knowledge exchange is needed -Misinformation abounds - Crucial. Currently only perspective of SG sector
Other	Other factors:	• Policy and legislation • Data privacy/data security • Uptake of grid-connected vehicles		

† Relative usefulness of the metric as an indicator of technical progress, or an input to assessing deployment progress. Values shown represent average 'utility' score from questionnaire responses.
†† Adequacy of the circumstances (as represented by the metric) to promote progress toward the ETP BLUE Map goals by 2050. Values shown represent average 'adequacy' score from questionnaire responses.

Appendix H: Speaker Bios

Rob Kool, Chair of the IEA Experts' Group on R&D Priority Setting and Evaluation, is Manager of the Energy and Climate Cooperation Europe for NL Agency, the Innovation and Sustainability of the Netherlands. Rob has over 30 years of experience with a broad range of topics in the energy field such as municipal energy policy, design of new efficient suburbs, district heating, build environment, joint implementation, CDM and leading international co-operation projects. Rob is active and holds leadership roles in many international fora, including the association of European Energy Agencies EnR, vice-president of European Council for Energy Efficiency, and vice-chair for the Demand Side Management Implementing Agreement. Rob holds a business degree, Netherlands Business School, and a PhD in biology (University of Utrecht).

Ambassador Richard Jones, Deputy Executive Director of the IEA, brings over thirty years of diplomatic and policy experience with high-level issues such as Middle East politics, trade negotiations and energy security. He served as U.S. Ambassador in Israel, Kuwait, Kazakhstan, and Lebanon and has acted as the U.S. Secretary of State's Senior Advisor and Co-ordinator for Iraq Policy from February-August, 2005. During his diplomatic career Amb. Jones was instrumental in facilitating negotiations on oil security issues in areas of political or financial sensitivity. Amb. Jones also held many posts in international organisations, most notably as the Economic Policy Advisor, U.S. Mission to the OECD. Amb. Jones holds a BA in mathematics (Harvey Mudd College) and MS and PhD degrees in Business/Statistics (University of Wisconsin).



Lewis Fulton is the Senior Transport Energy Analyst, transport team leader and Acting Head of the Energy Technology Policy Division. He has worked internationally in the field of transport/energy/environment analysis and policy development for over 20 years, at the IEA in Paris and for the United Nations Environment Program in Kenya on developing and implementing sustainable transport projects around the world. His IEA reports include Transport, Energy and CO2: Moving Toward Sustainability, Saving Oil in a Hurry, Biofuels for Transport: An International Perspective, and Bus Systems for the Future. Mr. Fulton holds a Ph.D. in Energy Management and Environmental Policy (University of Pennsylvania).

Antonia Gawel, Energy Analyst in the IEA Energy Technology Policy Division, is responsible for IEA's work on monitoring and evaluating clean energy technology progress for the IEA Energy Technology Perspectives, the G-20 and the Clean Energy Ministerial. Ms. Gawel also developed the strategy and launch of the G8 mandated International Low-Carbon Energy Technology Platform. Ms. Gawel was formerly the Deputy Director, Energy and Climate, World Business Council for Sustainable Development. Ms. Gawel has also held positions in the areas of energy and sustainability policy evaluation for private and NGO sectors in the United Kingdom and Canada. Ms. Gawel holds a BA in Resource Economics (University of Toronto), and a MSc in Policy and Regulation (London School of Economics and Political Science).

Robert Marlay is the Director of the Office of Climate Change Policy and Technology in the Office of Policy and International Affairs at the U.S. Department of Energy. Mr. Marlay has more than 30 years experience in the areas of national security, energy policy, science policy, and management of research and development programmes. Earlier, he served as Director of the Office of Science and Technology Policy. He has also held leadership positions in the Offices of Science, Energy Efficiency and Renewable Energy, and in the Federal Energy Administration. Mr. Marlay holds a BSE from Duke University, as well as two Masters degrees and a PhD from the Massachusetts Institute of Technology.

Uwe Remme, Energy Analyst in the Energy Technology Policy Division of the International Energy Agency (IEA), has more than ten years experience in energy systems modelling and analysis. Prior to joining the IEA, Mr. Remme researched several national and European projects in the field of energy modelling as well as assessment of technologies and policy instruments at the University of Stuttgart. Mr. Remme studied chemical engineering at RWTH Aachen University, Germany, and Carnegie Mellon University, Pittsburgh, and completed a PhD degree in mechanical engineering at the Institute of Energy Economics and the Rationale Use of Energy (University Stuttgart).

Wim Sinke, Chairman of the European Photovoltaic Technology Platform and professor of Science, Technology and Society (Utrecht University), began his career as a visiting scientist at the Hitachi Central Research Laboratory and the Institute for Atomic and Molecular Physics. Mr. Winke established the photovoltaics research programme at the Energy research Centre of the Netherlands, serving later as assistant director and senior staff member for Programme and Strategy in the Solar Energy unit. Mr. Sinke received several awards in solar science, technology and implementation programmes. Mr. Sinke studied experimental physics (Utrecht University), PhD research (FOM-Institute for Atomic and Molecular Physics) and received a Ph.D. from Utrecht University.

Birte Holst Jørgensen, senior scientist at Risø DTU Wind Division, was recently appointed Principal Coordinator of the Sino-Danish Centre for Research and Education Programme for Sustainable Energy, a strategic cooperation between Danish universities and the Ministry of Science, Technology and Innovation with the Graduate University of the Chinese Academy of Sciences and the Chinese Academy of Sciences. Ms. Holst Jørgensen holds a MSc in Business Economics (Copenhagen Business School) and a PhD in Political Science (University of Copenhagen). Ongoing research includes strategic energy technology policies, technology foresight, support mechanisms for sustainable energy and international energy cooperation.

Sascha T. Schroeder is employed at Risø DTU and pursues a PhD in collaboration with the Danish Transmission System Operator Energinet.dk. His focus is on market design options for a better integration of wind energy, especially in offshore grids. Mr. Schroeder has studied Industrial Engineering with a specialisation in Energy and Environmental Management at the University of Flensburg, Germany and ESC Rennes, France. Mr. Schroeder has experience with the economics of storage technologies, interconnector usage and network regulation as well as on micro-cogeneration.

Josef Spitzer is Associate Professor in Energy Economics at the Graz University of Technology and the former chair of the Bioenergy Implementing Agreement. Mr. Spitzer began his career in the nuclear industry and followed on with work at the Battelle Institute e.V. Frankfurt. For nearly 30 years he served as the Head of the Institute of Energy Research at JOANNEUM RESAERCH Forschungsgesellschaft mbH in Graz. Mr. Spitzer also served as Chairman of the evaluation of Finish energy research. Mr. Spitzer studied Mechanical Engineering at the Graz University of Technology and of Nuclear Engineering (United States).

Fedora Quattrocchi, Research Director at the National Institute of Technology, oversees several projects relating to underground use relate of energy production (including enhanced oil recovery using CO2 at the Weyburn field). Ms. Quattrocchi is also responsible for the unit treating Functional Fluid Geochemistry, Geological Storage and Geothermics in the Seismicity and Tectonophysics department. Ms. Quattrocchi also served as an expert reviewer for the International Panel for a Climate Change Convention report Carbon Dioxide Capture & Storage. Ms. Quattrocchi is a lecturer for Global Environmental Protection and International Policies, Faculty of Industrial Engineering (University Tor Vergata) and for Technologies for the Greenhouse Gases reduction (University of Perugia).

Charles Taylor is the Director, Chemistry and Surface Science, Office of Research and Development at the U.S. National Energy Technology Laboratory. Mr. Taylor's research includes synthesis, magnetic, and spectral properties of triorganosiloxy- and triorganogermoxy-copper (II) complexes, and conversion of methane to gasoline-range hydrocarbons. Mr. Taylor has served as Leader of the Hydrogen Membrane Separation Group, Methane Hydrate Research Group, the Leader of the Reactor Engineering Team, and the Methane Conversion Team. Mr. Taylor has authored over 70 publications and 6 U.S. patents. Mr. Taylor has held many leadership roles for the American Chemical Society's Division of Fuel Chemistry and the Pittsburgh-Cleveland Catalysis Society. Mr. Taylor earned a Ph.D in organic chemistry (Duquesne University).

Herbert Greisberger is Secretary General of the Austrian Society for Environment and Technology where his projects focus on R&D and innovation with a special focus on sustainable buildings and energy. Mr. Greisberger is also scientific manager for Future Dialog 2035 examining major European developments in the next 25 years. Mr. Greisberger was formerly the senior scientist, R&D, innovation and energy technologies for the Austrian Energy Agency and has experience managing large teams and organisations. Mr. Greisberger is lecturer at the Institute for Research and Education focussing on energy economy and energy management. Mr. Greisberger studied economics (University of Graz) and holds a PhD (University of Stuttgart).

Rod Janssen is an independent energy and environment consultant based in Paris and London with over 20 years of experience in authoring reports that monitor progress on energy efficiency, and particularly the buildings sector. Most recently, Mr. Janssen has been following the recast of the Energy Performance of Buildings Directive. Mr. Janssen was formerly with the IEA and also served as a senior advisor in energy efficiency policy for the European Commission. Mr. Janssen holds a BA in Political Science and an MA in International Relations (University of Western Ontario).

Photo

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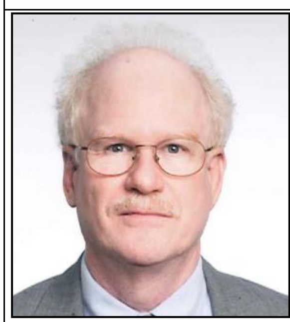
Frank Klinckenberg, energy consultant, has worked as an advisor on energy issues for more than 25 governments, including the EU, US, China, Croatia, Egypt, India, Kenya, Russia, Syria, Turkey, and Tunisia. Mr. Klinckenberg has been involved in establishing and shaping new policy frameworks for energy-efficient appliances for governments, the United Nations Development and Environment Programmes, the IEA, the Climate Technology Imitative, industry associations and NGOs. Mr. Klinckenberg managed the Dutch household appliance energy efficiency programme, served as Policy Director, UK Market Transformation Programme and Technical Director for the US-based Collaborative Labelling and Appliance Standards Program.

Andrew Chu is Vice President, Marketing and Communications, at A123 Systems. Since joining A123 in early 2003, he has served in multiple roles, including R&D, manufacturing support, applications engineering, program management, marketing, policy, and business development. To support the company's US battery manufacturing, Mr. Chu led the team that gained a USD 249M contract from the US Department of Energy. Mr. Chu has 17 years experience with lithium-ion batteries. Prior to joining A123 Systems, he was the Department Manager, Energy Technologies, for HRL (formerly Hughes Research Lab). Mr. Chu holds a PhD, Materials Science and Engineering (University of Pennsylvania), and two engineering degrees (University of Michigan).

Russ Conklin, Policy Analyst, Office of Policy and International Affairs, U.S. Department of Energy is also Vice-Chair of the International Smart Grid Action Network Implementing Agreement, a Clean Energy Ministerial initiative. Mr. Conklin coordinates U.S. government participation in ISGAN, working closely with DOE's Office of Electricity Delivery and Energy Reliability. Mr. Conklin helped coordinate the development and integration of 10 action plans for the deployment of clean energy technologies released under the Major Economies Forum Global Partnership at the UN Climate Change Conference. Mr. Conklin holds a MA in Public Policy (University of Maryland at College Park) and a BA with highest distinction and honours (Pennsylvania State University).



John Peterson is a senior energy modeler for the U.S. Department of Energy. Mr. Peterson has held a number of positions in government and industry in the modeling and simulation field. Mr. Peterson headed the initial MARKAL energy modeling effort at the Department of Energy's Office of Program Analysis and Evaluation, and combines modeling with serving as the department's nuclear energy specialist as well. Mr. Peterson holds a BA in mathematics and a PhD in Computer Science (modeling and simulation) from the University of Kansas.

Stathis Peteves is Head of the Energy Systems Evaluation Unit in the Institute for Energy at the European Commission's Joint Research Centre. Mr. Peteves has over 20 years of experience at the EC addressing issues all broad range of energy technology, modelling and policy issues. The key activities of his Unit include techno-economic assessments of energy technologies, energy technologies/systems modelling and impact analyses. Mr. Peteves' current focus includes the Strategic Energy Technologies Plan (SET-Plan) and specifically the Information System (SETIS), the scientific and technical support tool to the decision making of the SET-Plan governance. Mr. Peteves holds degrees from the National Technical University of Athens, George Washington University and the University of Florida.

Craig Zamuda is a senior policy advisor with the Office of Policy and International Affairs at the U.S. Department of Energy. Mr. Zamuda has 30 years of experience with the U.S. Department of Energy and the U.S. Environmental Protection Agency. Mr. Zamuda represents the Department of Energy in domestic and international fora for the advancement of climate change mitigation and adaptation activities, including international collaboration on technology development and deployment through the Clean Energy Ministerial, and the IEA. Mr. Zamuda serves as DOE's representative to the White House Climate Change Adaptation Task Force; and the Office of Science and Technology Policy's Interagency National Climate Assessment Working Group. Mr. Zamuda holds a PhD in Environmental Sciences (University of Maryland) and a MS and BS in Biological Sciences (Rutgers University).

Carrie Pottinger is Secretary to the IEA Experts' Group on R&D Priority Setting and Evaluation and carries out national R&D policy reviews and national R&D co-ordination efforts. Ms. Pottinger is also the secretary to the IEA Fusion Power Co-ordinating Committee. Ms. Pottinger has more than 20 years cumulative energy knowledge and analysis, particularly in the areas of energy statistics, energy policies and technology and R&D and has authored more than 30 statistical and technology publications. In her current post as Programme Manager for Technology R&D Networks, Ms. Pottinger oversees a 42 energy technology research groups comprised of more than 6,000 experts worldwide. Ms. Pottinger holds a BA in Communications (University of Washington) and has studied economics, data analysis and price forecasting.

Appendix I: List of Acronyms

4E	efficient electrical end-use equipment
AEI	Accelerating Energy Innovation
AMI	advanced metering infrastructure
ARRA	American Recovery and Reinvestment Act
BAPV	building applied solar photovoltaic
BIPV	building integrated solar photovoltaic
C3E	Clean Energy and Energy Efficiency Working Group
CCGT	combined-cycle gas turbine
CCS	carbon capture and storage
CdTe	cadmium telluride
CERT	IEA Committee on Energy Research and Technology
CO_2	carbon dioxide
CEM	Clean Energy Ministerial
CES	Clean Energy Standard
CLASP	Collaborative Labelling and Appliance Standards Program
CSP	concentrating solar power
DOE	U.S. Department of Energy
EII	European Industrial Initiatives
EOR	enhanced oil recovery
EU	European Union
EV	electric vehicle
ISGAN	International Smart Grid Action Network
KPI	key performance indicators
kWh	kilowatt-hour
LCOE	Levelised Cost of Electricity (LCOE)
Li-ion	lithium-ion
LNG	liquefied natural gas
MEF	Major Economies Forum
MEPS	minimum energy performance standards
Mtoe	Million tonnes of oil equivalent
MWh	megawatt-hour
NiMH	nickel metal hydride
NRAP	National Risk Assessment Partnership
O&M	operations and maintenance
OECD	Organisation for Economic Co-operation and Development
PHEV	plug-in hybrid electric vehicle
PMF	Performance Measurement Framework
PNNL	Pacific Northwest National Lab
PV	solar photovoltaic
R&D	research and development
FERC	Federal Energy Regulatory Commission
FP7	EU Seventh Framework Programme
EGRD	IEA Experts' Group on R&D Priority Setting and Evaluation
ETP	Energy Technology Perspectives
FIPs	feed-in tariffs
FITs	feed-in premiums
G-8	Group of Eight
G-20	Group of Twenty
GBS	Grid battery systems
GDP	gross domestic product
GHG	greenhouse gas
Gt	Gigatonnes
GW	Gigawatts
GWEC	Global Wind Energy Council
HELE	high-efficiency, low-emissions
HEV	hybrid electric vehicle
HOV	High Occupancy Vehicle
ICT	information and communications technologies
IGCC	integrated coal gasification combined cycle
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
SCADA	Supervisory control and data acquisition
SET-Plan	European Strategic Energy Technology Plan
SETIS	SET-Plan Information System
Si	silicon
TW	terawatts
UNEP	United Nations Environment Programme

iea Energy Technology Network

International Energy Agency

International Energy Agency

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