INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE

WMO

UNEP

IPCC SCOPING MEETING ON RENEWABLE ENERGY SOURCES

PROCEEDINGS

Lübeck, Germany, 20 – 25 January, 2008

IPCC SCOPING MEETING ON RENEWABLE ENERGY SOURCES

PROCEEDINGS

Edited by

Olav Hohmeyer
Vice Chair
IPCC Working Group III

Tom Trittin
Head, Local Technical Support Unit
IPCC Working Group III

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Preface

The Intergovernmental Panel on Climate Change (IPCC) was jointly established by the World Meteorological Organisation (WMO) and the United Nations Environment Programme (UNEP) to assess available information on the science, impacts and the economics of climate change and of mitigation options to address it. It provides also, on request, scientific/technical/socio-economic advice to the Conference of the Parties (COP) to the United Nations Framework Convention on Climate Change (UNFCCC). Since its inception, the IPCC has produced a series of Assessment Reports, Special Reports, Technical Papers, methodologies and other products which have become standard works of reference, widely used by policymakers, scientists and other experts.

At the IPCC plenary meeting in Mauritius, from April 26th to 28th 2006, a decision was taken regarding further work on Renewable Energy Sources and Climate Change Mitigation. The use of renewable energy sources has received relatively little attention in the Fourth Assessment Report. In the Plenary meeting, the Panel acknowledged the importance of issues related to the use of renewable energy sources and decided that, to support a decision on the preparation of a Special Report, an IPCC Scoping Meeting should be organised.

The aim of the IPCC Scoping Meeting is to produce a scoping paper on possible ways for IPCC to provide an assessment on the use of renewable energy resources for climate change mitigation. The most prominent option seems to be to produce a Special Report. The IPCC Plenary, where the decision regarding a possible Special Report will be taken, will take place in April 2008.

The Scoping Meeting was held at Lübeck, Germany from January 21st to 25th. The scoping paper outlines a possible structure of Special Report and provides an assessment of the availability of published scientific literature on the topic. Another product of the Scoping Meeting are the Workshop proceedings, published as supporting material of the IPCC and containing the revised, completed and updated versions of most of the papers presented during the workshop.

Before you lays the collection of the most of the papers that were presented at the IPCC scoping meeting on the use of renewable energy sources and climate change mitigation. Unfortunately two papers could not be made available by the deadline for the printing of this report. The 13 lectures served as a background for the drafting of the scoping paper

We extend our sincere gratitude to the German government for hosting this workshop. The organisation was well led by Prof. Dr. Olav Hohmeyer of the University of Flensburg Also the organisation of two excursions to the numerous sites of renewable energy applications is very much acknowledged. We also thank the members of the Programme Committee, who gave invaluable advice on programme, participants and papers.

We would like to thank all participants, who contributed to a very constructive and fruitful meeting, where exchanging views and opinions on the issues surrounding the use of renewable energy sources lead to more clarity of the issues involved and the current status of scientific research. We hope that this Scoping Meeting will be a major step in an increased understanding of the applicability of renewable energy sources for the mitigation of climate change.

Ogunlade Davidson
Bert Metz
Co-chairs of Working Group III

Foreword from the organizer, Vice Chair of IPCC WG III

Scoping Meeting on Renewable Energy Sources and Climate Change Mitigation

January 20-25, Lübeck, Germany

At its 25th Session in Mauritius, April 2006, the IPCC considered the possible contribution of the use of renewable energy sources to the mitigation of climate change and decided to hold a scoping meeting for a possible Special Report on renewable energy. In order not to interfere with the final review of the Fourth Assessment Report (AR4), it was decided not to hold the scoping meeting until after the 27th Session of the IPCC in Valencia, November 2007. The outcome of the scoping meeting should be an expert advice to the Panel on whether to develop a Special Report on this topic or to incorporate the issue into a later Assessment Report as was done in the AR4. In the case that the experts recommend a Special Report, the meeting should deliver a scoping paper, timetable and detailed outline for a Special Report for decision by the Panel at its 28th Session in the first half of 2008. This volume of proceedings is one result of the scoping meeting.

The German government offered to host the workshop. As the Co-Chairs of WG III and the Technical Support Unit (TSU) were heavily committed to the organization of the AR4 at the time of the decision, the Co-Chairs asked the European Vice Chair of WG III to assist in the organization of the scoping process. Thus, a very small Technical Support Unit (mini TSU) was formed at the University of Flensburg, Germany, to organize the preparation of the scoping meeting. The work of the mini TSU and the Vice Chair was funded by the German federal government.

The scoping meeting was held in the UNESCO World Cultural Heritage city of Lübeck with additional financial support from the state government of Schleswig-Holstein. We are also grateful to the state government and to those IPCC countries whose dedicated financial contributions made it possible to increase the international participation of experts from developing countries and countries with economies in transition. The workshop has shown that this high level of participation was extremely helpful in addressing all relevant aspects of the problem at hand.

It was very impressive to see the commitment of about 120 leading world experts who dedicated themselves to the task of the scoping meeting for an entire working week, considering that each of the experts is already heavily committed to their own work and in much demand in these times when governments are intensely searching for feasible mitigation options for climate change

I would like to thank the participating experts for their great commitment, the German federal Government and the State Government of Schleswig-Holstein for their financial support of the scoping process and the scoping meeting, the members of the German mini TSU, especially Tom Trittin, for their substantial efforts in organizing the process, the German IPCC coordinator, Pauline Midgley, for her great support, the Co-Chairs of IPCC WG III, Bert Metz and Ogunlade Davidson, for their advice and, last but not least, the members of the WG III TSU, Leo Meyer, Peter Bosch, and Rutu Dave, for many valuable hints on organizing the scoping process.

I think that the scoping process has produced good and solid expert advice for the Panel of the IPCC to make a sound decision on a possible Special Report on Renewable Energy Sources and Climate Change Mitigation. If there will be a positive decision on a new Special Report, it will take quite some effort to write, review and revise the report. Hopefully the final report can be made available to the governments of the world by the end of 2010.

After the election of the new IPCC Bureau in September 2008, the organization of the writing process of the report will most likely pass into new hands. I wish the responsible team all the success necessary to make a substantial contribution to the future mitigation of climate change.

I dedicate this report to our Danish colleague Jesper Gundermann, who helped so much to reach the positive decision of the IPCC Panel at its Mauritius Meeting in April 2006. His death right after the Mauritius meeting reminded me that all too often the best die far too young.

Olav Hohmeyer
Vice Chair WG III IPCC

Call for nominations IPCC scoping meeting on Renewable Energy Sources

No: 6979-07/IPCC/WG3 To designated IPCC Focal Points and
Ministries for Foreign Affairs (if no focal point has been designated)

Geneva, 19 September 2007

Call for nominations IPCC scoping meeting on Renewable Energy Sources

Sir/Madam,

I have the honour of bringing to your attention an IPCC scoping meeting on Renewable Energy Sources, scheduled to be held from 21 to 25 January 2008, in Lübeck, Germany.

At its 25th Session Mauritius, 26-28 April 2006, the Panel considered a proposal for an IPCC Special Report on Renewable Energy. Many countries expressed general support for such a Special Report. Taking into account the comments made, the Panel decided to hold a scoping meeting for a possible Special Report on Renewable Energy after the completion of the AR4. The Scoping Meeting is organised by one of the Vice-chairs of WG III, in close consultation with the Working Group III Cochairs. A small Technical Support Unit was set up for that purpose. Based on the outcome of the Scoping Meeting the Panel at its 28th Session in early 2008 will decide on further IPCC work on this issue.

Issues that might be discussed at the scoping meeting include:

- <u>Introduction, use of energy, historic role of renewables and climate change</u>
- <u>Technical, socio-economic and environmental matters related to</u>
  1. Biomass
  2. Direct solar energy
  3. Geothermal energy
  4. Hydro power
  5. Wind energy
  6. Other renewables
- <u>Integration of renewable energy into future energy systems</u>
- <u>Mitigation potential, costs of renewable energy systems and costs of transition</u>
- <u>Financing and insurance of renewable energy systems</u>
- <u>Regional utilisation options, capacity building, technology transfer and adaptation</u>
- <u>Climate change benefits and environmental impacts of renewables in the context of sustainable development</u>
- <u>Policies, barriers and opportunities for the introduction and diffusion of renewables</u>

It is with great pleasure that I extend this invitation to your Government to nominate experts for participation in the scoping meeting. Given its specialised, scientific-technical nature, attendance by appropriate experts is vital for the success of the scoping meeting. Thus, it would be most helpful if your Government nominates its representative(s) with appropriate expertise and excellent understanding in the fields mentioned above. This will also facilitate fruitful discussions within the smaller, parallel task groups that are planned, and which will form a substantial part of the scoping meeting programme. The attendance at the scoping meeting is limited to a total of 60-80 participants. Nominees invited to attend will receive further information on the scoping meeting.

I request that the nomination be made by completing the appropriate forms in the online registration tool at http://www.ipcc-sh.de (one per nominee per activity).

Limited financial support is available to representatives from the developing countries and countries with economies in transition, one per country. The offer of support to the government nominees will take into account the following factors, in the order mentioned: (i) balance of expertise across the various disciplines represented at the scoping meeting, (ii) balanced geographical representation and (iii) chronology of requests received.

All nominations should be made no later than **26 October 2007**. This deadline will be strictly adhered to because of the time required for the logistics of delivering the support. Copies of this letter are being sent to the IPCC Focal Point (or Permanent Representative for IPCC if you have such designation) and Contact Point(s), if any, the Permanent Representative with WMO and Focal Point(s) of UNEP of your country for information.

Sincerely yours,

(Renate Christ)
Secretary of the IPCC

Invitation Scoping Meeting on Renewable Energy Sources

Date : November 30th, 2007
Our Ref. : 405/07 IPCC OD BM /PB/Th
Subject : **Invitation Scoping Meeting on Renewable Energy Sources, 20-25 January 2008, Lübeck, Germany.**

We have the honour of inviting you to the IPCC scoping meeting on Renewable Energy Sources, scheduled to be held from 20 to 25 January 2008, in Lübeck, Germany.

At its 25th Session Mauritius, 26-28 April 2006, the Panel considered a proposal for an IPCC Special Report on Renewable Energy. Many countries expressed general support for such a Special Report. In the plenary meeting, the Panel acknowledged the importance of renewable energy systems and decided to hold a scoping meeting for a possible Special Report on Renewable Energy after the completion of the AR4. The Scoping Meeting aims to prepare a scoping document for a decision by the IPCC Plenary. Based on the outcome of the Scoping Meeting the Panel at its 28th Session in April 2008 will decide on further IPCC work on this issue.

The scoping paper should identify the aspects that would need to be covered in an IPCC assessment and the availability of published scientific information. It should also address the question if a Special Report is to be recommended, or that the option of assessing the information to be a part of the Fifth Assessment Report would be preferable. The workshop programme is designed to give an overview of the state of knowledge in different areas related to renewable energy sources. Subsequently, in breakout meetings, working groups will be asked to prepare input for the scoping paper that will be drafted by a small group during the last day of the meeting.

It is with great pleasure that we extend this invitation to you for attending this workshop, based on your expertise and experience in this area of research. We request that you complete the appropriate form in the attachment and forward it to Tom Trittin, IPCC Working III Extended Technical Support Unit at fax +49 461 8052532 or email tom.trittin@uni-flensburg.de no later than December 4, 2007. As soon as your registration has been received, you will be informed on further details concerning the accommodation and practical issues during the Scoping Meeting.

Limited financial support is available from the IPCC Trust Fund to representatives from developing countries and countries with economies in transition. The Trust Fund supports travel and accommodation costs. In order to facilitate travel arrangements it will be important to adhere strictly to the registration deadline of 4 December 2007.

Accept, Sir/Madam, the assurance of my highest consideration.

Bert Metz
Co-chairman IPCC Working Group III

Ogunlade Davidson
Co-chairman IPCC Working Group III

Enclosures:

1. Registration form Scoping Meeting
2. Scoping Meeting Programme

SCOPING PAPER
IPCC SPECIAL REPORT ON
Renewable Energy Sources and Climate Change Mitigation

Introduction

At its 25th IPCC Session in Mauritius, April 2006, the IPCC considered the possible contribution of the use of renewable energy sources to the mitigation of climate change and agreed to hold a scoping meeting for a possible special report on renewable energy (SREN). In order not to interfere with the final review of the Fourth Assessment Report (AR4), it was decided not to hold the scoping meeting until after the 27th Session of the IPCC in Valencia, November 2007. The outcome of the scoping meeting should be an expert advice to the Panel on whether to develop a Special Report on this topic. In the case that the experts recommend a Special Report, the meeting should deliver a scoping paper, timetable and detailed outline for a Special Report for decision by the Panel at its 28th Session in the first half of 2008. This scoping paper is the result of the scoping meeting.

Scoping meeting on Renewable Energy Sources and Climate Change Mitigation

From January 21st-25th, 2008, the IPCC workshop on Renewable Energy Sources and Climate Change Mitigation was held in Luebeck, Germany. A call for nominations was issued for the participation in this expert workshop and 63 member countries of the IPCC nominated about 200 experts. Only very few nominations were made by other organisations than government institutions. Of all nominations, about 120 experts were nominated by developing countries and countries with economies in transition. Taking into consideration the strong interest in the issue the 27th Session of the IPCC raised the number of journeys for Trust Fund financed participation to 40.

Due to the broad nature of the subject including six major areas of renewable resource use, the question of complex system integration of renewable energy source, questions of environmental and social impacts as well as policies to further advance technology diffusion and due to the rather different regional application possibilities, about 120 experts were invited. The participants came from about 45 different countries.

Thirteen major presentations were given and discussions were held covering all major areas of concern for a possible Special Report. After a very intensive discussion of different possible approaches to structure a Special Report, unanimous agreement of the participating experts was reached on the basic structure presented in this document. This structure was elaborated by eleven working groups and discussed at length by all experts present.

Why a Special Report?

The mandate of the meeting was to guide and support decision making by the IPCC on a possible Special Report on Renewable Energy Sources and Climate Change Mitigation or on the inclusion of this subject in the normal Assessment Report cycle. A Special Report could be finalised by end of 2010, while a fifth Assessment Report would probably not be available before 2013.

The participants concluded that a Special Report would be the appropriate choice for the following reasons:

The AR4 documented the accelerating rate of climate change and its impacts. It also described the much greater confidence of the scientific community in the role of human contributions.

As shown in the AR4 (SPM WG III IPCC, p. 17, Figure SPM 9), in association with energy efficiency measures, renewable energy sources can make a substantial contribution to climate change mitigation as early as 2030 (SPM WG III IPCC, p. 13) and an even larger contribution by 2100 (SPM WG III IPCC, p. 17).

The AR4 had to cover the full range of mitigation options which necessarily limited its treatment of renewable energy sources. Since then, many Governments as well as important actors in civil society and the private sector have asked for more substantial information and broader coverage of all questions pertaining to the use of renewable energy sources. As expressed by the interventions of many Governments at the 25th Plenary Session of the IPCC at Mauritius, this is particularly true of certain countries and regions where specific information is lacking.

Within the constraints of time and space, the AR4 identified the economic potential for renewable energy to provide heat, electricity and transport fuels to meet in part the growing energy demand and to reduce greenhouse gas emissions.

Since the AR4, significant new information and analysis has been reported in the literature on technological development and deployment, regional assessments, environmental and socio-economic impacts, cost reductions as well as mounting practical experience with implementation.
Due to the dynamic development of markets and investment and the experience gained from enabling policy frameworks, substantial additional evidence has emerged since the AR4 and the experts at the Workshop expect further relevant information by 2009, the last date available for inclusion in the Special Report.

A Special Report on Renewable Energy would provide a better understanding of:

- resources by region and impacts of climate change on these resources;
- the mitigation potential of renewable energy sources;
- the linkages between renewable energy growth and co-benefits in achieving sustainable development by region;
- the impacts on global, regional and national energy security;
- the technology and market status, future developments and projected rates of deployment;
- the options and constraints for integration into the energy supply system and other markets, including energy storage options;
- the economic and environmental costs, benefits, risks and impacts of deployment;
- capacity building, technology transfer and financing in different regions;
- policy options, outcomes and conditions for effectiveness; and
- the accelerated deployment could be achieved in a sustainable manner.

A Special Report on Renewable Energy Sources and Climate Change Mitigation would address the information needs of policy makers, private sector and civil society in a comprehensive way and would provide valuable information for further IPCC publications. Ideally it should be finalized in time to allow integration of its findings into the next comprehensive IPCC assessment of mitigation of climate change.

The vast majority of the more than one hundred experts participating in the workshop indicated that they would be available as lead authors for such a special report. Furthermore, there has been substantial additional interest shown by experts not present at the workshop to become involved in the writing process. Thus, there should not be any problem of recruiting the necessary expertise for an IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation.

Proposed Structure and Content of a Special report

Contents

The following structure was felt to ensure the best possible treatment of the issue. Indicative values for length of chapters as percentage of the total report given in parentheses ( ). These values were unanimously agreed by the experts at the workshop.
The technology chapters are in alphabetical order to avoid the impression that some technologies may be more important than others. Although the structures of the technology chapters do look similar, there are important differences in the details of the structures and the additional points raised in parenthesis. Thus, the full structure of each chapter is given here, although this may look repetitive at first sight. The experts stressed that the technology chapters (2 –7) have to feed into the overarching chapters (8 – 11) and that the system integration chapter (8) will be a key chapter bringing all different aspects of energy demand and supply together, pointing out how renewable energy sources can be utilized in the larger context of future energy systems.

Points added in parenthesis refer to major issues considered for inclusion at the third level of the structure. They are meant to give some additional guidance to the later authors. The experts compiled a far more detailed structure for each chapter at the Luebeck meeting, which can be made available to the later authors on request, if these authors feel that they would like to have more detailed input into the writing process. As this more detailed structure can only be indicative of one possible way to structure the final report, the experts deliberately abstained from recommending any more detailed structure. If asked, they will supply this indicative detailed structure to the later authors.

Suggested structure of the report

1. Renewable Energy and Climate Change (5%)
1.1 Background
1.2 Summary of renewable energy resources
1.3 Meeting energy service needs and current status
1.4 Barriers and issues *(in using renewable energy for climate change mitigation and sustainable development)*
1.5 Role of policy, R&D, deployment, scaling up and implementation strategies
1.6 Methodology (resource assessment, life-cycle assessment, setting boundaries for analysis, measures of sustainability, definitions, units, etc.)

2. Bioenergy (15%)
2.1 Introduction *(traditional and modern use)*
2.2 Resource potential *(including impact of climate change on resource potential)*
2.3 Technology *(e.g. biological and thermochemical conversion)* and applications *(electricity, heat, transport and cooking)*
2.4 Global and regional status of market and industry development
2.5 Environmental and social impacts *(e.g. competition with food, fodder, fiber, and land use)*
2.6 Prospects for technology improvement, innovation and integration
2.7 Cost trends
2.8 Potential deployment *(based on 2.7)*

3. Direct Solar Energy (10%)
3.1 Introduction
3.2 Resource potential *(including impact of climate change on resource potential)*
3.3 Technology *(e.g. solar thermal, photovoltaics, concentrating solar power)* and applications *(heating and cooling, lighting, cooking, electricity, fuel)*
3.4 Global and regional status of market and industry development
3.5 Integration into broader energy system
3.6 Environmental and social impacts
3.7 Prospects for technology improvement and innovation
3.8 Cost trends
3.9 Potential deployment *(based on 3.8)*

4. Geothermal Energy (5%)
4.1 Introduction
4.2 Resource potential
4.3 Technology and applications *(electricity, heating, cooling)*
4.4 Global and regional status of market and industry development
4.5 Environmental and social impacts
4.6 Prospects for technology improvement, innovation and integration
4.7 Cost trends
4.8 Potential deployment *(based on 4.7)*

5. Hydropower (5%)
5.1 Introduction *(large and small hydro)*
5.2 Resource potential *(including impact of climate change on resource potential)*
5.3 Technology and applications *(run-of-river, storage, multi-purpose)*
5.4 Global and regional status of market and industry development
5.5 Integration into broader energy system
5.6 Environmental and social impacts
5.7 Prospects for technology improvement and innovation, and multi-purpose use of reservoirs
5.8 Cost trends
5.9 Potential deployment *(based on 5.8)*

6 Ocean Energy (5%)
6.1 Introduction
6.2 Resource potential *(including impact of climate change on resource potential)*
6.3 Technology *(wave, tidal, ocean thermal, osmotic)* and applications
6.4 Global and regional status of market and industry development
6.5 Environmental and social impacts
6.6 Prospects for technology improvement, innovation and integration
6.7 Cost trends
6.8 Potential deployment *(based on 6.7)*

7 Wind Energy (5%)
7.1 Introduction
7.2 Resource potential *(including impact of climate change on resource potential)*
7.3 Technology and applications *(onshore, offshore, distributed)*
7.4 Global and regional status of market and industry development
7.5 Near-term grid integration issues
7.6 Environmental and social impacts
7.7 Prospects for technology improvement and innovation
7.8 Cost trends
7.9 Potential deployment *(based on 7.8)*

8 Integration of Renewable Energy into Present and Future Energy Systems (15%)
8.1 Introduction *(potential role of renewable energy in future energy systems)*
8.2 Integration of renewable energy into supply systems (electricity grids, heat distribution networks, gas distribution networks, liquid fuels; load management, grid management, energy transport, storage, interactions with conventional *systems)*
8.3 Strategic elements for transition *(transportation, buildings and households, industry, agriculture, interactions among demand sectors)*

9 Renewable Energy in the Context of Sustainable Development (10%)
9.1 Introduction
9.2 Environmental impacts: global and regional assessment
9.3 Socio-economic impacts: global and regional assessment
9.4 Implications of (sustainable) development pathways for renewable energy
9.5 Synthesis *(consequences of including environmental and socio-economic considerations on the potential for renewable energy)*
9.6 Gaps in knowledge and future research needs

10 Mitigation Potential and Costs (10%)
10.1 Introduction
10.2 Methodological issues
10.3 Assessment and synthesis of scenarios for different renewable energy strategies *(top-down and bottom-up)*
10.4 Cost curves for mitigation with renewable energy *(regional, sectoral, temporal; impacts of climate change on mitigation potential)*
10.5 Costs of commercialization and deployment *(investments, variable costs, market support, RDD&D)*
10.6 Social, environmental costs and benefits *(synthesis and discussion on total costs, and impacts of renewable energy in relation to sustainable development)*
10.7 Gaps in knowledge and uncertainties

11 Policy, Financing and Implementation (15%)
11.1 Introduction
11.2 Current trends: Policies, financing and investment
11.3 Key drivers, opportunities and benefits
11.4 Barriers to renewable energy implementation
11.5 Enabling environment and regional issues *(Technology transfer, capacity building, finance & investment)*
11.6 Experience with and assessment of policy options *(local, national, regional; innovation and deployment)*
11.7 Policy frameworks for innovation, systems integration and deployment of renewable energy

Time schedule and provisional budget estimate

If the 28th Session of the IPCC in April 2008 decides to go ahead with the preparation of a Special Report and a call for nominations of Lead Authors were to be issued no later than May 2008. Approval and acceptance of the Special Report would be planned for the second half of 2010. One Lead Author meeting in 2008, two Lead Author meetings in 2009 and one Lead Author meeting in the first half of 2010 are foreseen. The planning would be made to properly synchronise with the preparation of an AR5.

Budget 2008: assuming 1 Lead Author meeting, assuming 40 journeys of DC and EIT Lead Authors per meeting at 4.500 CHF per journey, plus 13% for other meeting costs, *203,400 CHF* will be needed from the IPCC Trust fund.

Budget 2009: 80 journeys of DC and EIT Lead Authors = approx. 406,800 CHF. In addition, 4 review editors from DC and EIT will be invited to the third LA-meeting, which corresponds to another 20,340 CHF. The total budget for 2009 will then amount up to *427.140 CHF*.

Budget 2010: 40 journeys of DC and EIT Lead Authors = approx. 203,400 CHF plus 4 review editors from DC and EIT = 20,340 CHF. WG III Plenary Session: assuming 4 days for the Summary for Policy Makers on this subject will cost approx. 748,000 CHF plus 76,275 for a preparatory meeting with 15 r Lead Authors and their participation in the WG Sessions . The total budget for 2010 will then amount to up to *1,048,015* CHF.

The experts expressed strong support for an additional expert workshop with the respective industry to draw on relevant information from the industry, which is not published in peer reviewed journals. To facilitate the inclusion of regional expertise, workshops with experts in Africa, Asia and Latin America might be considered. The funding of such meetings is not included in this budget estimate. The meetings would most likely be held in 2009.

Costs for translation and purchasing of the Special Report, shipping costs and outreach are to be included later.

Lead author selection process

Nominations can be called for in a letter to governments, no later than May 2008. Based on the nominations, the newly elected IPCC Bureau (September 2008) can select the Co-ordinating Lead Authors, Lead Authors, and Review Editors.

Table of Contents

Renewable Energy and Climate Change An Overview

William Moomaw

The Fletcher School, Tufts University, USA

I. Introduction

As the fourth Assessment Report documented, it is now clear that the planet is warming rapidly, and that the major contributor is the increase in heat trapping greenhouse gases (GHGs) from the combustion of fossil fuels and other industrial and agricultural processes (IPCC 4AR, WG I, 2007). The UN Framework Convention on Climate Change calls for stabilization of greenhouse gas concentrations in the atmosphere at a safe level. Many governments have adopted a goal of avoiding global warming of more than 2^{o}C. This would require keeping concentrations of carbon dioxide below about 450 ppm. Because of the dynamics of absorption of carbon dioxide by oceans, soils and forests, this would require reducing emissions by 80% over the next half century at a rate of 3% per year. In addition there is another 50 ppm CO_2 equivalent of other GHGs including methane, nitrous oxide, and industrial gases that need to be reduced by comparable amounts.

What ever concentration is decided upon by policy makers to meet the goal of Article 2 of the UN Framework Convention on Climate Change to avoid dangerous anthropogenic damage to the climate system, the introduction of low carbon emitting energy technologies will play a critical role. The continued use of fossil fuels will require a significant amount of carbon dioxide to be removed by either physical capture and storage geologically or in the deep oceans or through biological capture at the source as algae (IPCC, CCS, 2005). Enhancing biological sequestration in forests and soils can also reduce concentrations in the atmosphere (IPCC, LULUCF, 2000). However, it is also imperative to develop highly efficient, low and zero carbon energy systems if the goal of avoiding run away climate change is to be achieved (IPCC 4AR, WG III, 2007).

The only options on the energy supply side are nuclear power and the multiple renewable energy sources that rely upon capturing the natural energy fluxes of the sun, the wind, gravity, photosynthesis and geothermal heat. Renewable energy technologies are being called upon to reduce the release of carbon dioxide into the atmosphere through development of a more sustainable energy system, and are expected to play a role in "energizing" the development process for both large and small developing countries.
They are also expected to provide economic and energy security for developed and developing countries, and are seen as providing new business opportunities and jobs around the world

The focus of this paper and the subsequent ones is to explore the potential role of renewable energy and the conditions under which it might play a major role in meeting carbon dioxide atmospheric concentration goals. Major questions to be answered are 1) how many of our energy service needs can be met by renewable energy? And 2) how much of the emissions reductions can be met with renewables alone and in combination with one another, fossil fuels and efficiency gains?

II. The History of Renewable Energy

Human use of renewable energy goes back to the discovery of fire and the use of wood as a biomass fuel. All early civilizations learned to use animal fats and vegetable oils to produce light in oil lamps. Beginning with the domestication of animals for motive power and transportation, humans have relied on photosynthesis and the stored energy in green plants to fuel "animal machines." It is worth noting that these original forms of renewable energy are still in use among 1 - 2 billion people in the world today. Plant oils were the original choice of Otto Diesel in his early engine, and Henry Ford preferred grain ethanol to power his early vehicles. While these fuels were largely replaced by inexpensive petroleum during the past century, rising cost is creating demand for a return to biofuels for the transport sector and to a lesser extent for electric power production.

The discovery that mechanical energy could be extracted from the wind and from the kinetic energy of falling water was made independently in many parts of the world over the past millennia. The use of various water wheels to convert the gravitational energy of falling water into shaft energy was used for many tasks including grinding of grain, and formed an initial basis for the textile industry at the start of the industrial revolution before steam and electricity proved more effective. Modern hydro electric systems were developed only a little over a century ago with the harnessing first of natural falls such as Niagara Falls on the U.S. Canadian border, and then by building ever larger dams up to the recently completed largest in the world, Three Gorges Dam in China.

In the past two decades, modern wind turbine electric generators as large as 6 Gwatts of power have been developed and deployed. Wind turbines now provide more than 1 percent of global electricity, and wind is the fastest growing energy supply sector. Solar energy has always been used directly for heat and light, and this principle of "passive solar gain" is now being used in the design of new buildings to reduce their demand for commercial forms of energy. Solar hot water heating for domestic and commercial buildings is now cost effective and widely used in many countries around the globe. The direct conversion of solar energy into electricity through photovoltaic devices, and through thermal conversion is now the second most rapidly growing energy supply globally. Geothermal energy has been utilized where heat appears near the earth's surface, but there is a vast amount of accessible heat deeper in the earth that could be tapped (USDOE/MIT, 2007). It is a vast, but relatively modestly utilized energy source except in those countries that utilize heat from deeper in the earth directly for heating, and for electric power production. Despite their vast energy potential the oceans remain relatively unexploited as an energy resource. The world's largest tidal station at La Rance in France is only 240 MW, and the exploitation of wave energy and temperature and saline gradients have not reached the stage of commercial development.

III. Energy Services

There is utility in examining energy both from the demand side as energy services by sector and from the supply side as energy technologies. Energy services are basically high, medium and low temperature heat, cooling, mechanical and electrical work, lighting, information and entertainment services and transportation. Each of these services can be provided in multiple ways depending upon the energy source and the service conversion technologies available. The amount of energy required to provide a particular energy service depends upon the chain of efficiencies in capturing, converting and utilizing energy from its primary source to its ultimate use. While the structure of this report is based upon specific renewable supply technologies, it is important to keep in mind the energy services that are being provided so as to take advantage of each technology to its fullest extent. One can construct an energy demand services flow diagram through which one can connect the multiple options for each energy service required by each end use sector with each of the renewable energy supply technologies and an appropriate energy carrier (Figure 1).

For example, biomass energy can produce a liquid energy carrier that can meet the service demand of mobility, which is manifested in the transportation sector. Alternatively, any of the six renewable energy supply options can provide the energy carrier electricity that can meet the energy needs of mobility in the transport sector. If the demand service, lighting, is required, this can be supplied by any of the renewable energy sources by electricity supplying the service of lighting in the building sector. Alternatively, in many developing countries, biomass in the form of the energy carrier vegetable or animal oils can provide light directly through oil lamps in the building sector. Increasingly, it is being realized that significant lighting for the building sector can be provided directly from solar energy through the proper location and sizing of windows through day lighting.

Renewable Energy Supply	**Energy Carrier**	**Service Demand**	**End Use Sector**
		Mobility	
Biomass energy	Liquid/gas/		Transportation
	solid fuels	Heat (H,M,L)	
Direct solar energy		Cooling	
Geothermal energy			Buildings
	Electricity	Work (mech)	
Hydro energy		Work (elec)	
			Industry
Ocean energy		Lighting	
	Direct	Information	Agriculture
Wind energy		Entertainment	

Figure 1. Renewable Energy Supply-Demand Flows

IV. Energy and Power of Renewable Energy

There are three categories of renewable energy. The first is solar energy that strikes the earth in vast amounts, providing heat for the oceans and land surfaces, drives the winds and waves, produces biomass and fuels through photosynthesis, and provides the energy for the hydrological cycle. The second source is the heat of the earth, which results primarily from natural radioactive decay. Finally, there is gravitational energy from tides and falling water. One can compare current societal energy use with natural energy fluxes to get some sense of the enormity of the renewable energy supply. While these renewable energy "fuels" are free, the challenge and the cost lie in the development and deployment of the multiple technologies to harvest the available energy and to integrate them into an efficient integrated system. From Table 1, it is clear that there is vastly more energy available through most renewable energy modes than is required to meet current societal needs, or than is potentially available from reserves of fossil fuels or uranium, and renewable sources continue indefinitely into the future.

In order to be a viable energy supply source, it is necessary that there be sufficient energy to supply a specific energy service and that the energy be delivered at a rate that is sufficient to meet the power demand (energy/time).

Renewable source	Annual flux or use	Ratio Annual flux or resource/ annual demand	Total reserve
Solar	3,900,000 EJ/y*	8,700	- - -
Wind	6,000 EJ/y*	13	- - -
Hydro	149 EJ/y*	0.33	- - -
Bioenergy	2,900 EJ/y*	6.5	- - -
Ocean	7,400 EJ/y*	17	- - -
Geothermal	140,000,000 EJ/y*	31,000	- - -
Total conventional fossil fuel reserve	396 EJ/y*	104	46,700 EJ
Total unconventional fossil fuel reserve	0.06 EJ/y**	42	18,800 EJ
Total Uranium reserve	31 EJ/y***	6.7 - 23	3,000- 10,500 EJ
Current global energy use	448 EJ/y (2004)* Conv. Biofuels adds ~45 EJ/y	1	- - -

Table 1. Renewable energy fluxes – *World Energy Assessment, 2000 and 2004, ***IEA, 2006, **OGJ, 2004.

There is a set of important questions to be answered about renewable energy technologies and their ability to provide adequate energy services.

- What is the available energy and power density available to meet energy service needs?
- How is each technology best matched to an energy service?
- What is the scale and rate of penetration into the existing energy mix of each renewable technology in providing anticipated energy services over the coming decades and by 2050 and 2100?
- How can one deal with the intermittency of wind and solar?
- What is the true cost of each renewable technology within the energy system?
- What are the environmental and social tradeoffs of each renewable technology relative to other options including nuclear power and fossil fuels

Meeting demand for energy and power

The first two questions are directly linked and relate to the third. The energy density of renewable energy fluxes varies greatly. For example solar energy reaches the earth's surface at a rate of about 342 watts/m2, which is low for high power industrial needs, but quite adequate for passively heating or lighting buildings, to provide domestic hot water or to power building integrated solar photovoltaics making electricity at 10-20% efficiency. If the demand for electrically supplied services is low because of efficient end use devices, such a system may provide for most of the energy of the buildings. Over 7000 Passivhaus dwellings have been built in Europe that require only about 12% as much energy as the average German dwelling (Passivhaus Institut, 2007), and zero net energy homes that require only 14% as much energy to heat as code built dwellings are being built in the United States (USDOE, 2008). Hence there is a great synergy between energy service demand efficiency and the ability of even relatively modest power densities of some renewable technologies to meet them. The range of commercial structures with dramatically reduced energy demand include s major industrial research laboratory in Cambridge, MA, and commercial office buildings in London and New York and very large low energy commercial complexes that utilize renewable energy are being built in Delhi, Abu Dhabi and elsewhere. On the other hand, the persistence of glass curtain wall skyscrapers in both temperate and tropical zones creates an excessive demand for electricity. A single "northern style" glass tower complex built near the equator may require as much electricity to air condition as is required by a city of 250,000 people. Hence the management of passive solar energy as well as harvesting it can be critical to lowering carbon dioxide emissions.

To obtain higher power densities from solar energy requires either very large PV arrays or concentrating mirrors. The latter are being used increasingly to produce steam for turbines to drive electric generators. With thermal storage and some bio- or natural gas, such systems are capable of producing power continuously.

Wind and hydro power are very site specific, and in excellent locations can produce very high power densities. While wind and solar are intermittent, they can be coupled into larger integrated systems, or can generate carbonless fuels such as hydrogen or battery stored electricity for vehicles or other purposes. In many developing country applications, intermittent sources can be used for pumping water and other tasks where the time of use is less critical or can be matched to the peak of production. Hydropower has the advantage of being able to store water for later release, and is currently being used in conjunction with wind systems in Europe to address the intermittency of that resource. Furthermore, the development of solar thermal systems that are capable of storage can extend solar power production through the night. Tidal barrage systems also have some limited storage capacity so that the release of water can be better timed to meet demand peaks. Most other renewable systems including bioenergy, geothermal energy, ocean thermal systems have built in energy storage. The full range of the imitations and opportunities need to be fully analyzed.

Scaling Up

The issue of scaling up particular technologies is an issue, and some analyses conclude that only very large facilities such as nuclear power, large scale hydro or large coal plants with carbon capture and storage can meet the needs for growing energy demand. But let us explore this issue in further detail.

Consider for a moment the following example. A 1000 MW large power facility takes approximately 10 years to complete. If all goes well and it could operate at full power in the 11th year following its completion, it would produce 8.8 TWh of electricity. Now, let's assume we produce modular units of one-tenth the capacity of the final plant in each of ten years. Assuming again 100% utilization, by the end of the 11th year, the modular units would have produced 4.8 x 8.8 TWh, or nearly 5 times as much power by the time the large unit has produced for one year, and after that, the two systems will produce the same amount annually.

The rapid introduction of natural gas fired turbines during the past 20 years in North America and Europe has been due to three factors. The first is that they have become exceedingly efficient, the second is that because of economies of scale, their unit cost is low, and thirdly, they can be produced quickly in modules of 50 -100 MW and installed within a one year time-frame. This latter quality has meant low cost of capital, and a better match and immediate production of power upon installation. Finally, it is interesting to note that the total engine power of vehicles sold in the US each year exceeds the total electric power generation capacity of the country. Another testament to the capacity of modular scaling to produce sufficient modestly sized energy units to equal a large scale demand.

It is, therefore important to learn just how rapidly specific systems can be manufactured, and at current rates it appears that wind, solar and biomass have all demonstrated that they can be manufactured at a rate that is comparable to large-scale projects. Wind and solar capacity production is currently doubling in three years or less, and the U.S. bioethanol program has achieved significant growth in three years to pass Brazil as the largest producer.

Costs

It is also necessary to consider the full costs associated with each technology. There are two ways to calculate costs. In the first, one only considers the sum of capital costs over the life of the project plus fuels plus operation and maintenance costs. Under these assumptions, coal in many countries is the cheapest accounting for why it accounts for just over half of global electricity production. However, there are other human health and environmental costs as well for each energy source. With coal for example, there are pollutants such as SO_2, NO_x, particulates, mercury and other heavy metals. There is significant land disruption, stream acidification, surface subsidence and decades long underground fires. In the future it may be necessary to capture CO_2 and store it for very long periods of time. None of the renewable energy technologies have these externalities or the costs associated with addressing them. It is important to develop an agreed upon accounting system to make costs comparable among renewables, fossil fuels and efficiency.

Another important aspect of the cost of electric power production is the transmission and distribution systems. According to IEA, approximately 55% of the capital cost of electric power systems is in the “wires” and only 45% is invested in the generation technology. Hence if on-site, distributed generation is utilized (whether fossil fueled or building integrated solar or renewable technology), the transmission costs are generally zero, and the marginal cost of distribution if grid connected is much lower since most of the electricity is utilized where it is generated. This fact needs to be taken into account when comparing costs of alternatives. There are few studies to date that account for this sizable cost component.

Finally, it is important to recognize that our present energy system has developed with abundant and inexpensive fossil fuels. Hence there has until recently been little need to focus on efficiency. However, having highly efficient lighting and appliances to provide needed energy services will substantially lower the cost of the energy supply system whether it utilizes renewable technology or conventional fossil fuels (See Figure 3). The matching of supply closely to demand can yield major cost savings with renewable energy technologies as when demand becomes sufficiently low that solar panels can not only supply a building, but also can fit on the roof as a structural element.

V. Issues and Opportunities

In recent years, sufficient experience has been gained in the use of many renewable systems to identify both problems and opportunities. The scale of wind turbines has grown significantly in just a few years from sub megawatt scale to units as large as 5-6 MW. Better electronic controls, blade pitch controls and other technological advances have created higher performance machines that are more reliable, lower cost and which have higher capacity factors. Improvements in the efficiency of conventional silicon based photovoltaic solar cells have been complimented by the use of new higher efficiency materials. Even more exciting is the recent development of nanotechnology solar cells that claim to slash the cost per peak watt by 75%. Likewise, nanotechnology is leading to higher capacity electric storage batteries and even to improved super capacitors that could revolutionize hybrid vehicles and the storage of energy for many applications.

Bioenergy and Carbon Dioxide Capture and Storage

Nowhere have developments moved more rapidly than in the field of bioenergy. Liquid biofuels hold particular promise since they might be used to reduce emissions in the transport sector. Brazil has demonstrated the potential for harnessing its agricultural economy to produce bioethanol that now fuels over 40% of its auto fleet (IPCC 4AR, 2007). The US has rapidly scaled up corn based ethanol to surpass Brazilian ethanol production. The research announcements and corporate investments in second generation biofuels from cellulose suggest that this approach may move to commercial scale soon with much lower environmental and social costs. Several recent studies indicate that biofuels are not as climate neutral as earlier analyses have suggested because they release large amounts of N_2O, and initiate large land clearing . Grains and seed oils in particular that compete with food production can have very large (10-100 times) as much carbon dioxide release as is saved. The impact of biofuels production on food availability and prices and the expansion of replacement food agricultural into forest and grasslands, needs to be fully evaluated (Searchinger et al, 2008; Scharfemann and Laurance, 2008; Fargione et al, 2008, Crutzen et al, 2007). On the other hand utilizing urban, agriculture and forest waste and algae can have significant benefits.

On the opportunity side, it is necessary to stay attuned to new possibilities that can address multiple climate and other issues simultaneously. A great deal of attention has been directed to Carbon Dioxide Capture and Storage. This technology might become very important in the continued use of coal and gas power plants or in certain industrial processes including cement production and iron and steel making (IPCC, CCS, 2005). An alternative to the expensive physical capture and storage cost that that is being developed links directly to bioenergy. Several systems are being tested on existing coal and gas power plants in the U.S. and South Africa that utilize photosynthetically grown algae to capture carbon dioxide from power stacks. The data from the early trials are impressive. Because the concentrations of carbon dioxide are nearly two orders of magnitude higher than in the ambient air, yields are very high, and because these are not vascular plants, little water is required. Carbon dioxide can be held overnight and fed to the algae during daylight hours. The yields are impressive: 90,000 l/ha of vegetable oil compared to 1700 l/ha of canola, plus 100,000 liters/ha of bioethanol per year compared to 3000 l/ha of ethanol from corn or 6000 l/ha from sugar cane. The process also removes most NO_x and could use nutrients from sewage as fertilizer. The fuels produced can either be fed directly back into the power plant in a co-firing process without releasing very much to the atmosphere, or else sold as transport fuels where the carbon in effect gets “burned twice” (Pulz, 2007, US DOE, 2006).

Figure 2. Algae grown using carbon dioxide from power plant stacks in the United States

This example illustrates how it is possible to utilize a renewable energy technology in an integrated way jointly with fossil fuels to lower carbon dioxide emissions to the low rates needed to stabilize concentrations at an agreed upon concentration in the atmosphere.

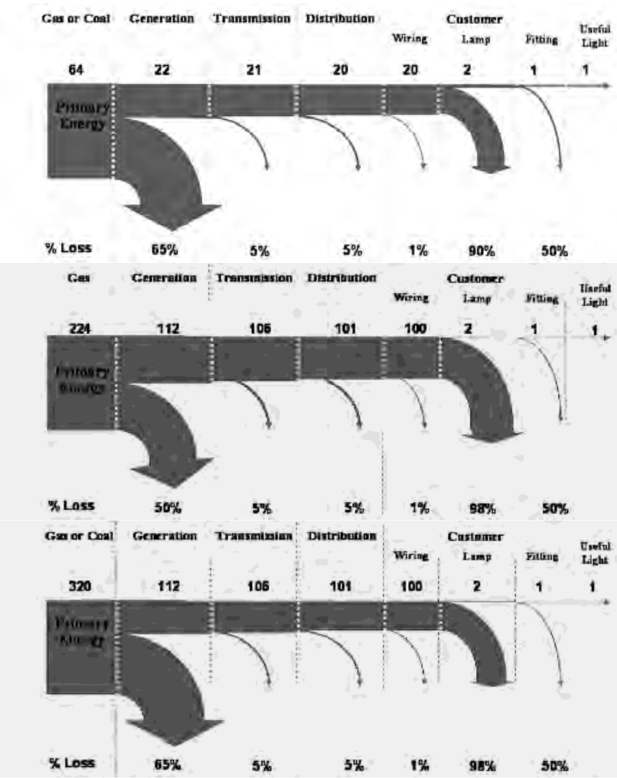

Figure 3 Efficiency and Emissions Reduction (IPCC 4AR, WG III, 2007)

Synergy Between Energy Efficiency, Fossil fuels and Renewable Technologies

In addition, it is possible to demonstrate that various combinations of end use efficiency, improved efficiencies of conventional fossil fuels and renewable technologies can provide major reductions in emissions. To deliver one unit of light energy can require between 320 and zero units of fossil fuel energy. The reductions in carbon dioxide emissions can be substantial, and most of them occur with the replacement of a standard incandescent lamp with a compact fluorescent or light emitting diode.

Note that replacing the end energy use with an energy efficient lamp, the input energy for even a relatively inefficient generating system that is only 35% efficient drops by 80% and carbon dioxide emissions drop by 80%. If a gas turbine of the same efficiency is used for generation, carbon dioxide drops by 90% compared to the base case coal driven steam turbine.

Of course emissions can be brought to zero by using a non-carbon electric power source such as wind, solar, geothermal, hydro, ocean or nuclear.

VI. Conclusions

The transformation in the energy system that is needed to address climate change is indeed massive. But this is much more than an environmental issue. It is in fact an economic development issue where the energy driven economy of the industrial revolution needs to be replaced with a system that is sustainable for both developed and developing countries. The strategies of the past with all of its energy inefficiencies developed because fossil fuels were abundant and cheap. That is no longer the case, and our future economic well being as well as the climate system will need to use traditional fossil fuels much more efficiently, to significantly reduce their release of carbon dioxide (and other industrial and agricultural gases) to the atmosphere, to provide energy services with much less primary energy and to develop technologies that produce little or no heat trapping greenhouse gas emissions. Renewable energy technologies along with improved demand side efficiencies can make a substantial contribution to lowering emissions along with nuclear power, carbon dioxide capture and storage from existing fossil fuels, and other technologies.

The analysis of how renewable energy might be used requires that these systems be seen not as stand alone devices, but as part of integrated systems. In this way natural and compensatory energy storage, matching of demand for specific energy services to supply, and will allow the extraction of the full potential of renewable energy options. By careful design, it is possible not to replace existing energy source by renewables on a gigajouole for gigajoul substitution, but rather to perform many energy services with much less use of primary energy.

As indicated earlier, it is important in assessing the potential for renewable energy to mitigate climate change to assess its potential within the context of sustainable development. The needs of the OECD industrial nations differ from those of the economies in transition and the large emerging economies such as India, China, Brazil and other industrializing nations. And each of these sets of economies differ from the smaller less industrialized nations that are most likely to suffer the greatest harm from climate change. It is useful to note just how the dynamic of renewable energy is being transformed as well. Brazil clearly developed the technology of biofuels that is now being adapted by the OECD countries. China now has the fastest growing solar industry, and is a major exporter with a single firm that will soon exceed the manufacturing capacity for solar cells of the United States. A single Indian firm has become one of the top five producers of wind turbines in the world, and now exports to China, Europe and the United States as well as builds for its domestic market. Efficient buildings are no longer the province of the OECD world as major super efficient buildings that use very large amounts of renewable energy emerge in large scale projects in China, India and the UAE.

Finally, it may also be useful to look to history. The world underwent an energy revolution of a comparable scale just 100 years ago. Soon after Thomas Edison improved the electric lamp, the New York Times editorialized that while it was a clever invention, it would find only limited use, and could not compete with cheap gas lights that dominated all major urban centers.

By 1905, 3% of US homes had electricity, and Henry Ford was producing just 14 vehicles per day at his two year-old factory. At this time, few of those who supplied town gas for lighting or those who met the needs of the extensive market for horse drawn carriages felt threatened by impending change. Who could have imagined that by the mid-twentieth century virtually every American home would have electricity and lighting, that the automobile would redefine American lifestyles as suburban living, and that the economy would have been fundamentally transformed?

Fast forward to 2005. Less than 3% of US electricity was generated by non-hydro renewable sources. Only a handful of efficient gasoline-electric hybrid vehicles were being driven. Who can imagine how the mid-21st century global economy might be transformed by efficient and cost effective renewable energy sources in a "new industrial economy," and how much they will be limiting the release of greenhouse gases into the atmosphere? It is important to conduct this analysis now, so that a cost effective set of low carbon emitting energy options can emerge.

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Biomass for energy: Uses, present market, potential and costs

José Roberto Moreira

National Reference Center on Biomass – CENBIO, Institute of Electrotechnology and Energy,
University of São Paulo, SP, Brazil. bun2@tsp.com.br

ABSTRACT

This paper analyses and quantifies the use of biomass as a source of energy. Several present uses are discussed based in information already available in the literature and some new considerations are included.

Bioenergy uses are leaded by traditional uses, which at global level, are still growing in absolute figures but not in their market share. New uses related to technological advances (electricity, heat+combined heat&power, liquid biofuels and modern gases) are increasing in absolute and relative terms, but still represent less than 2% of total world energy demand. Nevertheless, the relative growth is significant but smaller than the observed in the solar photovoltaic and wind sectors. Major new uses of biomass energy comprise: electricity generation, heat production, and liquid biofuels. Most of them are driven by subsidies or mandates; however, for certain applications in some regions, bioenergy is already cost effective. Moreover, given present oil price levels (US$ 90/bbl), the competitiveness of biomass is increasing. Regarding the future, most scenarios forecast a significant increase in modern bioenergy uses.

The paper discusses constraints beyond technology, which affect large scale use of bioenergy and challenge available forecasts. Energy security in Developed Countries, food versus fuel competition and political issues related to international trade are some examples. Although cost is still a serious barrier, its importance is lessening because oil prices are rising and bioenergy technology is improving. Nevertheless, the cost of bioenergy alternatives, which require large amounts of fossil fuel input, is coupled to fossil fuel costs. The food versus fuel issue is properly analyzed regarding its real global magnitude and the concept of multiple land use is proposed as a way to share soils between food and fuels.

1 Biomass Energy Uses

According to the FAR (IPCC, 2007a) biomass currently provides around 46 EJ of bioenergy in the form of combustible biomass and wastes, liquid biofuels, renewable municipal solid waste (MSW), solid biomass/charcoal, and gaseous fuels. Figure 1 show how several primary biomass energy sources are transformed from primary to secondary energy forms, and quantifies their use according to final consumption sectors. In order to produce this energy, a significant share of all harvested biomass is already diverted to the energy market. Table 1 shows that among the major biomass commodities the share dedicated to energy supply, mainly due the contribution of fuelwood, is comparable to industrial and food supply.

industry; residues from food and paper industries; municipal solid waste; sewage sludge; dedicated energy crops such as short-rotation (3-15 years) coppice (eucalyptus, poplar, willow), grasses (Miscanthus), sugar crops (sugar cane, beet, sorghum), starch crops (corn, wheat) and oil crops (soybean, sunflower, oilseed rape, jatropha, palm oil) (IEA – ETE, 2007).

As can be seen in Figure 1 woodfuels are responsible for most of the primary energy sources of biomass (39 EJ). And after suffering very simple transformation are delivered as final energy mainly for the building sector and others. Most of these woodfuels (30 EJ) are directed to fulfill traditional uses since fuelwood, charcoal, dung, straw are being used for centuries.

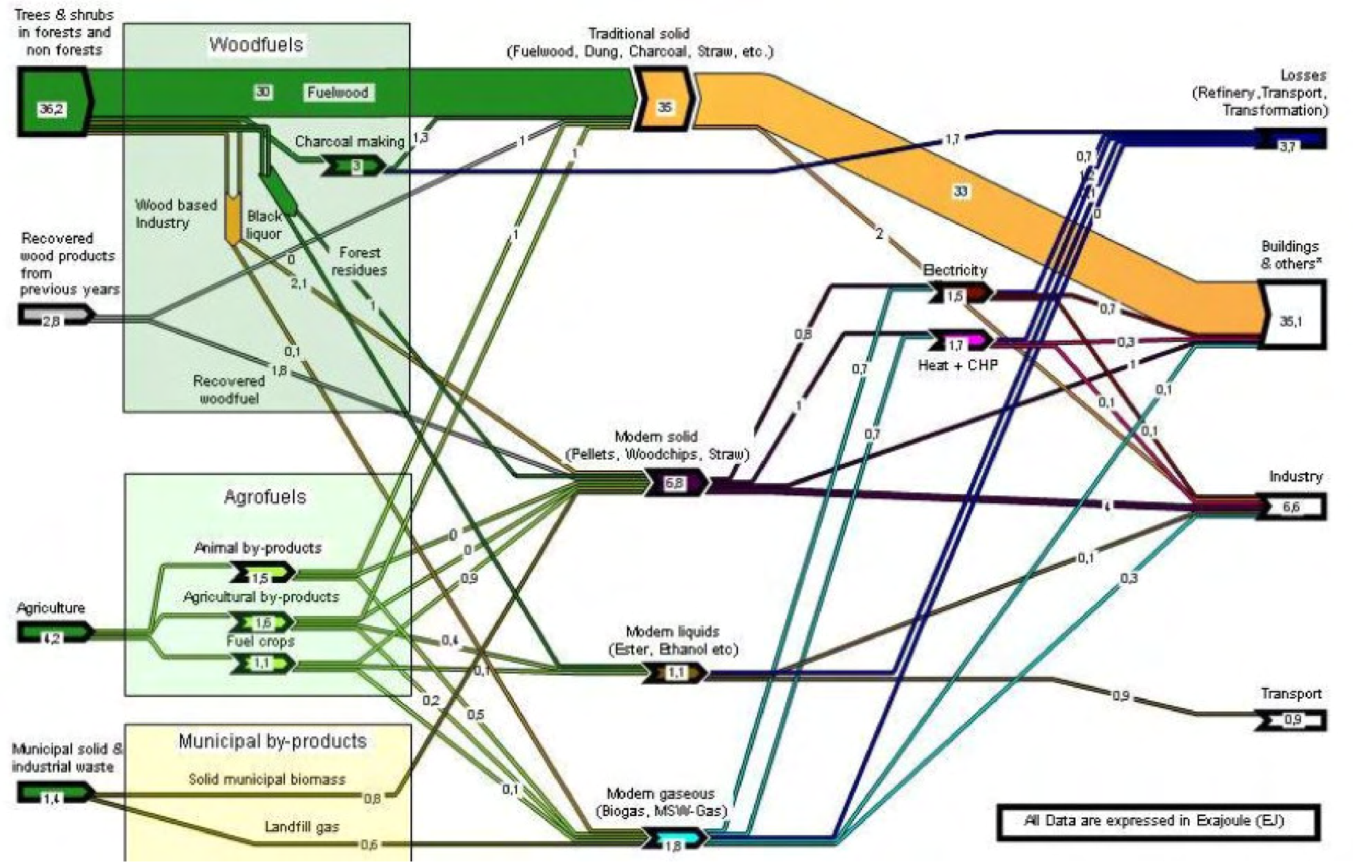


Figure 1: World biomass energy flows (EJ/yr) in 2004 and their thermochemical and biochemical conversion routes to produce heat, electricity, and biofuels for use by the major sectors.

Note: although most of the data is very uncertain, a useful indication of biomass resource flows and bioenergy outputs is conveyed. Source: IPCC, 2007a

In this section we will use Figure 1 as guidance to discuss the primary energy sources, some of the transformations, and also the final uses.

Biomass energy sources include agricultural residues; animal manure; wood wastes from forestry and

A small share of the biomass primary energy source (5 EJ) is subject to more elaborated transformation, and is transformed in pellets, woodchips, liquids such as ethanol, and gases such as biogas. After an initial transformation another one may follow such as the use of pellets or woodchips as a source of electricity or combined heat and power. Most of the more elaborated final energy forms are delivered to the industry and transport sector.

Table 1: An overview of selected (biomass) commodities production and international trade in 2004 (Heinimö and Junginger, 2007)

Product	World production in 2004	Volume of international trade in 2004
Industrial wood and forest products[(a)]		
Industrial round wood	1 646 Mm^3	121 Mm^3
Wood chips and particles	197 Mm^3	37 Mm^3
Sawn timber	416 Mm^3	130 Mm^3
Pulp for paper production	189 Mt	42 Mt
Paper and paperboard	354 Mt	111 Mt
Agricultural products[(b)]		
Maize	725 Mt	83 Mt
Wheat	630 Mt	118 Mt
Barley	154 Mt	22 Mt
Rice	608 Mt	28 Mt
Palm Oil	37 Mt	23 Mt
Rapeseed	46 Mt	8.5 Mt
Rapeseed oil	16 Mt	2.5 Mt
Solid and liquid biofuels[(c)]		
Ethanol	41 Mm^3	3.5 Mm^3
Biodiesel	3.5 Mt	<0.5 Mt
Fuel wood	1 772 Mm^3	3.5 Mm^3
Charcoal	44 Mt	1 Mt
Wood pellets	4Mt	1 Mt

Data sources: mainly FAOSTAT, 2006 Indexmundi 2006

Traditional uses represent the largest share of all biomass use and are usually studied with the purpose of quantifying its size, estimate future growth trends, and discuss policies to substitute them for modern technologies. Most of the use in the residential sector is for cooking purpose, which implies in very low efficiency (WEO, 2006). Yet, an estimated 2.4 billion people rely only on wood, charcoal or dung for cooking, and 1.6 billion are without access to electricity (IEA, 2002; IEA, 2004). The implications of improved access to commercial fuels for cooking on GHG emissions are ambiguous. On the one hand, emissions from fossil-fuels increase. On the other hand, unsustainable use of fuelwood and related deforestation decreases (IPCC, 2007b). As shown in Figure 1 woodfuels are essentially obtained from trees and shrubs removed from forests and non-forest areas. Therefore, forest present and future use has significant impact on biomass energy, mainly for traditional uses.

Forecasts of industrial wood demand have been consistently higher than actual demand (Sedjo and Lyon, 1990). Actual increases in demand have been relatively small (compare current demand of 1.6 billion m^3 with 1.5 billion m^3 in the early 1980s (FAO, 1982, 1986, 1988, 2005)). Recent projections of the FAO (1997), Häggblom (2004), Sedjo and Lyon (1996) and Sohngen et al. (2001) forecast similar modest increases in demand up to 1.8-1.9 billion m^3 by 2010 to 2015. In contrast, higher predictions of 2.1 billion m^3 by 2015 and 2.7 billion

m^3 by 2030 are less common (Hagler, 1998). Similarly, a FAO (2001) study suggests that global fuelwood use has peaked at 1.9 billion m^3 and is stable or declining; however, the use of charcoal continues to rise (e.g., Arnold et al., 2003). Most of the charcoal is produced using primitive technology (OECD/IEA, 2003), and consequently a significant share of energy is lost (1.7 EJ) as shown in the upper part of Figure 1. However, fuelwood use could dramatically increase because of rising energy prices, particularly if incentives are created to shift away from fossil fuels and towards biofuels.

Primary biomass may be also converted in electricity. In this case, most of the primary biomass comes from woodfuels but the contribution of agriculture, municipal, and industrial wastes is also significant. The electricity is mainly consumed by the industrial sector. Agricultural by-products also add to the supply of traditional biomass; and yet part of this resource is used as modern biomass such as pellets and liquid fuels. Animal byproducts, which are part of primary biomass sources generate by agriculture, are mainly used as traditional biomass, and as source of gases and liquid fuels.

Finally, fuel crops with the smallest participation in the agrofuels category shown in Figure 1 are being used as source of liquid fuels and electricity with a contribution smaller than 1 EJ. Even considering that most of the modern uses still represent a minor contribution to the total biomass use, it is important to carefully analyze these opportunities since their recent evolution indicates a significant growth (REN21, 2007).

1.1 Electricity generation

Figure 2 shows that biomass is the third most important new and renewable source of electricity at the global level and the second one in developing countries. Installed power in 2006 was, respectively, 55 GW and 25 GW. Unfortunately, these positions may be lost in the future if the biomass for power rate of growth is compared with other renewables (see Figure 3).

Biomass combustion is a carbon-free process because the resulting CO_2 was previously captured by the plants being combusted. Presently, biomass co-firing in modern coal power plants with efficiencies up to 45% is the most cost-effective biomass use for power generation. Due to feedstock availability constraints, dedicated biomass power plants for combined heat & power (CHP), are typically of smaller size[1] and lower electrical efficiency than coal power plants (30%-34% using dry biomass, and around 22% for municipal solid waste). In cogeneration mode, the total efficiency may reach 85%-90%. Biomass integrated gasification in gas-turbine plants (BIG/GT) is not yet commercial, but integrated gasification combined cycles (IGCC) using black-liquor (a by-product from the pulp & paper industry) is already in use (OECD/IEA, 2007).

Figure 2: Renewable Power Capacities in 2006(GW) for Developing Countries, EU, Top Six Individual Countries (excluding large hydropower)

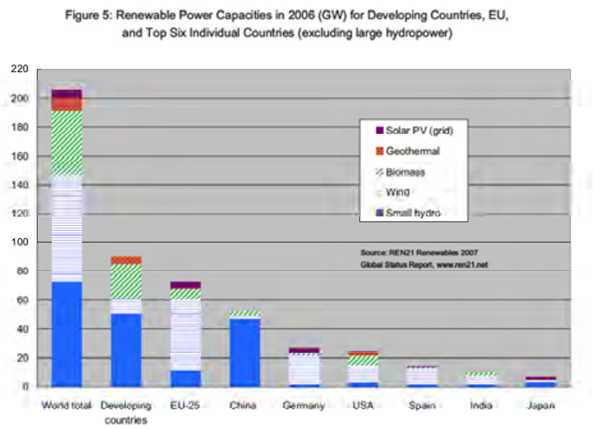
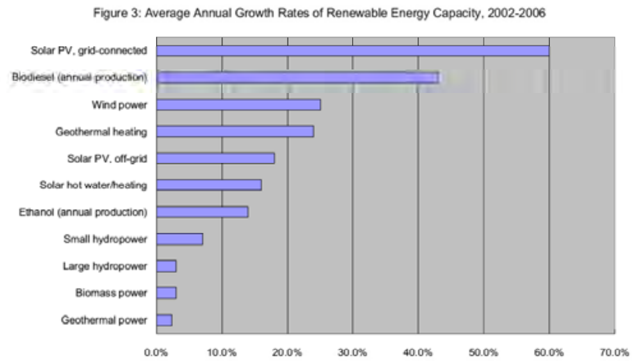


Figure 3: Average Annual Growth Rates of Renewable Energy Capacity, 2002-2006.



Source REN21, 2007 Source REN21, 2007 Global Status Report. www.ren21.net

1.2 Charcoal production and use

According to Table 1, 44Mt of charcoal was produced in 2004, corresponding to the consumption of 176 to 132Mt of woodfuel or 350 to 265 Mm^3. Thus, the impact of this use is similar to the pulp production sector (Table 1). This is the most important biomass use in Africa and contributes to the excessive harvest of wood fuel together with extraction of fuelwood, and demand for cropland (IPCC, 2001). Fuelwood is actually in high demand for cooking and (part of the year) heating. Because most of the present fuel wood and charcoal comes from destructive felling (forest mining), switching to renewable fuel wood produced on a sustainable basis is eligible as a small-scale CDM project. (UNEP, 2006). The demand for fuelwood and charcoal is driven primarily by rising numbers of rural poor, who depend on wood for their cooking and heating needs. Charcoal, which is often consumed in the form of briquettes, is also an important fuel among the urban poor, whose numbers are expanding rapidly. Charcoal is also an industrial energy source in some Latin American countries; the steel industry in Brazil, for example, depends heavily on charcoal.

Traditional charcoal-making techniques are inefficient. With appropriate charcoal-making methods, including traditional techniques, the mass and energy yields of the most commonly used techniques can be double or tripled. In addition, charcoal is two to five times denser than wood with the same energy yield on a mass basis. The costs and energy consumption incurred for transport are thus reduced. With equivalent emissions, greater transportation distances can be achieved while remaining economically acceptable, allowing supply sources to be diversified and forest resources better managed (G8, 2001). Economic growth might be expected to reduce demand for biomass fuels in coming years. The conventional view is that, as income rises, countries shift toward the use of commercial fuels and reduce their dependence on biomass. Nevertheless, it appears that, even with

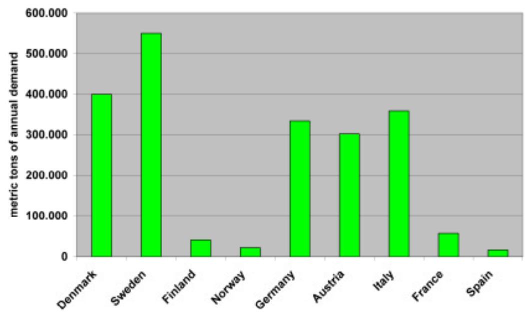
[1] See a very comprehensive illustration in UNEP, 2006, Figure 6

economic development, woodfuel use will not necessarily decline significantly.

1.3 Pellet Production and Use

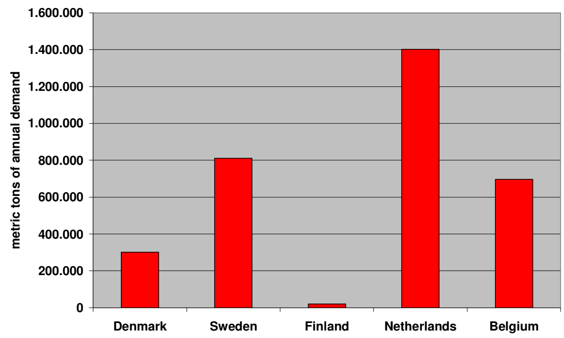
The penetration of biomass pellets in the market for heat and power production is recent. The market was developed in the earlier 80's in USA but the use was widespread at the end of the 90's in EU (see Table 1). As shown in Figure 4 and 5 pellets are being used in the residential sectors as a source of heat and in the electricity industry as a source of electricity. There are also industrial uses providing electricity and in some cases heat and power.

Figure 4: European markets for residential pellet heating in 2005



Source: IEA-Bioenergy, 2007; Pro Pellets Austria, 2007

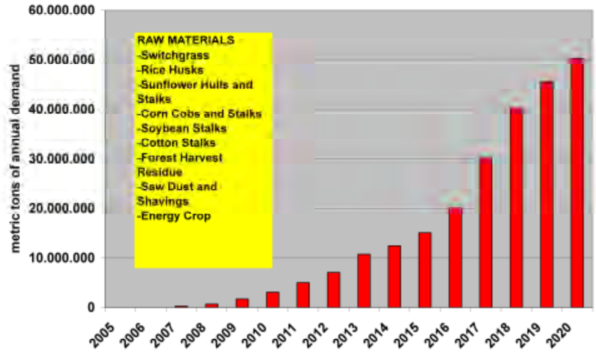
Figure 5. Pellets use in the power plantsin Europe in 2005



Source IEA-Bioenergy, 2007; Pro Pellets Austria, 2007

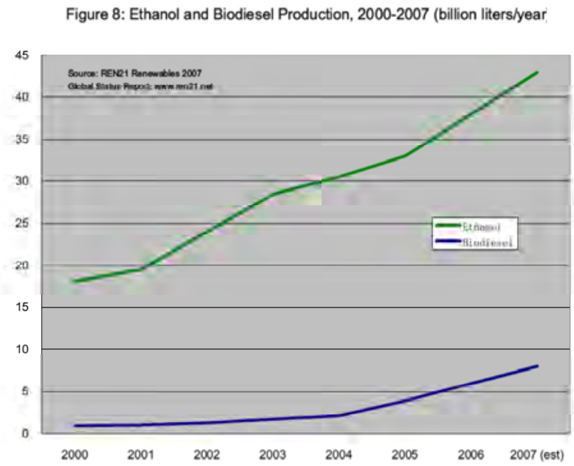
There are also evidences that China will become a significant user of pellets mainly for electricity purpose. Figure 6 shows forecasts for China. The scenario is impressive considering that by 2020 China consumption may reach 50 Mt while the current world's annual consumption is 4 Mt (see Table 1).

Figure 6: Production of Pelletized fuel in



Source: IEA-Bioenergy, 2007

Figure 7: Ethanol and Biodiesel Production China



Source: REN21, 2007

1.4 Biofuel Production and Use

Recently, biofuels have been subject to many debates and interest because they are the only commercially or almost commercially available alternative to liquid fossil fuels (WEO, 2006a). Biofuel market penetration is occurring rapidly (see Figure 7). The annual volume commercialized is 50 M cubic meters, but as shown in Figure 1 their contribution in the complete biomass energy uses is still modest (0.9 EJ). The growth rate of biofuels, as well as programs considered by the USA government and by the private sector in Brazil allows for very optimistic forecast in the short term (REN 21, 2007).

In most countries, ethanol has been introduced in a blend with gasoline. Refiners often modify the neat gasoline, which has a lower vapor pressure, to accommodate the increase in vapor pressure caused by adding ethanol (ESMAP, 2005).

Most major automobile manufacturers warranty their cars to run on ethanol blends of up to 10 percent of ethanol; however, current European standards allow only for blends of up to 5 percent ethanol. About 30 percent of all gasoline sold in the US is E10 (10 percent ethanol). Sweden is the first country in Europe that uses 85 percent blends of ethanol in gasoline, and Spain too has allowed marketing of E5 blends, while France and Spain primarily use ETBE blends. All gasoline sold in Brazil contains 20–25 percent of ethanol, a level achievable because automakers use components that are resistant to corrosion by ethanol IPCC, 2007d).

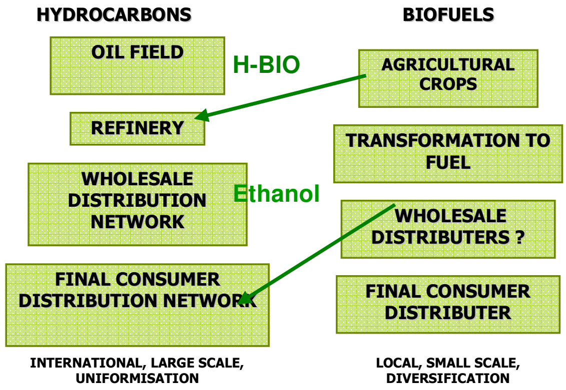
Cars with especially designed engines are able to run on even higher proportions of ethanol fuel. In Brazil, ethanol-only vehicles run on "neat," hydrous ethanol, which is available at more than 90 percent of gas stations. In Brazil, the US, and Europe, flexible-fuel vehicles (FFVs) that can run on low- and high-level ethanol blends are an increasingly popular option. In colder climates, where the low vapor pressure of pure ethanol can cause cold start problems, neat ethanol is not considered a viable option. Instead a blend of E85 is available for FFVs in the United States (at less than 1 percent of gas stations) and Sweden (IPCC, 2007d).

Biodiesel is less promising in terms of cost and production potential than cellulosic fuels but is receiving increasing attention. Bio esters are being produced by a chemical reaction between vegetable or animal oil and alcohol, such as ethanol or methanol. Their properties are similar to those of diesel oil, allowing for blending of bio esters with diesel or the use of 100% bio esters in diesel engines. Any mix including vegetable or animal derived bio esters is called biodiesel. Blends of 20% biodiesel with 80% petroleum diesel (B20) can generally be used in unmodified diesel engines[2].

Green diesel is a new technology not yet commercialized but with some reasonable prospects. Green diesel is diesel oil manufactured using vegetable oils or fat oil directly through hydrogenation of the feedstock (Wisconsin, 2008, Curbelo, 2005, www.biodieselbr.com/destaques/2006/h-bio-novo-diesel-petrobras.htm, Marker et al, 2007). The advantage of green diesel is the integration of the oil industry with biomass producers earlier in the process than compared with bioethanol. As suggested in Figure 8, through the use of green diesel it is possible to increase the interest of oil companies, which are able to use their installed refineries capacity to produce renewable fuel. In comparison, bioethanol is essentially produced by other agents and only at the end of the production chain it uses distribution facilities designed for liquid fossil fuels supply. Bio-refineries may open the door to combined, cost-effective production of bio-chemicals, electricity and biofuels.

1.5 Biogas Production and Use

Figure 8: Production and commercialization of liquid fuels



Source: Curbelo, 2005

Biogas production is obtained through anaerobic digestion, which is a biological process that converts solid or liquid biomass into gas in the absence of oxygen. The gas consists mainly of methane and carbon dioxide and contains various trace elements. Anaerobic digestion is used in the treatment of wet wastes of industrial (0.1 EJ of primary energy), agricultural (0.8 EJ) and domestic origin (0.6 EJ) (see Figure 1). The derived gas is increasingly used for the production of heat (0.7 EJ) and electricity (0.7 EJ), yielding a modest amount of final energy (0.3 and 0.1 EJ, respectively (see Figure 1). Solid and liquid residues from the anaerobic digestion process can be used as compost and fertilisers. Farm-based facilities at household or village-scale are common, in countries such as China and India. The biogas produced is used for cooking, heating and lighting. Over 600 plants treating farm wastes (often co-digesting wastes from a variety of sources) are in operation in North America and Europe. There are also scattered examples of biogas use as a transport fuel in vehicle fleets (Bauen et al, 2004). Anaerobic digestion of biomass has been demonstrated and applied commercially with success in many situations and for a variety of feedstocks, including organic domestic waste, organic industrial waste, manure, and sludge. About 25 million households worldwide receive energy for lighting and cooking from biogas produced in household-scale plants (called anaerobic digesters) (REN 21, 2007). Large advanced systems have been developed for wet industrial waste. In India there is widespread biogas production from animal and other wastes. (Johansson et al, 2004). Anaerobic digestion to produce biogas is also expanding in small, off-grid applications.

[2] http://www.eere.energy.gov/afdc/altfuel/biodiesel.html.

2 Market Penetration

Bioenergy market share has increased at an annual rate of 2.0%, between 2000-2005, which was greater than the rate of 1.6% between 1980-2000. It is expected that the observed trend will continue (WEO, 2007). Unfortunately, during the same periods global energy consumption has increased, respectively, 2.7 and 1.6%, essentially due to significant increases in coal and NG use, which means that bioenergy share has not increased (WEO, 2007). Nevertheless, this is not of concern since new and renewable sources are increasing above average global energy consumption (see Figure 3) while traditional uses are increasing below average (0.36%/yr for non-commercial uses of woodfuel and 0.61%/yr for commercial uses (FAOSTAT, 2007)). As already described in section 1, traditional biomass uses are growing at modest rates with the exception of charcoal, which represents a small share of woodfuels demand (see Table 1). The growth of modern uses are being driven mainly by biofuels, bioelectricity and pellets.

The following list of major trends provides a clear and concise view of bioenergy market penetration (REN21, 2007).

2.1 Global Market Trends

Renewable power capacity of about 240 GW in 2007 (ex. large hydro) represents almost 6% of total global power capacity (~4,300 GW) and the share is increasing. Bioelectricity represents 55 GW or 1.3%

Worldwide Biomass-fueled heating still provides five times more heat than solar and geothermal combined, and continues to grow in northern Europe.

Present consumption of bioenergy is 5 times greater than the energy from hydroelectricity (Johansson et al, 2004)

The U.S. has become the dominant ethanol producer (corn-based), although Brazil has started an ambitious program to increase production by 50% by 2009 (sugar cane-based).

The U.S. recently launched a program to produce 136 Mm^3 of ethanol by 2022, which is 3 times greater than present world production (Energy Bill, 2007)

Ethanol provided over 40 percent of all (non-diesel) motor vehicle fuel in Brazil in 2005.

Biodiesel production has increased by 20-100% annual rates in recent years, particularly in Germany, France, Italy, Poland, and the US. Almost half of the world's biodiesel production continues to be in Germany.

Commercialization of diesel type engines powered by additivated ethanol is evolving outside of Sweden, where it has occurred in the last 15 years (BEST, 2007).

Production of green diesel in oil refineries through hydrogenation of vegetable oil and animal fat is occurring in Brazil and other countries are planning to start very soon (www.biodieselbr.com/destaques/2006/h-bio-novo-diesel-petrobras.htm).

About 14 million hectares of land are now used in the production of biofuels, which equals to about 1% of the world's currently available arable land. According to WEO (WEO, 2006) scenarios this share rises to 2% in the Reference Scenario and 3.5% in the Alternative Policy Scenario.

The number of jobs worldwide in the renewable energy industry exceeds 2.5 million, out of which the biofuel industry is responsible for more than 1 million.

New investment in ethanol production facilities could reach $3 billion in 2007, with more than 85 plants under construction in the U.S. and Canada, and a major program starting in Brazil that could increase national output by 50% by 2009.

The investment value of new ethanol production facilities under construction or announced during 2008 is more than $6 billion in Brazil, Canada, France, Spain, and the US.

Targets for biofuels as a share of transport energy exist in EU (5.75% by 2010 and 10% by 2020), France (10% by 2015), Belgium (5.75% by 2010), and Japan (5% by 2030).

Mandates for blending biofuels into vehicle fuels have been enacted in at least 30 states/provinces and 12 countries. Most are 10-15% for ethanol and 2-5% for biodiesel.

US Renewable Fuels Standard requires 28 billion liters/year of biofuels by 2012 (vs. 18 b/y in 2006)

Biofuels tax exemptions have been enacted in a growing number of countries during 2005-2007, including Argentina, France, Germany, Greece, Ireland, Italy, Lithuania, Slovenia, South Africa, Spain, Sweden, and UK. Many of them call for 100% tax exemptions.

3 Biomass Energy Potential

3.1 Theoretical Potential

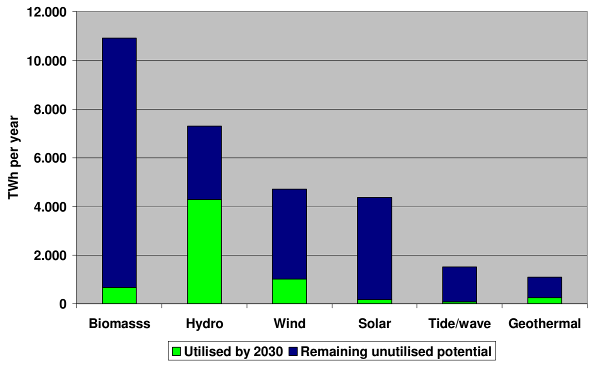
Table 2 condenses several bioenergy supply potential results published in the last decade, while Table 3 is a classical summary of major conclusions from the IPCC TAR. An interesting conclusion from Table 3 data is the comparison between hydroelectric and biomass energy potential.

Table 3: Total land area required and theoretical potential for alternative energy production

	Million Ha	EJ/year
Wind	300 (1)	630
Solar Energy	393 (2)	1600
Biomass	1280 (3)	440
Hydroelectricity	40 (4)	10
1) 10% of all world land area with wind speed above 5.1 m/s at 10 m height		
2) 10% of all world area classified in category "other lands" by FAO (2000)		
3) Using all potential surplus land area for agricultural cultivation not necessary for food crops by 2050. 15 ODT/ha and 20GJ/ODT		
4) Production in year 2000		

For more than a century society has strongly relied on hydroelectricity as the main source of renewable energy. and its intense use triggered the concept of multiple uses of water (WCD, 2000). When compared with biomass, the potential of hydroelectricity is modest. Thus, we can speculate first why not believe that biomass, with a much larger potential than hydroelectricity, cannot contribute with a larger energy share than what is currently supplied by large-scale hydroelectric plants (see Figure 9). Second, is really valid the concerns on land scarcity, which is currently subject to inflamed debates?

Figure 9: World Long-Term Renewable-Energy Potential for Electricity Generation



Source WEO, 2004

Table 2: Estimates from the literature on the global potential of biomass energy

		Biomass residue potentially available (EJ/yr)			
		Year			
Source[(a)]	**Types of residues**[(b)]	**1990**	**2020 – 2030**	**2050**	**2100**
1	FR, CR, AR		31		
2[(c)]	FR, CR, AR, MSW		30	38	46
3	FR, MSW		90		
4					272
5	FR, CR, AR, MSW			217-245	
6		88			
7[(c)]	FC, CR, AR, MSW		62	78	
8	FR, CR, AR		87		
A1[(d)]	Energy crops			660	1118
A2[(d)]	Energy crops			310	396
B1[(d)]	Energy crops			449	703
B2[(d)]	Energy crops			324	485
9	Energy crops, FR, CR			273-1381	
Source: Johansson et al 2004, adapted from: Hoogwijk, M., et al, 2005					

Notes:
(a) 1)Hall et al, 1993; 2)Williams 1995; 3)Dessus et al 1992; 4)Yamamoto et al 1999; 5)Fischer and Schrattenholzer 2001; 6)Fujino et al 1999; 7)Johansson et al 1993; 8)Swisher and Wilson 1993; 9)Smeets et al 2004
(b) FR: forest residues; CR: crop residues; AR: animal residues; MSW: municipal solid waste
(c) These studies rather estimated the potential contribution, instead of the potential available
(d) IPCC 2000

Table 4 presents the latest evaluation of bioenergy supply and demand potential carried out by IPCC (IPCC, 2007e). Energy crops have the largest share of the total supply potential that ranges from 125 to 760 EJ by 2050. A proper comparison between demand and supply is not possible because most of the supply estimates have been done for 2050 and demand has been assessed for 2030. Taking this into account, the lower end of biomass supply (estimated at about 125 EJ/yr) is greater than the lower estimate of biomass demand (estimated to be 70 EJ/yr) (see Table 4, second column). Noting the large range allocated for bioenergy supply and demand, it is not a surprise the major conclusion extracted from that same reference "given the relatively small number of relevant scenario studies available to date, it is fair to characterize the role of biomass in long-term stabilization (beyond 2030) as very significant but with relatively large uncertainty. Further research is required to better characterize the potential. A number of key factors influencing biomass mitigation potential are worth noting: the baseline economic growth and energy supply alternatives, assumptions about technological change (e.g., rate of development of cellulosic ethanol conversion technology), land use competition, and mitigation alternatives (overall and land related)".

Nevertheless, it is important to add that the above conclusion puts too much expectation on the use of biofuels (responsible for 45-85 EJ of primary biomass energy –see Table 4, fourth column) and ties this use to the necessity for developing second generation biofuels (WEO, 2006). Major arguments supporting the conclusion are the present high cost of starch-based ethanol production and vegetable oil-based biodiesel coupled to the energy security approach adopted by developed countries (WEO, 2007). These arguments are not supported when costs of sugar cane-based ethanol are considered (CONSECANA, 2007), the number of potential producer countries are included (FAOSTAT, 2007), and the observed high increase on the price of wood pellets since 2006 due the huge increase on their demand[3] (IEA, 2007). Furthermore, the potential and relevance of co-production of electricity and ethanol have not been considered in Table 4. This occurs because the technology is poorly discussed in the literature. As shown by Moreira, (Moreira, 2006) it is possible to produce simultaneously from sugar cane feedstock almost the same amount of energy in the form of ethanol and bioelectricity. This discussion is important since most of the potential demand evaluations focus on primary energy availability, while what really matters is final energy. Approaches considering final energy supply potential are valuable and could increase the interest for biofuels that are already in the market but not optimally used. Obviously, such evaluations would not impact the supply potential but could facilitate the identification of more credible demand scenarios and help to minimize the food versus fuel issue since less land would be necessary to provide the bioenergy.

As stated in the IPCC report (IPCC, 2007e) innovation will also be crucial for mid-century, as well as longer term deep reductions of GHG emissions. Some of the technologies responsible for emission reductions until 2050 are already commercialised, but others (such as carbon capture and storage (CCS)) are not. In particular Biomass Carbon Capture and Storage (BCCS) when applied to CO_2 emissions from sugar fermentation is highlighted by the IPCC report (IPCC, 2006) as a potential technology. Its simplicity, considering that pure CO_2 flows out of the fermentation vessel reducing the operation process from carbon capture and storage to only storage, and the fact that due the very high CO_2 balance already obtained in the case of sugar cane-based ethanol (Macedo, 2004) it is possible to obtain negative CO_2 emission[4] are factors to be considered when forecasting the market potential of ethanol. It is worthwhile considering that ethanol derived from starch is also subject to this new technology Due a modest CO_2 balance when replacing liquid fossil fuel by ethanol obtained from starches (Shapouri et al, 2002), BCCS provides a significant increase in the CO_2 balance, and allows for the use energy sources such as of coal, which are highly impactant, in the ethanol processing facility. Thus, cost reduction obtained due the use of coal instead of natural gas in starch-based ethanol plants should be compared to the additional costs of the BCCS.

3.2 Economic Potential

This evaluation is much more difficulty to perform. On the one hand, most of modern biomass uses are being driven by subsidies and by energy security motivation. On the other hand oil price has been increasing in the last 3 years due to various reasons, which prevents a clear analysis. The importance of public awareness regarding climate change and its

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[3] Price increase for wood pellets was triggered by the significant demand. Thus, it is not clear that use of cellulosic feedstock for the production of high volumes of ethanol will not replicate the observed trend of the pellet industry.

[4] Thus, as more biofuel is produced and used more net CO_2 is removed from atmosphere.

impact is also an important driver that affects market demand for clean energy sources. Finally, it is possible to note that, at least for biofuels, commercial and political interests have significant impact in the market.

The economic barrier is presently surpassed by sugar cane based ethanol in some developing countries. Given present oil prices (around US$ 90/bbl), there is evidence that even corn ethanol can be commercially competitive (WEO, 2006a, USDA, 2006). The economic issue is more complex for biodiesel because vegetable oil production is still being performed to match the food market demand, which is growing at high rates (see Figure 10). This imposes severe price increase when even a small additional demand for energy occurs. In Malaysia, demand for palm-based biofuel is growing so fast that the government has decided to stop licensing new plants until industry works out a way to split the raw material between food and energy (Reuters, 2006: Dufey, 2006). The country recently announced that it has reached an agreement with Indonesia, in which both countries commit to set aside 40 per cent of their crude palm oil output for biodiesel production (Reuters, 2006). These two countries account for 90 per cent of the global palm oil production. This problem is also present when analyzing starch demand for ethanol; however, observed price spikes have been higher for vegetable oil than for starches, followed by ethanol from sugar cane, which poses much less concern.

In the short term, co-firing remains the most cost-effective use of biomass for power generation, along with small-scale, off-grid use. In the mid-long term, BIG/GT plants and biorefineries could expand significantly. IEA projections suggest that the biomass share in electricity production may increase from the current 1.3% to some 3%-5% by 2050 (WEO, 2006), depending on the assumptions considered. This is a small contribution compared to the estimated total biomass potential (10%-20% of primary energy supply by 2050), but biomass is also used for heat generation and transport fuels.

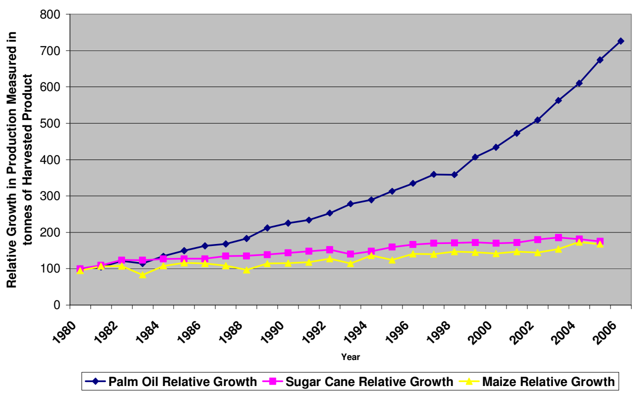
Table 4: Biomass supply potentials and biomass demand in EJ as based on Chapters 4 to 10 (IPCC, 2007e).

	SUPPLY	DEMAND			
SECTOR	**BIOMASS SUPPLIES TO 2050**	**ENERGY SUPPLY BIOMASS DEMAND 2030**	**TRANSPORT BIOMASS DEMAND 2030**	**BUILT ENVIRONMENT**	**INDUSTRY**
Agriculture					
Residues	15 – 70			Relevant, in particular in developing countries as cooking fuel	Sugar industry significant. Food & beverage industry No quantitative estimate on use for new biomaterials (e.g. bio-plastics) not significant for 2030
Dung	5 – 55				
Energy crops on arable land & pastures	20 - 300				
Crops on degraded lands	60 – 150				
Forestry	12 – 74	Key application	Relevant for 2nd generation biofuels	Relevant	
Waste	13	Power and heat production	Possibly via gasification	Minimal	Cement industry
Industry	Process residues				Relevant: paper & pulp industry
Total supply primary biomass	125 – 760				
Total demand primary biomass	70 - 130	28 – 43 (electricity) Heat excluded	45 - 85	Relevant (currently several dozens of EJ: additional demand may be limited	Significant demand; paper & pulp and sugar industry use own process residues; additional demand expected to be limited.

Main barriers remain costs; conversion efficiency; transportation cost; feedstock availability (competition with industry and biofuels for feedstock, and with food and fiber production for arable land); lack of supply logistics; risks associated with intensive farming (fertilizers, chemicals, soil erosion, biodiversity).

As the economic barrier is loosing its importance due to high oil prices and learning by doing progress, other kind of barriers are being introduced in the market, some due to real issues, others due lack of understanding of the biofuel contribution for climate change, and others tied to political interests (IEA-Bioenergy, 2006; UNCTAD, 2007a). These barriers must be tackled even if this adds up to the cost of biofuels and makes competition with fossil fuels even harder because the latter are not challenged (Smeets et al, 2006). Coupling biofuels use with energy security is a very common approach adopted by Developed Countries but it is not necessarily well justified taking into account the small share of biofuel participation in the market (see Figure 1) and the existence of several potential suppliers. Environmental impacts are another frequent barrier that is imposed by potential importers as a way of limiting biofuel market (see Table 1). Economic and consequently social impacts due competition between food and fuel is a very debatable issue (IFPRI, 2007) but there are many evidences (see Table 2) that significant extension of available agricultural land exists in order to attend human food demand as well as much more fuel production. In particular, the IPCC (IPCC, 2000) published some very large potential for biomass energy potential.

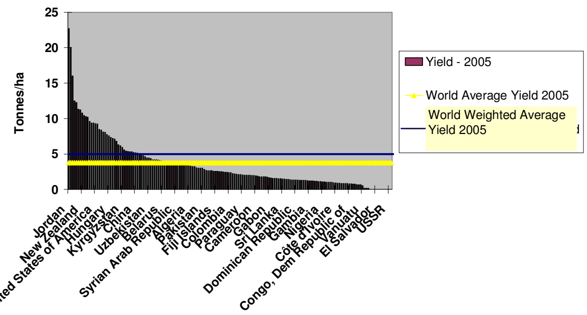
Figure 10: Biofuel Feedstock Relative Relative Growth at World Level



Source: Author based on FAOSTAT, 2007

Another important aspect to discuss, when opening opportunity to people concerned with potential soil scarcity and its inability to be shared between food and fuel, is the concept of multiple land uses (WCD, 2000). A similar concept was raised decades ago when discussing how to share limited water availability between several competing demands e.g. water for irrigation, for hydroelectricity and for transportation. The major agreement on this discussion was the optimization of water use in order to best fulfill all three different and important issues. Transposing this solution to land scarcity it is ease to conclude that scarce soil should be used efficiently both for food and fuel production. Based on food yields it is clear that many countries and regions use agricultural soil for food production with low efficiency, as shown by the average crop yields (see Figure 11). In addition, land used for fuels may be used inefficiently, usually stimulated by the energy security principle. The literature shows the significant advantage of sugar cane over starches when using presently available technologies (IEA, 2005). Nevertheless, sugar cane is not suitable for temperate countries, where the use of starches as ethanol feedstock makes more sense.

Figure 11: World Maize Yield for Producing Countries - 2005



Source: Author based on FAOSTAT, 2007

The issue of efficient land use for food or fuel should be also observed in the case of biodiesel production. Almost all commercial sources of vegetable oil presently available, with the exception of palm oil, are low yield crops (IEA, 2005). In addition, there is technology to operate quite satisfactorily diesel engines using ethanol mixed with a small percentage of a cetane enhancer (BEST, 2007). Considering the higher yield from sugarcane than from oil crops and the technology availability, ethanol may be a better solution than biodiesel. Nevertheless, some vegetable oil feedstocks (e.g. corn, soy) have the merit of producing food or fodder byproducts. A final evaluation requires the adoption of the multiple land use concept.

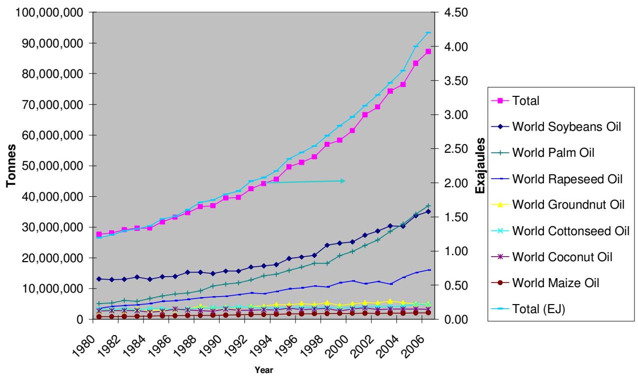
While endless discussions proceed with the purpose of creating less expensive biofuels while reducing food versus fuel competition and minimize environmental impacts, significant amount of financial resources and man-power are being directed to technologies that may bring about the commercial production of biofuels known as second generation technologies

(UNCTAD, 2007b). They include biomass gasification and conversion of cellulose to ethanol. Apparently these technologies would not be commercially available before the next ten years and will not be cost competitive with sugar cane ethanol (Energy Bill, 2007; Pacheco, 2007; Phillips et al, 2007). Nevertheless, they are expected to significantly increase the availability of biofuel feedstock. Biomass gasification faces less technology breakthroughs but high costs are an important barrier.

Ethanol produced from sugar cane and biodiesel from palm oil have been subject to much debate because of their potential perverse environmental or social impacts (Dufey, 2006). Developed Countries limit the trade of ethanol from sugar cane, the only biofuel that is presently cost competitive with fossil fuel, by imposing high importation taxes (WEO, 2006a). Quite often, arguments about natural forest removal due to Palm oil and sugar cane plantation expansion are presented in scientific and political forum (WEO, 2006a). In the case of vegetable oils, most of the production increase was due to food uses as shown in Figure 12 (see footnote 1). Global vegetable oil production reached near 100 Mtonnes (4.2 EJ) in 2006 from which only 6 Mm^3 (0.2 EJ) are being used for fuel (see Figure 7 and 1). In the case of sugar cane, less than 4 Mha of soil is being used in the world[5], compared with over 1.300 Mha dedicated to the global food production (FAOSTAT, 2007). Even assuming that a large increase in biofuel production occurs, the necessity of land may be modest if its production is based in optimized land use. This is the case, for example, for maize production. Average world yield in 2005 was 3.76 tonnes/ha, while weighted average yield (total production/total harvested area) was 4.76 tonnes/ha (Figure 11). Assuming productivity improvement in the countries with very low records occurs and world average yield increases from 3.76 to 4.76, total harvest area could be reduced from 147 Mha to 116 Mha while keeping the world total production and increasing soil availability by 31 Mha. Such land area is enough for the production of 184 Mm^3 (4.2 EJ) of sugarcane-based ethanol from sugarcane planted at present world weighted average yield (70 tonnes/ha). A similar study was recently prepared (UNCTAD, 2007c) but putting more emphasis in pasture land shift to open space for bioenergy crops. Nevertheless, the concept of multiple uses of land are not discussed in the literature while barriers for biofuels production continue to appear. An interesting example is that in comparison with bioelectricity, biofuels methodologies which can trigger CDM projects in developing countries are scarce (UNCTAD, 2006) and the only one approved in 2007 for biodiesel production and use sets so many constraints that should exclude most of the potential projects (www.unfccc.int).

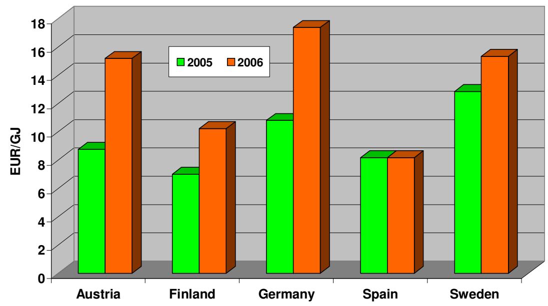
With all such components economic potential evaluation is subject to great uncertainty. As an example, IEA forecasted that the share of biofuels in total transport consumption, which was only 0.4% in 2002, is expected to increase more than fourfold by 2030, reaching 36Mtoe. The projection was baked by government policies that are in place to spur biofuel consumption in several countries, especially in the United States, European Union, India, and Brazil (WEO -2004). Global biofuel consumption was 8 Mtoe in 2002, of which Brazil accounted for 70% and the United States for 23%. Surprisingly, global production in 2007 is expected to be 43 and 7 Mm^3 for ethanol and biodiesel, respectively, (see Figure 7) which is equivalent to 32Mtoe. Furthermore, the recent energy bill (Energy Bill, 2007) in the US claims that 36 billion gallons of ethanol (82Mtoe) should be domestically produced by 2022. Adding the expected Brazilian production (30Mtoe) (UNICA, 2007) and other potential producers the market size can reach 120Mtoe, in 2022.

Figure 12: World Vegetable Oil Production According with the Major Feedstock Sources



Source: Author based on FAOSTAT, 2007

Figure 13: Pellet prices in Austria, Finland, Germany, Spain and Sweden in 2005 and 2006 (Eubionet II)



Source: IEA-Bioenergy, 2007

[5] From the 14 Mha used for biofuels (WEO, 2006a), 20% of maize crop used for ethanol in USA requires 8.5 Mha while the 4 Mtonnes of biodiesel produced essentially from rapeseed and pal oil require the remaining.

Pellet market is also increasing fast; nevertheless, on a smaller scale than biofuels. Its use mainly for bioelectricity can easily be supported by concerns with climate change (see Figures 4 and 5). Sugar cane residues may be extensively used for electricity generation in Brazil and other developing countries mainly due voluntary compromises and official regulation to eliminate pre-firing harvesting (AMBIENTE EM FOCO, 2007), as well as other developing countries, which may add, at global level, an extra amount of more than 300 Mt/yr (120Mtoe) of biomass to be used for electricity or heat generation (WEC, 2001). In this case, forecasts such as the ones made by IEA can deviate from reality. The view that bioelectricity can increase its present share in electricity production from 1.3% (200TWh) to 3-5% (1200 to 2000TWh) by 2050 (IEA ETE, 2007a) may be conservative.

Within these estimates, bioenergy options are important for many sectors by 2030, with substantial growth potential beyond, although no complete integrated studies are available for supply-demand balances. Key preconditions for such contributions are development of biomass capacity (energy crops) in balance with investments in agricultural practices, logistic capacity, and markets, together with commercialization of second generation biofuel production. Sustainable biomass production and use implies that disputes are equated (competition between land for energy and food, water resources, biodiversity and socio-economic impacts). (IPCC, 2007e).

Biomass is an example of a cross-sectoral technology in which there is potential for resource competition. Any assessment of the use of biomass, e.g., as a source of transportation fuels, needs to consider competing demands from other sectors for the creation and utilization of biomass resources. With technical breakthroughs, biomass could make a larger future contribution to world energy needs. Such breakthroughs could also stimulate the investments required to improve biomass productivity for fuel, food and fiber. (IPCC, 2007e).

4 Bioenergy Costs

The cost of biomass for energy supply has been widely quoted in the literature (Intelligent Energy, 2007; Bauen et al, 2004; IEA-ETE, 2007b). Biomass prices used as biofuels and pellets feedstocks are better known because the formal market is ample and well analyzed (IEA-Bioenergy, 2007; Propellets Austria, 2007). Pellets price in some EU countries are shown in Figure 13. Raw biomass is usually considered at prices around US$3/GJ in developed countries (OECD/IEA, 2007) and less than US$2/GJ in developing ones. Sugar cane prices are well known in several countries – Brazil US$ 18.5/t (CONSECANA, 2007), Mexico US$40/t (GTZ, 2006) of harvested cane. Woodchips and whole trees and shrubs prices are less available. Figure 14 shows energy prices in Sweden from which it is possible to infer wood shavings price as well as wood pellets (IEA, 2007). Using the 2005 exchange rate[6] pellet price at that year is 12.5 US$/GJ, while wood shaving price is 4.2US$/GJ. For sugar cane the delivered price includes transportation to the sugar mill. Considering a tonne of sugar cane yields 85 liters of ethanol and 130 kg of dry biomass with low heating value of 16 GJ/t, we conclude that 1 tonne of harvestable sugar cane has 1.87 GJ as liquid fuel and 2.08 GJ as solid biomass that equals to 3.95 GJ. This means a cost of US$ 5.06/GJ. Once the juice is extracted, wet bagasse is available for commercialization at prices very sensitive to supply and demand factors. High prices is around US$ 15/wet tonne (50% moisture), yielding a price at the sugar mill gate of US$ 2.00/GJ. Nevertheless, prices around US$ 5.00/wet t may occur, yielding a value of US$ 0.70/GJ. For maize, traditional prices were around US$ 2.50/bushel (2.5/25.4 = US$ 0.099/kg), achieving values around US$ 3.75 more recently (Westcott, 2007). Considering an energy density of 16 GJ/t of harvested maize the feedstock is delivered to alcohol mills at a price of US$ 6.2 to 9.3 US$/GJ.

Because of the variety of feedstocks and processes, costs of bio-power vary widely. Co-firing in coal power plants requires limited incremental investment ($50-$250/kW), and the electricity cost may be competitive (US$ 20/MWh) if local feedstock is available at low cost (no transportation). For biomass, typical cost of $3-$3.5/GJ, the electricity cost may exceed $30-$50/MWh. Due to their small size, dedicated biomass power plants are more expensive ($1500-$3000/kW) than coal plants. Electricity costs in cogeneration mode range from $40 to $90/MWh. Electricity cost from new gasification plants is around $100-$130/MWh, but with significant reduction potential in the future (Bauen et al, 2004).

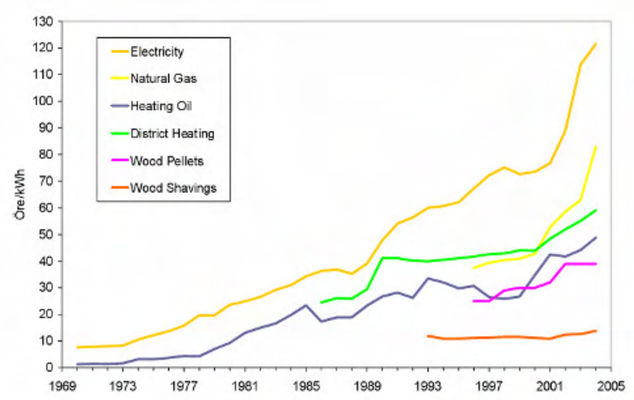
In order to have a metric for these costs it is important to note that oil prices at around US$ 90/bbl are equivalent to 13.3 US$/GJ. Thus, economic competition with oil is still difficult, mainly when considering the very high conversion efficiency of oil in oil derivates (typical energy losses of less than 10%), while the efficiency of conversion from biomass to final energy is much lower. Figure 15 shows the amount of primary energy in planted sugar cane crops in Brazil compared with the primary energy in

[6] 1 US$ = 6.65 SK by January 2005

national oil production for several years. Both are comparable at almost the same level. Nevertheless, 1/3 of the primary sugar cane energy is burned or left in the soil and the other 2/3 is used efficiently for ethanol production (85 liters/t) and inefficiently for electricity generation (50 kWh/tcane). Only recently some interest for using the share left in the soil is being considered, while electricity generation is starting to be performed with high pressure steam boilers (100 bars) (Purohit and Michaelowa, 2007). Such low conversion efficiency may help to explain why biofuel and bioelectricity being produced require subsidies in most countries. Few exceptions are known, e.g. in Brazil where due a long learning-by-doing process ethanol and bioelectricity are being produced without subsidies and in other efficient sugar producing countries such as Pakistan, Swaziland and Zimbabwe that have production costs similar to Brazil's (EC, 2006). Under such difficult economic context all available mechanism that can improve biomass-based energy competition are valuable.

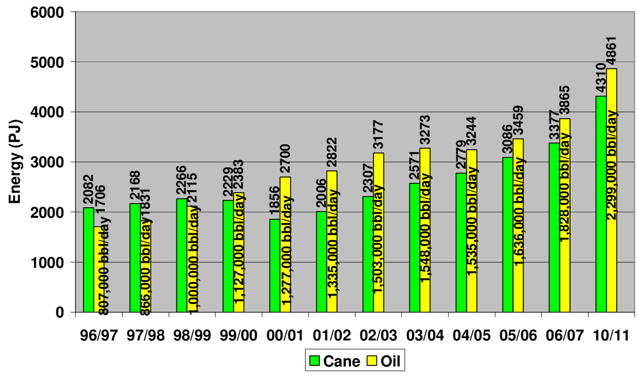
Analyses of the impact of CO_2 taxes on potential biomass uses have been carried out by many authors. A recent and concise review has been presented (IPCC, 2007e), where bottom up and top down results are published (Table 11.5). It is noticeable that the mitigation potential in the power generation and transport sectors are not very sensitive to CO_2 prices. The minimum mitigation potential in the power sector is 5.8 EJ (1.3 + 4.5) for low CO_2 value (less than US\$ 20/tCO_2) and 9.1 EJ (2.4 + 6.7) for high CO_2 value (up to US\$ 100/tCO_2) by 2030. When considering the maximum mitigation potential, figures 8.4 and 13 show that the differences between low and high CO_2 costs, when accounting for large uncertainties, are relatively low. For the transport sector, values in the respective figures range from 2.6 to 3.2 EJ both for low CO_2 prices to 4.2 and 5.0 EJ for high CO_2 prices. This is an evidence that CO_2 taxes also have modest impact in the amount of fuels used for transportation when uncertainties are considered. All these figures are valid for bottom-up evaluations. For top-down assessments in the energy supply sector figures ranges from 3.9 to 9.7 EJ for low CO_2 prices and 8.7 to 14.9 EJ for high CO_2 prices. For the transportation sector figures ranges from 0.1 to 1.6 EJ for low CO_2 prices and 0.8 to 2.5 EJ for high CO_2 prices. It is possible to see that uncertainties are larger for top-down than bottom-up models but the transportation sector is less sensitive to CO_2 prices than the energy supply sector. This may impact the way bioenergy is used, since there is less motivation to transform biomass into biofuels than generating bioelectricity.

Figure 14 Commercial energy prices development in Sweden Öre/kWh



Source: IEA-Bioenergy, 2007

Figure 15: Primary energy from sugar cane and from oil produced in Brazil



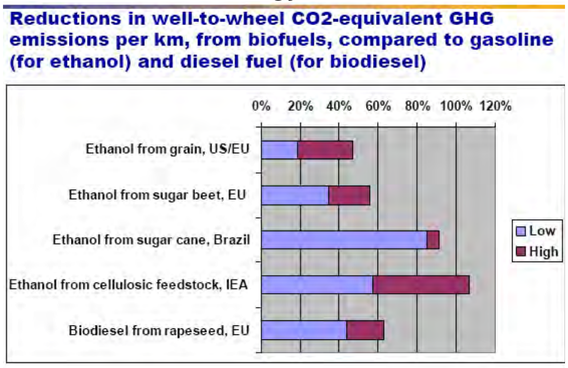
Source: Oliverio, 2005

Given the present oil prices, gasoline and diesel in the US are being market for the end-user, excluding taxes, at values around US\$ 700/m^3 (IEA, 2007). Considering this cost should be covered only by CO_2 taxes, it corresponds to US\$ 218/tCO_2. Assuming biofuels would have the same price as fossil fuels per amount of energy, it is very clear that CO_2 tax around 20 US/tCO_2 has a modest impact in the biofuel market expansion. Nevertheless, high CO_2 values presented in Table 11.5 (IPCC, 2007e) may, in principle, add almost 50% extra value to renewable sources of energy. Unfortunately, biofuels are not completely CO_2 free since fossil energy is consumed for crop development as well as for processing biomass into final biofuel. Fossil energy consumed is significant, as shown in Figure 16, for ethanol from grains and sugar beet. When significant amount of fossil energy is used for biofuel production, the real financial contribution of the CO_2 tax per liter of biofuels is reduced. Fossil fuel expended in biofuel production also impacts its economic competitiveness since the latter price is quite dependent of the former, explaining why commercial feasibility is not yet achievable for most bioenergy sources even with significant oil price escalation, as opposed with some recent estimates that claim that bioethanol in the EU becomes competitive when the oil price reaches US\$ 70 a barrel (Petroleum

Econ.,2005; UNCTAD, 2007b) while in the US it becomes competitive at US$ 50 - 60 a barrel.(Sexton et al, 2006; UNCTAD, 2007b))

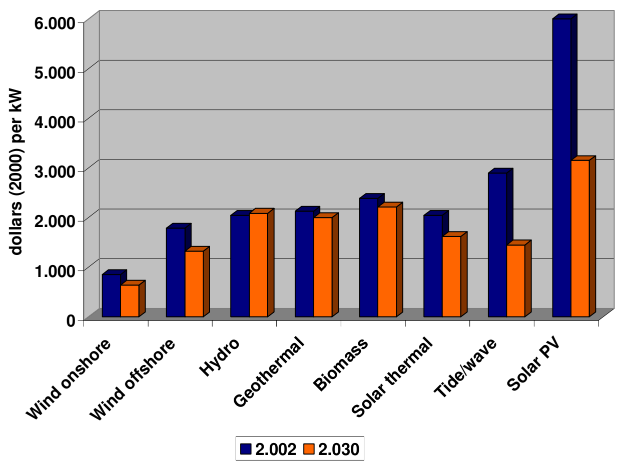
The above discussion on bioenergy cost has dealt with feedstock cost. This is justified because the capital cost for processing biomass is not different from required for fossil fuel (OECD/IEA, 2007). Furthermore, there are expectations that these costs will decline in the future as the technology become to be more used. As noted from Figure 17, capital costs for biomass-based energy should decline by 2030, but at rates lower than some other renewables

Figure 16: GHG Reductions significant, but vary by feedstock and technology



Source: IEA, 2005

Figure 17: Capital Costs of renewable Energy Technologies, 2002 and 2030



Source: WEO, 2004

5. Conclusions

Most researchers agree that the energy challenge of this century – providing enough affordable energy in order to achieve, expand and sustain prosperity for all, while avoiding intolerable environmental disruption – cannot be met without a huge increase in the global energy-innovation effort. Alternative energy sources, including biofuels, are part of this effort.

Several developed and developing countries are establishing regulatory frameworks for bioenergy They are also providing different kinds of subsidies and incentives to support nascent biofuel industries. These developments are expected to spur a sustained worldwide demand and supply of bioenergy in the years to come.

Efficiency considerations and optimized use of land indicate that feedstock and bioenergy production has to take place in the most efficient countries. Several developing countries – with land to devote to biomass production, a favourable climate to grow them, and low-cost farm labour – are well placed to become efficient producers. However, energy security concerns may prompt less efficient countries to engage in biofuel production – instead of imports – irrespective of economic and environmental considerations.

This paper has reviewed a variety of bioenergy production and uses. The discussion has been set in a "supply-side" context, i.e., how biomass can provide increased electricity, heat and liquid fuel supplies for fossil fuel substitution. The "demand-side" context, i.e., how efficiently the biofuels are utilized (in vehicles, in cooking, etc.) has not been addressed.

The ranking of liquid biofuels in first and second-generation have some attractions, but can create an incomplete view of the problem. One of the most misleading ideas is that first generation biofuels will be surpassed by second generation ones and as such the effort to produce and market such energy forms are useless in the long-term. This is not what is being quoted in the literature, where for example sugar cane ethanol coupled with electricity generation is a good example of the success of first generation biofuel. Sugar cane ethanol stands out among first-generation biofuels as suffering few economic, social and environmental limitations, in large part because energy for processing sugar cane into ethanol is provided by biomass from sugar cane itself and its yield is large requiring less soil use compared with other alternatives. Even some described limitations, which include direct competition with food production, may be challenged when global land availability is evaluated and the concept of multiple uses of soil is considered.

Present and predicted high oil prices, increasing pressure to mitigate climate change effects, along with efforts to diversify agricultural production and provide new opportunities for rural communities, are expected to sustain interest for biofuels as potential instruments to address energy security, climate change and rural development concerns. Hence, production and international trade of biofuels are expected to grow significantly in the years to come. Certifying biofuels on the basis of sustainability may play a role in ensuring that biofuel production and use indeed contribute to climate change stabilization, improved energy security and rural development, without having detrimental side- effects on food security, land and water use or biodiversity preservation. If well-planned, biofuels and feedstock production may be a unique opportunity for developing countries to enter a new market which appears very profitable. Many of these countries enjoy the appropriate land and labor conditions for becoming efficient biofuel and feedstock producers and eventually exporters

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Potential Role and Contribution of Direct Solar Energy to the Mitigation of Climate Change

Dr. Dan E. Arvizu

National Renewable Energy Laboratory, Golden, Colorado USA

Abstract

Solar thermal, photovoltaic, and concentrating solar power technologies use the vast energy available from the sun to generate heat and electricity that can be used by end-users in the buildings, transportation, and industrial sectors. To promote significant growth of solar markets, many countries have established solar-related targets while fostering technological development and market transformation. Success in achieving aggressive growth will allow solar energy to contribute at significant levels to the world's energy portfolio. A key environmental benefit will be the lowering of greenhouse gas emissions as fossil fuels used for electricity generation and transportation fuels are displaced by the application of clean solar technologies.

The ubiquitous sunlight that illuminates the Earth is, not surprisingly, a tremendous energy source. Specifically, the energy from the sun that strikes the Earth every hour is approximately equivalent to the world's entire energy demand for a whole year. Direct solar energy (DSE) technologies—as differentiated from indirect solar source such as wind or biomass—can take advantage of this solar resource to provide needed energy—both in the form of solar heat or thermal energy from direct and passive approaches in the built environment and of solar electricity from photovoltaics (PV) and concentrating solar power (CSP).

This escalating growth is already contributing to today's energy needs, but also holds great potential for the mid and long term. So, for example, in some parts of the world, solar thermal technologies are currently making significant contributions; but they hold promise to meet the need for hot water, space heating, and cooling in many other parts of the world. Additionally, in buildings, solar electricity can meet the needs of residential or commercial buildings. Integrated solar building designs, taking into account energy efficiency and passive solar, can also help to lower overall energy demand.

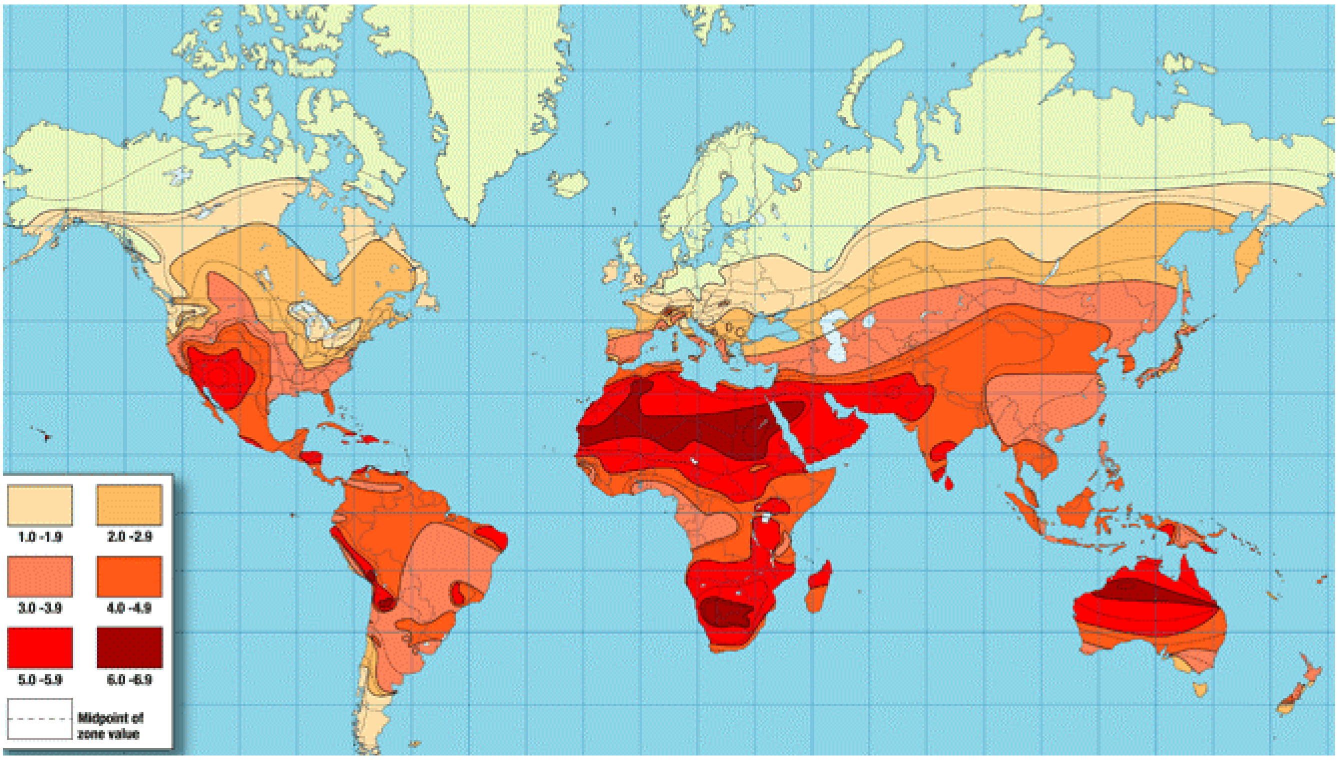


Figure 1. The solar resource—sunlight—is robust across much of the world. This map shows the number of hours of solar energy received each day on an optimally tilted surface during the worst solar month of the year [www.howto.altenergystore.com]. The most intense areas of color indicate the most hours of sun.

During the last decade, solar technologies have seen significant growth in manufacturing, installations, and investment. This growth can be attributed to the interplay among technology, policies, and markets. Technological progress has led to improved efficiencies, lower costs, and products with better reliability. Policies have helped to lower financial and institutional barriers, spurring deployment. And markets have blossomed within developed and developing countries for thermal and electricity needs in the end-use areas of buildings, transportation, and industry.

In transportation, solar-generated electricity can lead to fuel switching, from petroleum fuels to either electricity (as in plug-in hybrid vehicles) or hydrogen (as in fuel-cell vehicles using hydrogen generated from the solar-powered hydrolysis of water). In the industrial sector, manufacturing facilities can be designed to be more energy efficient, with at least some portion of industrial power and heating needs being met by on-site generation.

The success of solar technology holds promise for multiple objectives. While addressing climate concerns, solar may also be of particular benefit in developing nations—where the tension between fossil fuel interests as represented by less democratic governments and renewable technology provided by more democratic nations will play out in the coming decades.

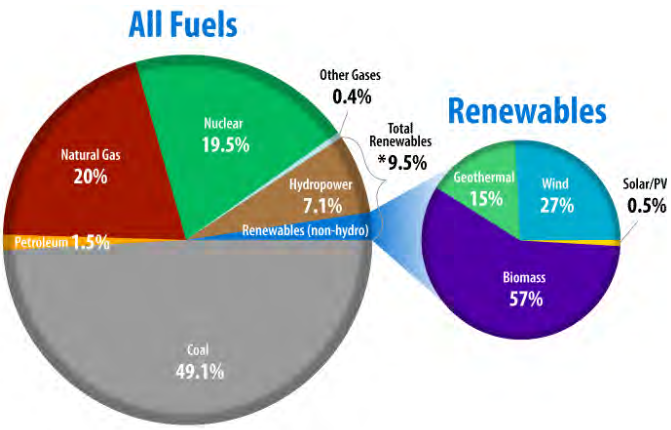


Figure 2. (Left) U.S. electricity net generation by all fuels, and (Right) contribution of biomass, wind, geothermal, and solar technologies to the non-hydro renewables wedge [EIA 2007].

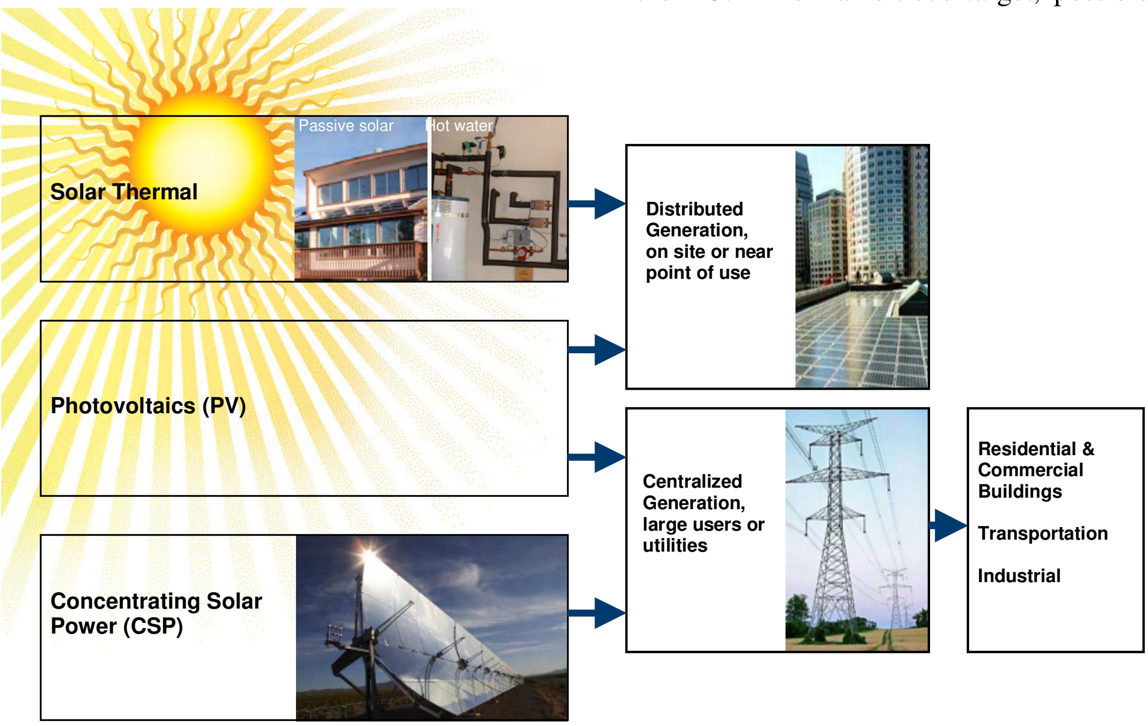


Figure 3. The solar resource can be used by direct solar technologies to supply thermal energy and electricity to end-users in the buildings, transportation, and industrial sectors

In this paper, we first review the potential and targets set by the U.S. national program and others for reaching significant penetration of DSE technologies worldwide. We review the contribution that solar via various pathways can make in the overall energy portfolio and consider an approach, exemplified by the U.S Solar America Initiative, for reaching these targets. We provide an overview of the status of solar technologies within the solar thermal and solar electric areas. We further discuss some of the ways that these DSE technologies may help to mitigate climate change. In the final section, we elaborate on challenges related to policy, market, and business issues that solar technologies face in trying to rapidly achieve aggressive goals and targets.

I. Solar Targets

Various targets and goals are provided below in the areas of solar thermal, PV, and CSP technologies for the European Union, United States, and other countries, where known. We will update this paper in the future as more detailed information with broader geographic focus beyond the U.S. and EU becomes available and is compiled.

Solar Thermal Targets

The European Solar Thermal Industries Federation (ESTIF) has proposed that a minimum target for the EU in 2020 should be to reach Austria's 2005 solar thermal usage (i.e., 199 kW_{th} per 1,000 capita), equivalent to a total capacity in operation of 91 GW_{th} in the EU. Their ambitious target, possible with a suitable support framework, is to reach 1 m^2 of collector area (0.7 kW_{th}) for every European in 2020, equivalent to a total capacity in operation of 320 GW_{th} in the EU [ESTIF 2007].

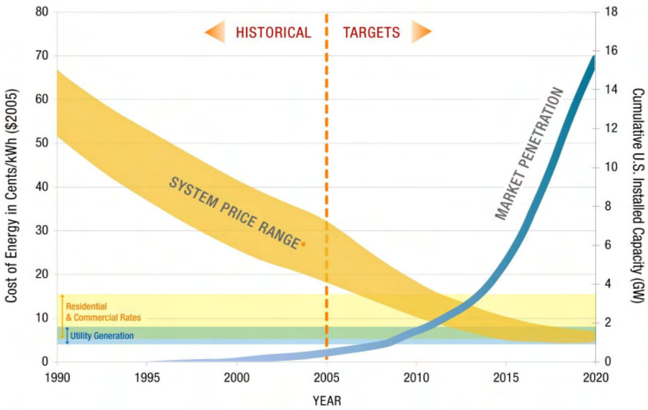
The U.S. Department of Energy (DOE) Building Technologies Program goal is to make zero-energy commercial buildings (ZEBs) marketable by 2025 [Griffith 2006].

China is purported to have the following targets for solar hot water deployment [Martinot 2007, NDRC 2007]:

	2006 actual	2010 target	2020 target
million m^2 of solar hot water collectors	100	150	300

PV Targets

In 2006, the U.S. Solar America Initiative (SAI) was announced, in support of the President's Advanced Energy Initiative, and is led by the DOE's Solar Energy Technologies Program [DOE 2007b]. The overall goal of SAI is to make photovoltaic-generated electricity cost-competitive with conventional energy sources across the USA by 2015, with specific energy cost targets for various market sectors tabulated below.



Market Sector	Current U.S Market Price (¢/kWh)	Cost (¢/kWh) Benchmark 2005	Cost (¢/kWh) Target 2010	Cost (¢/kWh) Target 2015
Residential	5.8 – 16.7	23 – 32	13 – 18	8 – 10
Commercial	5.4 – 15.0	16 – 22	9 – 12	6 – 8
Utility	4.0 – 7.6	13 – 22	10 – 15	5 – 7

Figure 4. The graph highlights the DOE Solar America Initiative target to gain more than 30% market share for annual PV capacity additions on par with the price of grid electricity. The table shows target energy costs in the three key utility end-use segments.

PV roadmaps developed for the European Union, Japan, and Australia also consider cost targets, as well as other areas such as installed capacity, cell and module efficiencies, and manufacturing capacity. For example, the EPIA Roadmap in 2004 established a target of 3 GW peak installed PV by 2010 in the European Union [EPIA 2004].

The *Solar Generation IV* report [Greenpeace 2007] includes a chart that lists expected PV generation costs for rooftop systems at different locations. An excerpt providing the range of high and low values is given below:

Sunshine Hours	2006 (€/kWh)	2010 (€/kWh)	2020 (€/kWh)	2030 (€/kWh)
900 (Berlin)	0.45	0.35	0.20	0.13
1,800 (Los Angeles)	0.22	0.17	0.10	0.07

CSP Targets

The DOE CSP program aims for gigawatt-scale intermediate load power plants by 2015, with an early focus on trough designs. The current potential (considering a 50-MWe plant using 2004 technology) is an energy cost of ~$0.11/kWh. With scale-up, volume production, and technology development, the 2012 cost is expected to drop to less than $0.05/kWh [Mehos 2008a].

The Western Governors' Association (WGA) concluded that CSP could provide electricity at 10 ¢/kWh or less by 2015 if 4 GW of plants were constructed in the southwestern United States; this lower cost is due, in part, to the economies of scale in production [WGA 2006]. Furthermore, 30 GW could be installed by 2030 if the Investment Tax Credit (ITC) is extended; and 80 GW is possible under a more aggressive policy scenario that includes a carbon tax of $35/ton CO_2 [Kutscher 2007, CSP chapter].

Spain has a goal of installing 500 MW of CSP power by 2010, using a 0.21 €/kWh feed-in tariff. As many as a dozen 50-MW plants may be involved, and storage will be an important part of the projects [Mehos 2008a]

II. Current Market Overview

The charts below indicate aspects of the state of solar thermal, PV, and CSP markets from the perspective of installed capacity, energy costs, and overall financial outlook. Other market factors are also mentioned.

Capacity and Cost

The number of installations of solar thermal, PV, and CSP systems has been growing steadily, while the cost of energy from these direct solar energy technologies has declined markedly.

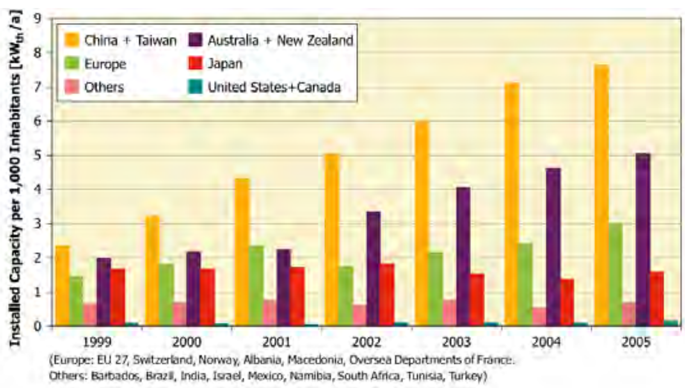


Figure 5. Annual installed capacity of flat-plate and evacuated-tube solar collectors for various countries or regions [Fawer 2006, IEA 2007].

Solar Thermal. China continues to be the major market for flat-plate and evacuated-tube solar thermal systems for producing domestic hot water. In contrast, the United States solar thermal market is much smaller, dominated by unglazed pool-heating systems.

Figure 6. Heat and power worldwide in 2006. Orange bars are total capacity in operation in 2006, in gigawatts (either thermal or electric); aqua bars are annual energy generation in 2006, in terawatt-hours (either thermal or electric) [Fawer 2006, IEA 2007].

	Installed capacity (GW_{th})	Energy output (PJ/yr)	Costs (2005) Range (€/GJ)	Costs (2005) Average (€/GJ)	Projected avg cost reduction by 2030 (% 2005 costs)
Solar thermal	100–110	200–220			
water & space heating			8–226	52	-42
solar-assisted cooling	<0.05		11–307	66	-44

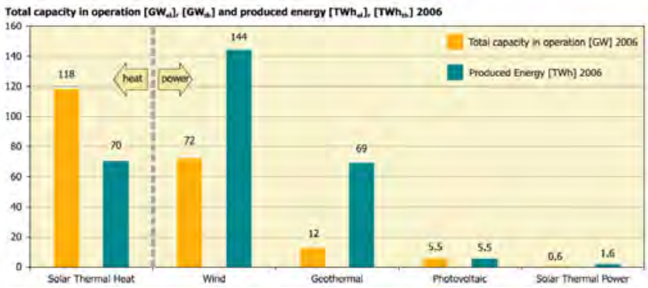


Figure 7. Estimated global capacities, energy outputs, and 2005 and projected costs out to 2030 for solar thermal energy [IEA 2007].

The cost of energy has dropped for solar thermal (as well as for photovoltaics and other renewable energy technologies), in part, because of economies of scale of manufacturing and deployment of more systems—but also, because of improved systems as a result of successes in research and development (R&D).

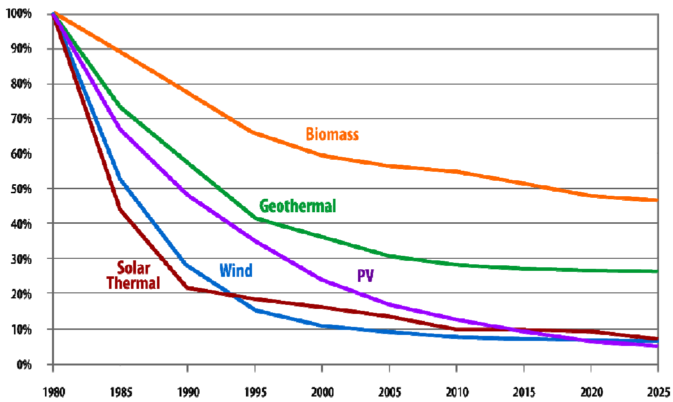


Figure 8. Past improvements in R&D on various renewable technologies, including solar thermal (red curve) and photovoltaics (purple curve), have yielded impressive cost reductions.

Photovoltaics. Annual growth rates of PV shipments worldwide have been in the 25%–40% range for the last five years due to increased manufacturing capacity and demand for PV products. The shortage of polysilicon feedstock curtailed the growth of some silicon cells and modules during the last couple of years, but new sources of feedstock are coming on line and should alleviate the bottleneck.

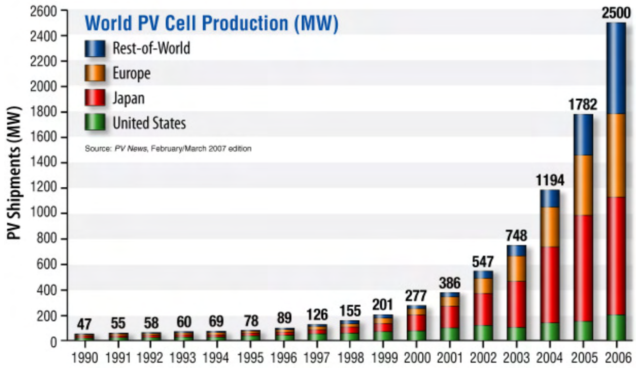


Figure 9. PV cell shipments are expected to continue to grow at the high rates experienced over the last several years [Maycock 2007].

Concentrating Solar Power. New CSP plants have been constructed during the last year in the United States and Spain, and plans for parabolic-trough and central-receiver plants are under development in various countries that have appropriate solar resources.

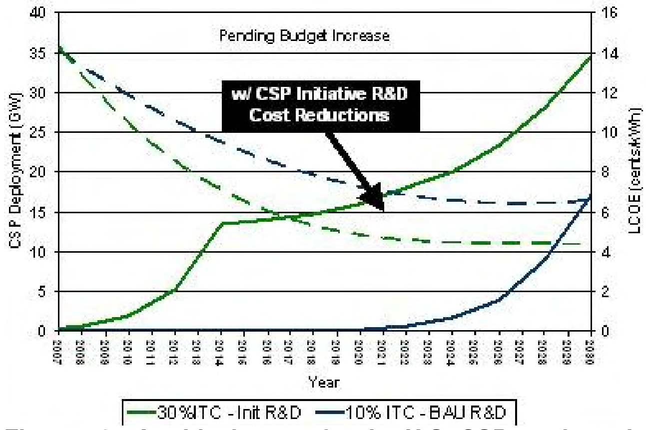


Figure 10. A critical target for the U.S. CSP roadmap is to install CSP plants at a gigawatt scale that generate electricity at baseload-equivalent price and dispatchability. The green curves include a 30% investment tax credit (ITC) and CSP Initiative R&D cost reductions; the blue curves assume a 10% ITC and business-as-usual R&D.

Financial Investments

The last year saw a significant increase in venture capital investment for the solar industry. The result has been an upswing in start-up companies seeking to develop new solar products to meet growing demand.

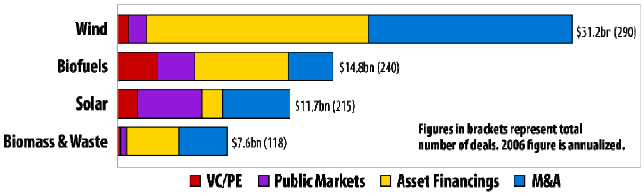


Figure 11. 2006 investment and mergers & acquisitions (M&A), by sector and asset class (venture capital/private equity [VC/PE], public markets, and asset financings) [New Energy Finance 2007].

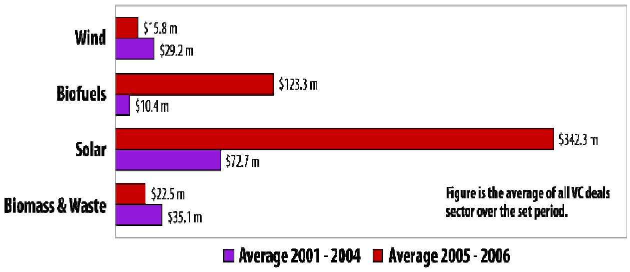


Figure 12. 2006 venture capital investment volume: 2001–2004 compared with 2005–2006 [New Energy Finance 2007].

Other Market Factors

Several other market factors are considered below.

Innovative Financing. Innovative models that help consumers use solar power systems have also been driving the market forward—in addition to the increased investment and advances in capacity and cost reduction discussed above. Companies that "sell electrons," as opposed to the solar systems themselves, have been growing. These entities see their offering as providing solar power, where they own the system and are responsible for maintenance, but customers benefit from a predictable price for their renewable energy source. This model overcomes purchase price "sticker shock," facilitating solar energy usage without the sale of actual solar systems to consumers.

Building-Integrated PV Advances and Creative Applications. Thin-film advances have created potential new applications for solar technology. For example, the ability to produce pigmented solar components may expand the use of solar products for commercial buildings applications.

Micro-Solar Markets. Solar technology is increasingly being used for smaller power needs. Companies are growing the market for applications such as powering electronics, which is a particularly significant development for countries where technology is widely distributed, but access to an electrical power infrastructure is lacking.

III. Roadmap For Reaching Targets

What will it take to get to these targets? Clearly, the solar community worldwide is focusing on the twin areas of technology R&D and market transformation, because neither alone will be sufficient to ensure a successful solar future. Scientists and engineers continue to work toward developing solar devices and products that have higher efficiencies, lower costs, and improved reliability. Those on the market transformation side focus on such areas as the need for favorable policies, more deployment projects, and technical assistance and education.

Solar Thermal

ESTIF [2007] has developed a *Solar Thermal Action Plan for Europe* that outlines a similar approach taken by the Solar America Initiative (which focuses on PV and CSP growth in the United States and is described in detail in the next section). The ESTIF approach takes into account the following: (1) The need to set ambitious goals for solar thermal in Europe; each member state then needs to set specific targets. (2) The most successful countries to date have supported solar thermal over a relatively long period of time, thus avoiding the stop-and-go market, which proves to be destructive. (3) Various measures need to be implemented that address the whole host of barriers to growth; these barriers disappear as markets grow beyond a critical mass.

ESTIF's approach seeks to foster a future where the following are true: People know about solar thermal and find it natural to use. Standard training of trades people, such as plumbers and construction workers, includes solar thermal. Architects foresee solar thermal as a standard feature in buildings. Every installer offers solar thermal systems. Industry invests heavily in market development. And mass production and marketing drives down costs.

The European Solar Thermal Technology Platform (ESTTP) is developing a comprehensive roadmap for the solar thermal sector. Their plan will cover R&D needs (i.e., technological issues), as well as market deployment needs (i.e., non-technological issues) [ESTIF 2007, Markets in Europe].
The Chinese solar thermal market is seven times bigger than the EU market—with China at ~10,500 MW_{th} versus the European Union at ~1,500 MW_{th} [ESTIF 2007]. Therefore, China will undoubtedly be developing products to be deployed to meet its huge demand for thermal systems.

PV and CSP

In the United States, the SAI plan spells out such a two-pronged approach for growth and success of PV and CSP [DOE 2007b]. The strategy for technology development includes funded activity across the entire technology pipeline, as described in the following examples:

- Materials and Devices Concepts: The "Solar Energy Utilization" solicitation focuses on novel technologies far from commercialization, such as nanostructured inorganic and organic materials, and multijunction cells. These new and novel materials and pathways for solar-to-electric conversion are being identified, synthesized, and observed.

- Devices and Process Proof-of-Concept: A technology may be ready for prototype system development. The "Future Generation PV Devices & Processes" solicitation focuses on slightly more mature technologies than those at the R&D stage. These include thin-film silicon, nanocrystalline materials, biomimetic concepts, organic materials, photoelectrochemical cells, dye-sensitized materials, and very-high efficiency epitaxial solar cells.

- Component Prototype and Pilot-Scale Production: The "PV Component/System Incubator" solicitation involves small businesses and non-university research institutes. It is designed for technologies/processes that have successfully demonstrated proof of concept in the laboratory, but are not yet mature enough for large-scale commercial production. The emphasis is on the barriers to entry toward 2010 commercialization. Prototypes of these PV systems and components will be produced on a pilot-scale in a relevant operational environment to demonstrate cost, reliability, and performance advantages. PV and CSP modules, components, and systems are all targeted in this phase of the technology development pipeline with goals that include the more efficient use of materials, better performance, higher reliability, storage systems, and improved manufacturing.

- System Development and Manufacturing: The "University Product and Process Development Support" focuses on targeted materials science and process engineering research to support industry-led university teams developing new PV systems for commercialization in 2010–2015. The last stage of the technology pipeline before commercial replication is targeted by "Technology Pathway Partnerships." These partnerships between U.S. industry, national laboratories, and universities focus on developing, testing, and demonstrating new PV components, systems, and manufacturing equipment ready for mass production that deliver energy at targeted costs.

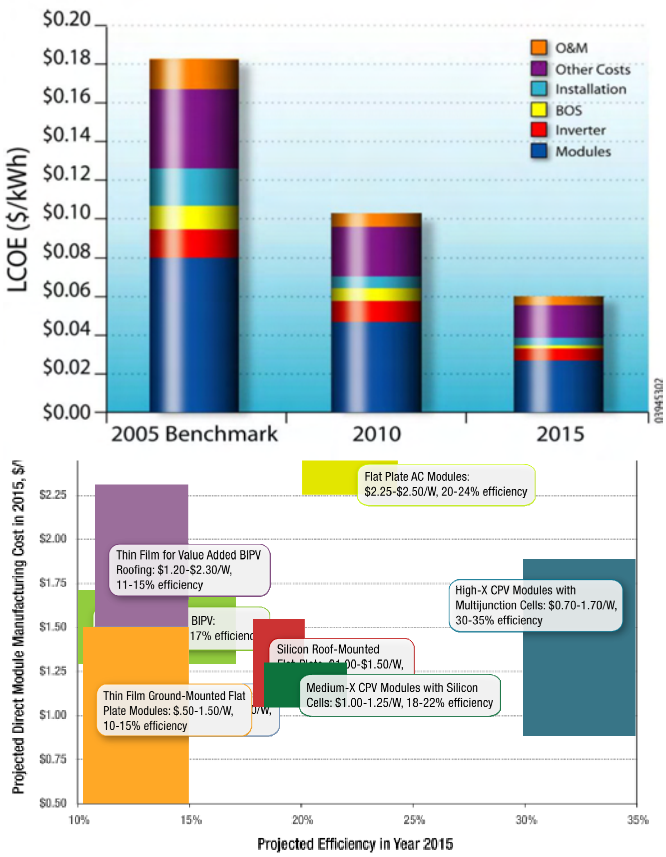


Figure 13. The roadmap to PV electricity in parity with conventional grid power includes scaling up manufacturing, improving processes, designing products driven by applications, and developing products for easy installation.

Non-R&D Institutional Barriers

The targeted, coordinated efforts supported by these initiatives need to be joined by a focus on non-R&D and institutional barriers that prevent full-scale market penetration of solar technologies. For example, the lack of an interconnection agreement could prevent the installation of even a highly efficient, low-cost PV system. To accrue energy security and environmental benefits, R&D achievements must be coupled with rigorous activities in codes and standards, technical outreach, advanced policies, and infrastructure-related market barriers.

In particular, U.S. market transformation activities in the Solar America Initiative focus on four key partners:

- Government (includes federal agencies, regional entities, states, city/local governments, and tribal councils)
- Commercial (includes the PV industry, commercial users, industrial users, building community, and finance/insurance community)
- Utility (include investor-owned, federal, municipal, and rural cooperatives)
- Institutional (includes educational community, unions, standards-development organizations, independent laboratories, and non-governmental organizations).

DOE provides key partners with technical assistance on codes, standards, and regulations. Education and certification is also promoted for solar installers and code officials. Improved financing and insurance options are promoted for solar systems. Other assistance opportunities are made available through projects such as "Solar America Cities" and "Solar America Showcases," which include large installations of solar systems using advanced or novel solar products or installation methods. [Cornelius 2007b]

We also need to mobilize private-sector capital to reduce investment risk for the early deployment of solar systems. This requires policy support of various types, such as federal tariffs, production tax credits, investment tax credits, and renewable portfolio standards.

The following table details some of the non-R&D-related roadblocks to solar electricity that SAI and other PV and CSP programs around the world are trying to overcome:

IV. Status of Solar Thermal Energy Technology

The need for heat can be met by the sun in a variety of ways. Solar technologies can supply thermal energy for space heating and cooling, water heating, solar cooking, and industrial processes that require heat. We also consider passive solar thermal technologies in the design of buildings.

Issues Impeding the Development of Solar Electricity

Photovoltaics

- **Interconnection**. Predictable and reasonable regulations governing interconnection of PV systems are required to assure timely and cost-effective development of PV projects.
- **Net Metering**. Net metering allows generators interconnected to a utility grid to be compensated for the electricity that their PV system produces when it is not used on-site at the time of generation. These provisions are inconsistent across states and often do not reflect fair market value.
- **Grid Integration Codes and Standards**. As PV market penetration increases, new codes and standards are needed to maintain grid reliability and economics. The focus is on advanced metering infrastructure, real-time pricing signals, and communications protocols for distributed generation / grid interaction.
- **Lack of Long-Term Policies and Market Predictability.** PV manufacturers site capacity close to markets and are reluctant to make major capacity investments in the United States while the long-term incentive environment is uncertain, inhibiting scale-up and cost reduction. Downstream PV companies are even more reluctant to invest in distribution /installation capacity while long-term incentive structures are uncertain.

Concentrating Solar Power

- **Land Access.** Efficient and predictable permitting processes for use of federal lands in CSP project development are needed. The current regime is causing protracted timelines and increasing development costs.
- **Transmission Access.** Development of CSP projects requires construction of new transmission "spurs" and corridors. The current regime does not allow for efficient cost allocation or rapid permitting for new lines.
- **State CO_2 & Renewable Portfolio Standards (RPS) Regulations.** Uncertainty about compliance costs for RPS requirements and CO_2 prices introduces complications into power purchase agreement (PPA) negotiations for CSP project development.
- **Lack of Long-Term Policies and Market Predictability.** Financing for CSP project development can be secured only on the basis of a negotiated off-take contract (PPA) with a utility. Uncertainty in the long-term incentive environment complicates transactions.

Space Heating and Cooling, Solar Water Heating, Solar Cooking, and Industrial Process Heat

We discuss the status of space heating by heated air or water, solar cooling, and low- and moderate-temperature water heating for domestic and industrial use.

Space Heating and Cooling. The sun can heat a space passively through direct solar gain, where the sun shines directly into a building and warms materials in the space such as bricks, concrete, or adobe. These materials can serve as a mechanism for thermal storage as they are heated during the day; at night, they then release their heat to warm the space. More sophisticated materials, such as special phase-change materials, are being investigated for use in thermal storage.

Heated air can also be used for space heating. One application is the transpired solar collector, which draws air through the perforations of a solar absorber, warming the air in the process. This heated air is then collected and used directly in the building, or it may serve as pre-warmed air to be input to a conventional heating/ventilation system. A Trombe wall is another passive application to provide solar heating and ventilation.

Space heating can also be accomplished by using hot water. Various systems are available that use a solar collector to heat ordinary water or an antifreeze solution such as glycol, depending on the climate of the region. Active solar space-heating systems have electric fans or pumps that transfer and distribute the solar heat. The hot water may be used in a baseboard heating system or in a radiant-heat floor system. R&D activities are focusing on improving the performance, cost, and reliability of the solar collectors and associated thermal-storage systems. Heat exchangers may also need to be designed for some applications.

Active solar cooling can be achieved through several applications. An absorption refrigeration cycle may be powered by solar means. In a desiccant cooling cycle, solar thermal energy can be used in the regeneration phase to dry desiccant material that has absorbed moisture in a cooling system. Solar mechanical processes can also provide cooling, as in a solar system used to power an ice-making plant.

Solar Water Heating (SWH) (or Low-Temperature STE). Water heating is the second largest consumer of energy in homes behind space conditioning [Kutscher, 2007, solar thermal chapter]. Low-temperature solar thermal energy is typically for end-use temperatures below about 100°C. Flat-plate and evacuated-tube collectors are mainly used for SWH and space heating, whereas unglazed plastic collectors are used to heat swimming pools [Weiss 2007].

SWH technologies have seen significant improvements during the last 20 years [DOE 2007c]. But to make SWH technology more competitive—by increasing performance and reliability and reducing cost—we need improvements in materials, manufacturing processes, and product design. Some areas of improvement include the following:

- Improved durability and reliability while reducing costs. R&D must identify and develop low-cost polymer materials, predict degradation from optical and mechanical processes, develop protective coatings, and improve active system components such as electronic sensors and controls.
- Improve freeze protection. Success could help to expand the geographic range of SWH markets from systems primarily made of low-cost polymers.
- Standardize SWH system components. We need to develop more easy-to-assemble "plug and play" systems that incorporate standardized, packaged sets of subsystems and components (i.e., pumps, values, controls, tanks). Success here could dramatically reduce installation cost, facilitate the ease of installation by contractors and consumers, increase sales, and improve reliability.
- Develop innovative "combination" technologies and integrate SWH into buildings. New opportunities exist for integrating solar thermal technologies with other water-heating and building-system technologies. R&D is needed to improve SWH integration into buildings.

SWH is a readily deployable technology in the United States that can decrease the use of natural gas. Denholm has determined the technical potential of SWH to reduce fossil fuel consumption and associated greenhouse gas emissions in U.S. residential and commercial buildings. His analysis concluded that within the residential and commercial building sectors—which emitted 2,230 million metric tons of CO_2 in 2004—SWH could reduce CO_2 emissions by 2%–3% [Denholm 2007].

Solar Cooking. Solar cookers are a simple technology employed to cook food, boil water, dry materials, and pasteurize food or water. They can be as simple as an insulated box with a transparent lid, which can produce temperatures in the range of 50° to 100°C. Or they can use reflectors in dish or trough concentrator designs, where direct (not diffuse) sunlight can produce temperatures up to about 300°C. Solar cookers use no fuel other than sunlight. So in developing countries, where firewood may normally be needed for cooking, solar cookers can slow deforestation and desertification, while decreasing air pollution from soot and providing healthier operating conditions.

Industrial Process Heat (Medium-Temperature STE). The use of solar energy in commercial and industrial companies is currently insignificant when compared to the residential sector. The industrial sector is the biggest energy consumer Organisation for Economic Co-operation and Development (OECD) countries, using more energy than the transportation, household, or service sectors. The greatest need in these industrial applications is for medium-temperature collectors, which typically yield less than 250°C [Weiss 2005].

The Potential of Solar Heat for Industrial Processes (POSHIP) project is a study on the potential for solar heat in industrial processes (funded by the European Commission). Heat at temperatures up to 250°C is required in many industrial processes, such as steam generation, washing, drying, distillation, and pasteurization [POSHIP 2001].

Passive Solar Design in Buildings

We discuss the need for solar resource data with high spatial and time resolution, the necessity of modeling and using a whole-building approach to design for optimal energy performance, and examine advances for various buildings components.

Solar Resource Data. The sun is obviously the common denominator across differing solar technologies. Assessing the solar resource in various locations is essential for project planning and system deployment. The most useful and reliable assessments for the solar industry combine satellite-derived data with quality ground-based measurements linked to the World Radiometric Reference.

Various international institutions provide information on the solar resource, including NREL, the National Aeronautics and Space Administration (NASA), Brazilian Spatial Institute (INPE), German Aerospace Institute (DLR), Bureau of Meteorology Research Center (Australia), CIEMAT (Spain), and others.

For U.S. projects, NREL has recently released an updated version of the National Solar Radiation Database (NSRDB) that now has 1,454 ground locations for 1991–2005. The gridded data includes hourly satellite modeled solar data for 1998–2005 on a 10-km grid. The data can be combined with hourly meteorological data for PV and CSP simulation [Stoffel 2008]. These hourly values of the solar resource components (direct beam, global horizontal, and diffuse) can be used by designers to determine the solar resource for any orientation of a solar collector; they can also indicate the illuminance that is available to windows installed in any configuration [Walker 2003].

For EU projects, Satel-Light is a Web-based tool that uses data from the geostationary satellite Meteosat to provide near real-time (30-minute) information on solar resources and illuminance values at high spatial resolution across Europe.

Building Design Integration and Modeling. A successful solar building must integrate the influence of all the individual building components to develop a building with optimal energy performance. Computer simulations using software such as *Energy-10* help designers understand and quantify the interactions among the various building systems such as heating, cooling, and lighting.

Significant energy savings can be realized by considering building designs that respond to local climatic conditions; these designs should use as many passive systems as possible, such as passive solar heating, natural ventilation, daylighting, and shading. Homes and small businesses are especially sensitive to climatic conditions, and their energy profiles focus predominantly on space heating and cooling loads.

Climate plays a lesser role in the design of large commercial and industrial buildings. Instead, designing for these facilities must take into account the larger core of the building in proportion to the perimeter; lighting and other internal loads are also a primary concern. The diversity of business types and occupancy in these buildings adds to the importance of sensor technologies, along with advanced control technologies such as neural networks and adaptive controls. These systems will eventually allow building designers and managers to optimize building energy services so that energy use is reduced and the occupants' experience is improved [Kutscher 2007, buildings chapter].

Modeling can also help materials scientists to develop superior building materials. It can be difficult to determine the potential impact that a new material or component will have on the overall building energy, cost, and environmental performance over the life of the building. Therefore, considering materials within a modeled design can enhance overall building performance [Judkoff 2008].

Building Components. A basic goal is to design an efficient building that requires less energy, whether electricity or heat, and where the energy used is generated from renewable sources, as much as possible.

The building envelope is the interface between the interior of the building and the outdoor environment. Energy pathways through the building envelope are usually divided into the roof, wall systems, windows, air infiltration, thermal storage, and insulation. Energy-consuming equipment in homes and small businesses include heating, ventilation, and air conditioning (HVAC), water heating, and lighting. Below, we discuss advances being made within these various components [Kutscher 2007, buildings; Walker 2003].

Roof—New roofing materials contain pigments that can reflect more heat than conventional materials. Preventing heat from entering the home through the roof can help to reduce the amount of energy needed to cool the living space. Other research focuses on "smart" roofing materials: when the outdoor temperature is cool, the roof will absorb solar energy; but when the outdoor temperature is warm, the roof will reflect the solar energy.

Wall systems—New wall designs can minimize heat loss significantly by reducing the amount of framing used and optimizing the use of insulating materials. These materials include structural insulated panels and insulated concrete forms. In existing buildings, new insulating fabrics can be hung or applied to interior walls to control indoor temperatures.

Windows—Today's high-quality windows do a good job of addressing the three main energy paths through a window: energy through windows via radiant energy, heat conduction through the frame, and air leakage around the window components. Low-emissivity (low-E) window coatings effectively increase the window's R-value by reducing the flow of infrared energy out of the building; other low-E coatings can block infrared energy from entering the window to reduce the cooling load. Electrochromic windows are being developed that darken automatically as light intensity on the window increases, thus reducing space cooling needs.

Thermal storage—Stone, concrete, and adobe are common materials used to slowly absorb heat during the day and slowly release the stored heat at night. Lighter-weight components, such as phase-change materials, are being developed, and future designs based on molecular or nanocomposite materials will be integral elements of building components.

Insulation—Vacuum insulation is very thin compared to traditional insulation and has an R-value that is 5 to 10 times greater for a comparable thickness.

Solar space heating—A transpired solar collector is an efficient solar technology for providing warmed air. In this application, air is pulled through a perforated, dark-colored absorber sheet warmed by the sun; the air enters a contained space or plenum, where the heated air rises and is used directly for space heat or as pre-warmed input to a ventilation system.

Solar water heating—Technical improvements are being made in the areas of heat-pump water heaters, water-heating dehumidifiers, heating water with waste heat, and solar water heaters.

Lighting—A primary consideration when designing a building is to provide as much light through passive daylighting, with additional lighting needs handled by compact fluorescent lighting. In daylight design, the type of windows, their size, and orientation are carefully considered to provide adequate interior illumination, while minimizing glare and controlling interior temperatures. Building designs can also include clerestory windows, sawtooth roofs, skylights and light tubes, and light shelves to bring light into the deeper recesses of buildings. Energy use can be offset both directly, by replacing artificial lighting, or indirectly, by reducing cooling loads.

One new lighting technology being developed is hybrid solar lighting. A roof-mounted solar dish collects sunlight, focusing it on a fiber-optics receiver, which transmits the visible light inside to a light fixture; this fixture may also include supplementary fluorescent lighting. Solid-state lighting is another option being developed, with a goal of producing brighter light-emitting diodes (LEDs). All these lighting options use significantly less energy than conventional incandescent lighting.

Electricity—Electrical needs for lights, pumps, and appliances can be supplied via PV systems. Perhaps the most exciting option is to use building-integrated PV (BIPV), which produces electricity while also serving as construction material. For example, BIPV can replace traditional building components, including curtain walls, skylights, awnings, roofing tiles or shingles, and windows.

V. Status of Solar Eelectricity Technology

Electricity can be generated by the sun using two different types of technologies: photovoltaics (PV) and concentrating solar power (CSP). Photovoltaic devices are specially constructed semiconductor assemblies that can produce electricity directly when illuminated by the sun. In contrast, CSP technologies—which include parabolic troughs, dish/Stirling engine systems, and power towers—use various configurations of mirrors to focus the sun and collect the thermal energy used to drive turbines or engines. Below, we will provide an overview of the status in these two areas.

Photovoltaic Technology

PV conversion efficiencies indicate the ability of a solar cell to convert sunlight into electricity. Figure 15 shows the improvements since 1975 of conversion efficiencies for various technologies of laboratory PV cells. The trends show that efficiencies continue to climb and that different materials are at different stages of their ultimate potential. The summary below takes a brief look at various PV technologies, describing their current status and some remaining issues.

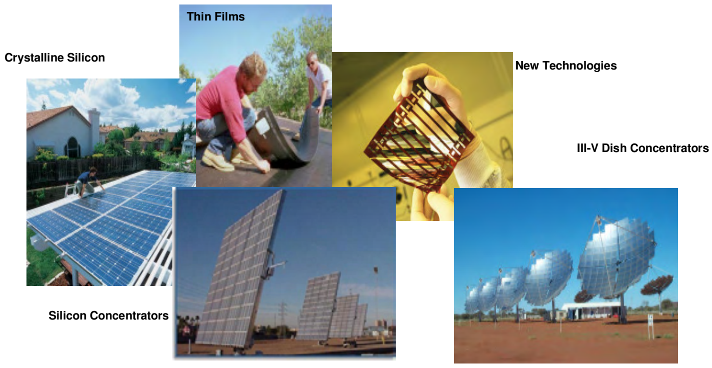


Figure 14. Various examples of photovoltaic technologies, from flat plates (crystalline silicon and thin-film devices, plus new second- and third-generation technologies) to concentrators (using silicon and III-V high-efficiency cells).

First-generation PV. So-called first-generation PV devices include those that use silicon (Si) wafers. Current PV production is dominated by single-crystal and polycrystalline (e.g., multicrystalline, ribbon, and sheet) modules, which represent about 94% of the present market. These single-junction devices are limited to a maximum theoretical conversion efficiency of ~31%.

Over the years, steady improvement has produced cost reductions described by the classical 80% learning curve (i.e., every doubling of manufacturing capacity leads to a 20% drop in PV price). But to meet near-term expectation for climate-change mitigation, these technologies need to expand and accelerate. Therefore, R&D continues on Si cells that use less material (e.g., thin and thinned wafers < 100 micrometers thick) and have high efficiencies of 25%–29%. Scientists are also pursuing innovative processing and device engineering to lower costs and increase manufacturing throughput and yield.

Second-generation PV. Second-generation technologies such as thin films do not require Si wafer substrates and can possibly be manufactured at significantly lower cost. Reasons for the lower cost may include lower materials usage, fewer processing steps, automated fabrication, possible use of flexible substrates, and monolithic integration design of modules [Ullal 2008]. Current worldwide production of thin films is about 6% of the PV market. However, thin-film modules make up a much larger percentage of the U.S. manufacturing market due to the capacity of thin-film leaders Uni-Solar (a-Si) and First Solar (CdTe).

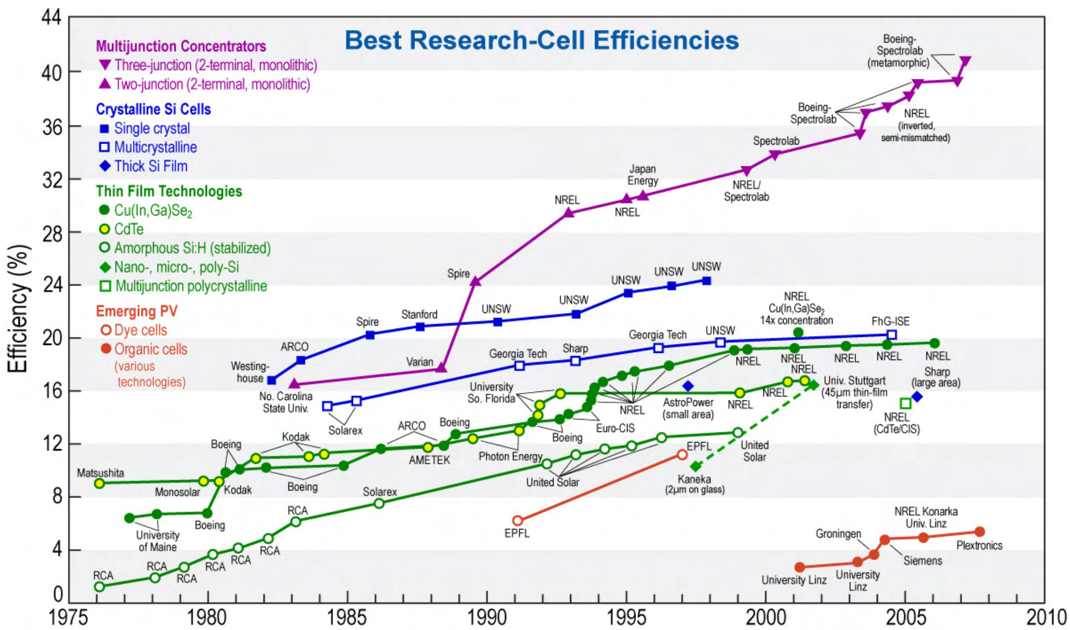


Figure 15. Improvements in conversion efficiencies for various technologies of laboratory photovoltaic cells (compiled by L.L. Kazmerski, NREL).

Conversion efficiencies for commercial products are lower than those of first-generation cells, but steady progress has been made in boosting conversion efficiencies of devices based on amorphous silicon (a-Si), cadmium telluride (CdTe), and copper indium gallium diselenide (CIGS) materials.

Some second-generation technologies are considered disruptive, in the positive sense that they represent innovations that shift the learning (experience) curve to a steeper angle or lower point, i.e., a greater cost reduction is realized for every doubling of manufacturing capacity. Such disruption is needed to help meet mid-term cost targets. In addition, lower-cost thin films will be required to offset lowering levels of financial incentives established by government and market policies; higher-cost first-generation technologies will no longer be as viable under this scenario.

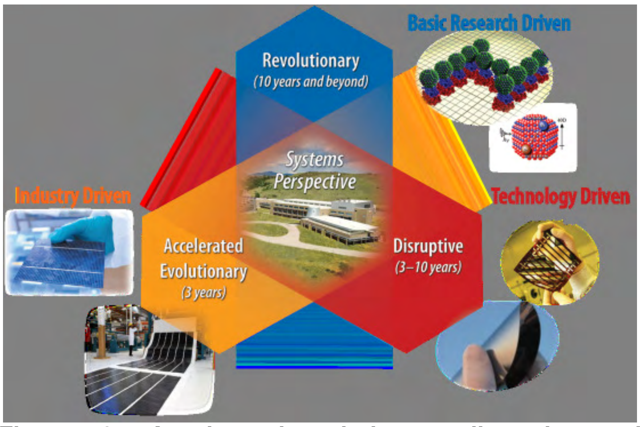


Figure 16. Accelerated evolutionary, disruptive, and revolutionary technologies are needed to meet near-, mid-, and long-term goals, respectively.

a-Si—Multijunction a-Si cells have been the most successful second-generation product because they can be fabricated at relatively low cost. One manufacturing technique uses a roll-to-roll process on flexible substrates that allows high-speed production. Challenges for amorphous Si technologies include higher conversion efficiencies, reduced performance degradation due to initial light soaking, faster rates for depositing tandem structures, and greater depositional and performance uniformity over large areas.

CdTe—The best CdTe laboratory cell efficiency is currently 16.5%. First Solar reports that they manufacture their thin-film product for $1.25/W, which is the lowest rate in the thin-film sector. Challenges for CdTe include achieving higher module efficiencies, better stability of the back contact, a thinner absorber layer, and better uniformity over large areas.

CIGS—The National Renewable Energy Laboratory (NREL) recently reported a new record total-area efficiency of 19.9% for a CIGS-based thin film [Repins 2008]. Challenges for CIGS include higher module efficiency, as well as better control of moisture ingress in flexible modules, thinner absorber layers, and uniformity of material stoichiometry over large areas.

High-efficiency and concentrator devices—Spectrolab GaInP/GaAs/Ge triple-junction cell has an efficiency of 40.7% at 240 suns [Emery 2006], which was the first cell of any kind to exceed the 40% mark—an accomplishment that could be compared to running the first sub-4-minute mile. An Emcore/NREL cell with a GaInP/GaAs/GaInAs structure in a lattice-mismatched, inverted design with an efficient of 38.9% at 80 suns [Geisz 2007]. Challenges include the need to optimize III-V multijunctions, develop lower-cost manufacturing methods, and simplify the materials system.

Third-generation PV. Third-generation technologies represent "innovation at the extreme," where there may be enormous payback, coupled, of course, with immense risk. These revolutionary technologies are often considered under one of two approaches.

The first type includes novel approaches that strive to achieve very high efficiencies—by using concepts such as hot carriers, multiple electron-hole pair creation, and thermophotonic—with theoretical maximum efficiencies much greater than the 31% target for single-junction devices. The allowable cell costs could be quite high. Research in this area is in its infancy, the most common case being that a fundamental concept has been demonstrated, but a working mechanism has yet to be achieved.

The goal of the second type of revolutionary technology is to achieve very low cost, which requires inexpensive materials for the active components and packaging, low-temperature atmospheric processing, and high fabrication throughput. Organic photovoltaic (OPV) devices have potential for significant impact here. These devices encompass a range of approaches: dye-sensitized nanostructured cells, small-molecule organic semiconductor stacks; organic-organic composites, organic-inorganic composites, photoelectrochemical cells, and others. Organic-based solar cells have the potential to be produced inexpensively. Recent advances in solar power conversion efficiencies have propelled OPV out of the realm of strictly fundamental research at universities into industrial lab settings.

Other third-generation concepts being pursued include: (1) Multiple-exciton generation (MEG), where more than one exciton is generated for each photon of sufficient energy absorbed by the PV cell. MEG raises the theoretical attainable power conversion efficiency of a single-junction PV solar cell from 33.7% to 44.4%. (2) Intermediate-band PV is proposed as a means of creating a single-junction cell with a theoretical efficiency similar to that of a three-junction cell. (3) Nano-architecture PV considers aspects of quantum confinement on providing more flexibility in electronic structure engineering [Nozik 2007]. All three of these third-generation concepts are in the fundamental, proof-of-concept developmental stage. NREL has developed succinct roadmaps, reviewed by industry, for key solar technologies that include these third-generation areas, as well as first- and second-generation areas [DOE 2007a].

Concentrating Solar Power Technology

CSP technologies include parabolic troughs, dish/Stirling engine systems, power towers, and concentrating PV systems (Fig. 17). CSP plants are utility-scale generators that produce electricity by using mirrors or lenses to efficiently concentrate the sun's energy to drive turbines, engines, or high-efficiency PV cells.

A CSP initiative through the DOE is providing up to $5.2 million to 12 projects with nine U.S. companies. The projects are expected to reduce today's 12–14 ¢/kWh cost of power to 7–10 ¢/kWh by 2015 and <7 ¢/kWh with 12–17 hours of storage by 2020. Projects will focus on thermal storage, trough component manufacturing, and advanced CSP systems and components. [www.nrel.gov/csp/news/2007/544.html] Below, we provide a basic review of the technology types and discuss some of these key challenges and research topics.

Figure 17. Four different categories of concentrating solar power technologies: power tower, parabolic trough, dish/Stirling, and concentrating PV.

Parabolic troughs. Parabolic trough systems concentrate the sun's energy through long, rectangular, curved mirrors. The mirrors are tilted toward the sun, focusing sunlight on a receiver, which is a special tube that runs along the focal line of the trough, and heating oil flowing through the receiver. The hot oil is then used to boil water in a conventional steam generator to produce electricity. Alternatively, water can be boiled directly in the receiver using a direct-steam receiver. As in towers (see below), parabolic trough systems can use thermal storage, thus giving the systems the flexibility to dispatch electricity coincident with peak utility loads, which often occur late into the evening.

At present, parabolic troughs are the leading commercial CSP technology. They have proven to be reliable, as evidenced by nine trough plants, with a combined capacity of 354 MW, that have operated in the California Mohave Desert for two decades. The most recent trough plant to be completed is Acciona's 64-MW Nevada Solar One, near Las Vegas, Nevada, completed in 2007.

Challenges that exist for troughs include the need to optimize receiver and concentrator designs; developing next-generation collector designs; and successfully scaling up plant size and increasing operating temperatures of the systems [Cornelius 2007b]

In advanced absorber materials for CSP, the important factors are high absorbtivity, low emissivity, and good performance at high temperatures. A specific way to reduce the cost of parabolic trough technology is to increase the operating temperature of the solar field from 400°C to 500°C or higher. Therefore, a materials-related challenge is to develop new, more-efficient selective coatings for the absorbers that have both high solar absorbance and low thermal emittance at 500°C. Although the absorbers are likely to be used in an evacuated environment, the coatings need to be stable in air in case the vacuum is breached. [Mehos 2008b]

In advanced reflectors, key factors are high reflectivity, high durability, and low cost. In one example of mirror research, environmental issues are causing researchers to explore new designs for manufacturing mirrors. For example, some scientists are studying thin-glass mirrors with copper-free reflective surfaces that use lead-free paints. This basic mirror construction is radically different from the historical constructions, and outdoor durability must be determined and any problems mitigated to develop a commercially viable product.

Scientists are also developing mirrors using a silvered polymer commercial laminate construction. Another option is front-surface reflectors that use a silvered substrate protected by an alumina hardcoat deposited under high vacuum by ion-beam-assisted deposition. All these reflectors must be able to be produced at low cost and maintain high specular reflectance for lifetimes of 10 to 30 years under severe outdoor conditions. [Mehos 2008b]

Advanced CSP concepts. The Compact Linear Fresnel Reflector (CLFR) technology, developed by Ausra, maintains a primary advantage of troughs systems, with fewer foundations and tracking motors per area of mirror. However, it also exhibits a key advantage of power towers—namely, direct steam generation and energy storage. When compared to a trough system, a CLFR system lowers costs by replacing curved mirrors with standard flat glass. The mirrors also remain near the ground, which lowers wind loading and the amount of steel required [Ausra 2008, web].

In dish/engine systems, a mirrored dish-shaped surface collects and concentrates the sun's heat onto a receiver, which absorbs the heat and transfers it to a gas within a Stirling engine or gas turbine. The heat allows the gas to expand against a piston (Stirling engine) or power a turbine to produce mechanical power. The mechanical power is then used to run a generator or alternator to produce electricity. The challenges facing this CSP technology relate to the mass manufacturing of the dish, as well as the reliability of the Stirling engine.

Power tower systems use a large field of mirrors to concentrate sunlight onto the top of a tower, where a receiver is located. This focused sunlight heats a working fluid such as molten salt or water/steam flowing through the receiver. Similar to oil in a parabolic trough receiver, the salt in a tower receiver is used to create steam (via heat exchangers) to produce electricity through a conventional steam generator. Molten salt can be stored in tanks, allowing the collection of solar energy to be separate from the generation of electricity. This is an important consideration if peak utility loads occur in the evening after the sun has set. Future low-cost storage options should allow both troughs and towers to operate as baseload plants, potentially displacing coal-based generation. The challenge for power towers relates to the need to demonstrate new plant designs that are cost effective.

High-performance storage. Additional materials R&D is needed in thermal energy storage, including development of advanced thermal storage materials and improvement of heat-transfer fluids. Note that the electricity generated by CSP can be stored by other technologies such as batteries and flywheels. But storage in the realm of CSP specifically refers to effectively storing *thermal* energy in the system, which currently is much more efficient and cost effective than electricity storage. This stored thermal energy is used to generate electricity at a later time, when the solar resource may not be available. Materials with improved heat-capacity characteristics will extend the storage capabilities and overall generating efficiency of CSP systems [Mehos 2008b].

Thermal energy storage (TES) allows solar electricity to meet utility peak demands and can even enable solar to become a baseload power source. SEGS I and Solar Two both demonstrated that TES can be used to dispatch solar electricity or run baseload solar power. The current indirect 2-tank system is too expensive to achieve long-term cost goals that are required to meet the mainstream power market. SunLab believes that using molten salt for both the solar field heat-transfer fluid (HTF) and the TES media is the most promising TES option. There is a clear risk in moving to molten salt as the HTF in the solar field (it could freeze in the solar collectors and piping), but most developers support this research. Field demonstrations will be essential for commercial adoption of the technology. Currently, solar power is too expensive to compete directly with conventional generation without additional subsidies or financial incentives. The addition of molten-salt thermal storage could allow trough power to compete [Price 2007].

Castable ceramic and high-temperature concrete are being tested for solid-media, sensible-heat storage systems. Other scientists are pursuing the development of improved phase-change materials to allow large amounts of energy to be stored in relatively small volumes [Mehos 2008b].

The first commercial installation to incorporate thermal storage is a 50 MW plant in Spain with seven hours of molten salt storage; others are being designed around the world. The goal may be for up to 16 hours of storage to allow for the generation of electricity 24 hours a day.

VI. Mitigation of Climate Change by Solar Technologies

Several pathways exist for solar thermal, PV, and CSP technologies that can allow them to help mitigate climate change. Our overall conclusion is that these technologies can make a significant contribution in reducing greenhouse gas emissions. But we are also mindful that these technologies are relatively immature, and that dramatic growth in market penetration is needed so that we can realize their potential contribution—which will be on a timescale of decades, not years.

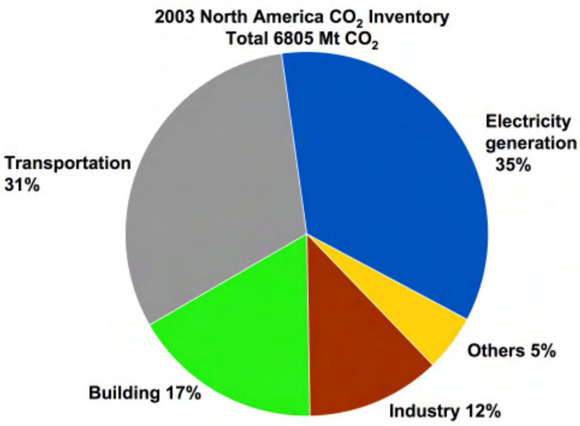


Figure 18. A 2003 inventory for North America indicates 6,805 million metric tons of CO_2 emissions attributed to key end-use sectors according to the percentages shown. (Derived from EIA 2004)

Solar Thermal Energy Technologies

Solar thermal technologies can provide the following two benefits:

Displace fossil fuels used for heating/cooling/ cooking/daylighting.
The International Energy Agency's (IEA) Solar Heating & Cooling Programme calculated the CO_2 reduction of all solar thermal systems from 45 nations around the world at the end of 2005. Flat-plate and evacuated-tube collector capacity was 86.3 GW_{th} and unglazed plastic collector capacity was 23.9 GW_{th}, for a total annual yield of 66,406 GWh. This corresponds to a calculated oil equivalent of 10.7 billion liters and an annual CO_2 reduction of 29.3 million tons of CO_2 [Weiss 2007].

The current technical potential of SWH in the United States is estimated at about 1 quad of primary energy savings per year (where primary energy is the energy content in the fuel required to make one unit of electricity). This is equivalent to an annual CO_2 emissions reduction potential of between 50 and 75 million metric tons [Denholm 2007].

Lower or eliminate energy demand of buildings. Commercial buildings account for about 18% (17.9 quads) of the total primary energy consumption in the United States. NREL's study of six current-generation low-energy buildings helped to determine lessons learned and best practices for future constructions that are more energy efficient [Torcellini 2006]. In the zero-energy building (ZEB) concept, the essence is a building designed in such a way that on-site energy consumption is reduced to a level that can be met entirely by on-site renewable energy production over a typical one-year period. One study [Griffith 2006] found that with projected 2025 technologies, the technical potential is that 64% of the U.S. commercial buildings analyzed could be ZEBs. This is up from 22% under today's technologies and practices. Clearly, the more ZEBs built, the greater the overall reduction of electricity required from the utility grid—leading to lower concomitant greenhouse gas emissions. Another residential study demonstrated the feasibility of building efficient, affordable zero-energy homes in cold climates (Denver, Colorado) with standard building techniques and materials, simple mechanical systems, and off-the-shelf equipment [Norton 2008].

A rough estimate of the current carbon emissions from the world's building stock is about 20% of the total annual world anthropogenic carbon emissions of about 6500 MtC/yr, or 1300 MtC/yr [Judkoff 2008]. Advances in materials for buildings could help reduce the energy and environmental impacts of these buildings.

Solar Electricity Technologies

Photovoltaic and CSP technologies can provide the following four benefits:

Displace fossil-fuel electricity generation. Solar technologies emit no CO_2 while generating electricity. Almost all of the CO_2 emissions related to solar technologies come into play when looking at the entire life-cycle of the technologies, as in the energy expended in producing the raw materials and fabricating the products themselves, and in transportation and installation; actual operating & maintenance emissions are minimal. Therefore, displacing fossil-fuel-generated electricity with clean solar generation can offset considerable amounts of CO_2.

Reduce transmission losses. Many, but not all, PV applications are distributed, meaning that they are installed at or very near the point of use of the electricity generated. Hence, there is no need for transmission lines, and distribution lines are either short or unnecessary. Therefore, there is minimal transmission (I^2R) loss, and no energy use (with its concomitant CO_2 emission) related to constructing a transmission system.

Reduce the need for other building components. Building-integrated PV (BIPV) can be used to generate power for a building. But in addition, the BIPV product replaces other building materials, such as window glazing or roofing shingles or insulation. Therefore, less building material is needed, and with reduced fabrication, energy use and CO_2 emissions also are reduced.

Displace petroleum transportation fuel use. Despite the use of PV modules in solar car races, such as the American Solar Challenge or the World Solar Challenge in Australia, powering cars is not an ideal application for PV. However, PV and CSP can still be of great use in the transportation sector in two ways: plug-in hybrid vehicles/electric vehicles, and hydrogen.

Plug-in hybrid vehicles (PHEVs) are powered by an internal combustion engine, an electric motor, or both, depending on driving conditions and other demands. While driving, the motor uses electrical energy stored in an on-board battery. The battery can be partially recharged while driving if the internal combustion engine is being used or if there is a regenerative braking system. But at some point, the battery needs to be fully recharged. The PHEV can be plugged into an outlet during the day, for example, when a person is at work and not using the car. The battery is being recharged so it is ready when needed later in the day. If the electrical power comes from a clean source, such as PV and CSP solar, rather than from a conventional generation source, then a considerable reduction in greenhouse gas emissions can be obtained.

Another transportation option, as well as a building-related application, relates to hydrogen. Hydrogen for use in a fuel cell, whether for use to power a vehicle or provide power for a home or business, can be produced by reforming a hydrocarbon. But hydrogen can also be produced by hydrolyzing water, which requires electricity in the process of splitting hydrogen and oxygen from the water. As in the example above, if the electricity source is PV and CSP, then the hydrolysis process is a sustainable, clean process. The use of PV-generated electricity to produce hydrogen is also a storage option for this technology: if the electricity is not needed for another purpose while the sun is shining, it can then be used to store energy by producing hydrogen for later use, perhaps at night, or other times when there is little available sunlight.

Related to this application is the exciting potential to use a photoelectrochemical technique to split water. A special tandem-junction PV cell immersed in water has been shown to generate hydrogen directly; initial experimental results produced an incredible solar-to-hydrogen efficiency of 12.4% [Khaselev 1998]. This revolutionary concept continues to be developed as an enabling technology for the "hydrogen economy."

VII. Issues and Challenges

We have already mentioned the interplay of technology issues with those of markets and policies. In this final section, we delineate specific issues and

Figure 19. Creative work focusing on technologies, policies, and markets is needed to meet aggressive solar goals, which, if attained, can allow solar technologies to help mitigate climate change.

Policy Issues

Solar technologies face various policy-related issues, some of which present vexing challenges; six issues are discussed below:

Buydowns, feed-in tariffs, and renewable portfolio standards. Technology advances are obviously needed to develop solar products that have higher efficiency, lower cost, and improved reliability. But R&D alone is not enough to cause an explosion in the use of renewable energy, including solar technologies. Favorable policies have stimulated the use of solar technologies in Japan through an incentive program, which reduced the first-cost of a solar system, putting it on par with conventional energy. Some countries in the European Union have instituted a feed-in tariff, which guarantees the system operator a reduced energy cost per kWh produced from an installed system over a fixed number of years. In the United States, California and other states have had various buy-down programs to subsidize the original purchase of systems by homeowners or businesses.

More than half of U.S. states have some form of a renewable portfolio standard (RPS), where utilities are mandated to provide a certain percentage of their electricity to customers from renewable, sometimes solar, sources, by a certain year. For example, New Jersey utilities must generate 22.5% of their electricity from renewables by 2021, with 2.12% specifically from solar [DSIRE, www.dsireusa.org]. Currently, the United States does not have a national RPS, and the current U.S. investment tax credit, which gives a 30% credit to people purchasing new system, is due to expire later in 2008, unless extended by Congress.

Carbon tax. The IEA suggests that a carbon tax of \$40 to \$90 per ton of CO_2 is needed to induce electricity generators to adopt carbon capture and storage systems to reduce CO_2 emissions. This tax is equivalent to raising the price of electricity 1 to 2 ¢/kWh [Zweibel 2008]. In producing power, solar technologies generate no CO_2 emissions; thus, they would not be impacted by a carbon tax, enabling a shift away from fossil fuels that incur the tax burden.

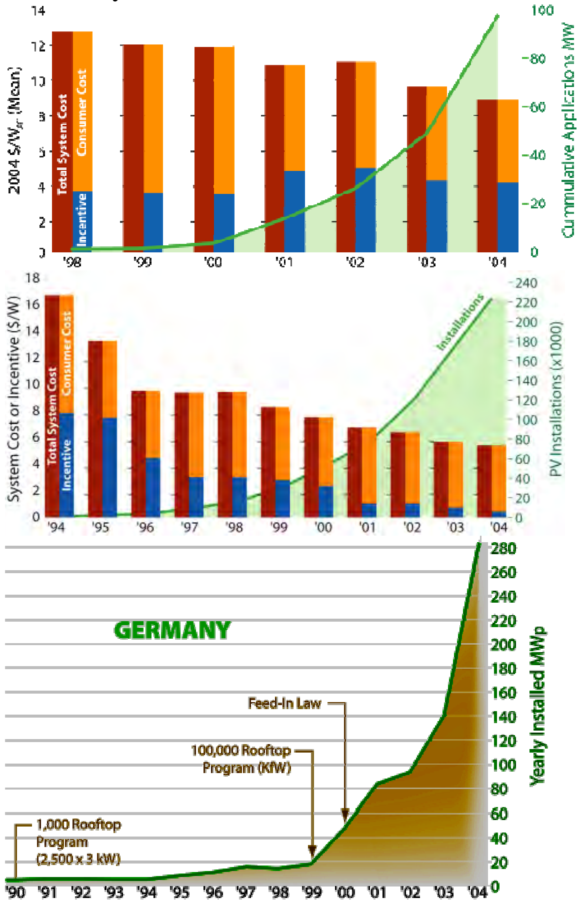


Figure 20. Growth in cumulative PV applications in California (upper left) and Japan (upper right), related to the total PV system cost, which is shown split into the incentive portion and the cost to consumer portion. Growth in German annual installations (lower graph) related to the Rooftop Programs and Feed-In Tariff Law.

Government funding levels. Another policy issue concerns the level and continuity of funding for national R&D. Without certainty and stability of funding, research managers cannot plan solid R&D programs. Also, private industry relies on national research facilities to do the basic research that it can develop into commercial products. It must be remembered that the most novel ideas—the revolutionary concepts in solar research—may require perhaps 20 or 30 years to be proven, developed in the lab, moved into industry, and finally, commercialized. Such development cannot be realized if funding levels are insufficient or vacillate significantly.

Electricity transmission. Various studies—such as the Western Governors' Association study of CSP deployment in the U.S. Southwest—have shown the great potential for generating enormous levels of power. But with CSP, for example, the generation is from a central location and the electricity must be distributed to the point of use. Some potential generating locations are not far from major cities in Nevada and Arizona, for example, but power from this region could also be transported to other regions that have a lesser solar resource. What is needed for full national implementation of solar technologies and other renewables is a new, high-voltage, direct-current (HVDC) transmission backbone. Improvements to aging and bottlenecked transmission infrastructures around the world may provide opportunities for further expansion of solar generation.

Environmental mandates. Policies that include environmental mandates will also impact the growth and use of solar technologies. This may be at the local, state, national, or international level—from a desire for a city to be "green," to a state mandating air-quality levels, to a country striving to meet the guidelines of the Kyoto Protocol.

Buildings-related policies. There are a number of buildings-related policies enacted and under consideration. One U.S. study considered seven such policies: building codes, appliance and equipment efficiency standards, utility-based financial incentive programs, low-income weatherization assistance, the ENERGY STAR® Program, the Federal Management Energy Program, and federal funding for building technologies R&D. The study concluded that these seven policies could potentially reduce the forecasted CO_2 emission increase from buildings to less than 7% between 2002 and 2025 (from a forecasted increase of 250 MtC [million metric tonnes carbon] to an increase of only 40 MtC). At the same time, the built environment in 2025 will be meeting the needs of an economy that will have grown by 96%. After 2025, the nation could begin to achieve the much deeper reductions that many believe are needed to mitigate climate change. [Kutscher 2007, buildings]

Several countries have now introduced solar obligations for new buildings or those undergoing major renovations; this may be the single-most powerful tool for promoting the increased deployment of solar thermal technologies. For example, in September of 2006, Spain introduced a nation-wide solar obligation in its building codes for new buildings. The regulation seeks to mimic the success of many municipal "solar ordinances," and it applies to almost any building, either new constructions or those undergoing major renovation [ESTIF 2007a, 2007b].

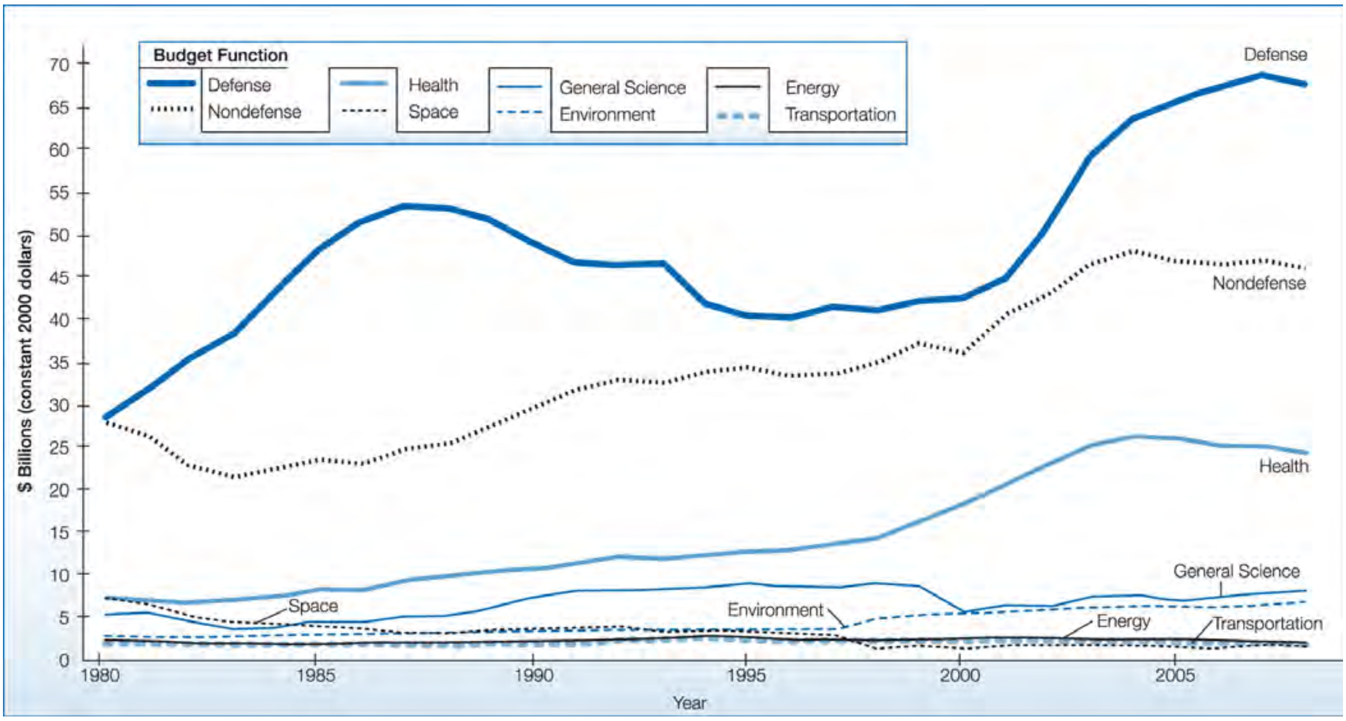


Figure 21. Federal R&D budget authority by budget function, FY 1980–2008. More than half of all U.S. federal R&D investment is spent in support of defense, although investment in space research and in general science has grown more recently [NSF 2008].

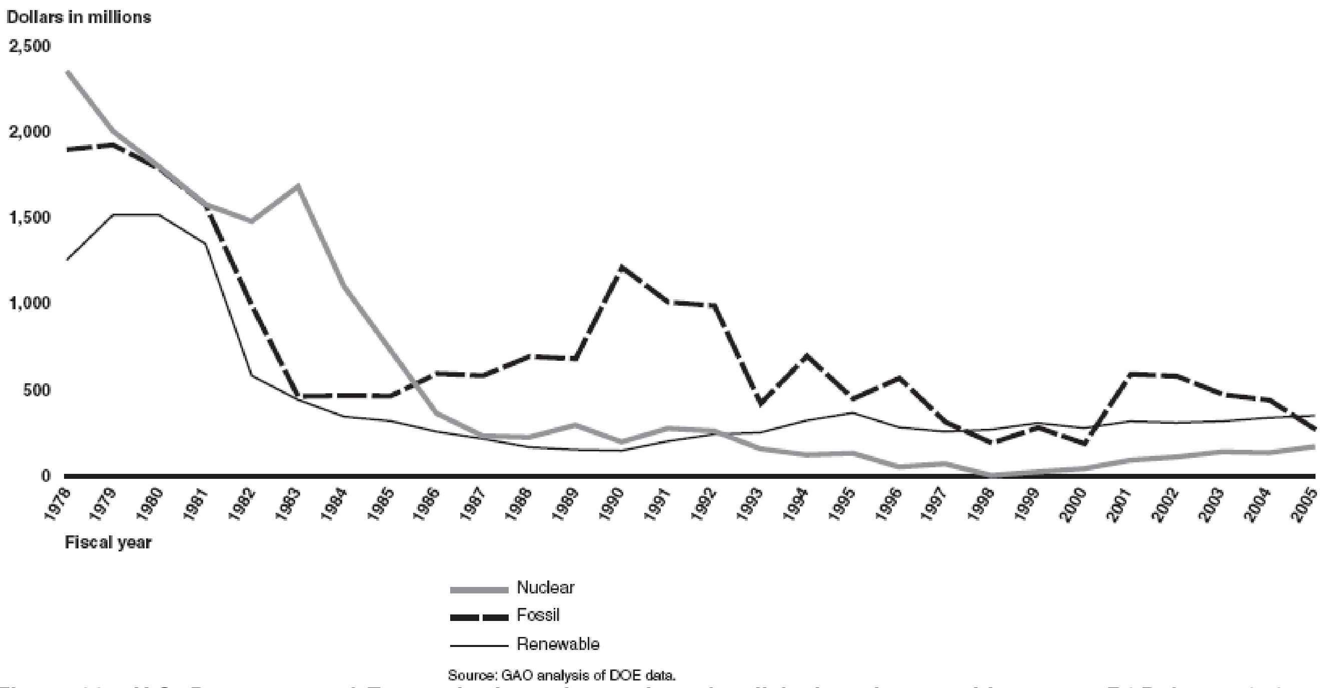


Figure 22. U.S. Department of Energy budgets for nuclear, fossil fuel, and renewable energy R&D from 1978 to 2005.

Market Issues

Solar technologies face various market-related issues, some of which present challenges; four issues are discussed below:

Need for energy. Overall energy use will continue to rise, especially with the further industrialization and economic development of countries such as China and India. Finite petroleum and other fossil-fuel resources will continue to be stretched thin, resulting in a rise in costs and high potential for instability in supply. Solar technologies are currently contributing less than 1% to the overall global energy portfolio. But with energy needs only expected to grow, clean and affordable energy from solar technologies can greatly expand to meet these needs.

Demand for solar products. The demand for solar products obviously requires a tremendous scale-up of the manufacturing of solar products. In 2006, worldwide PV shipments were at about 1.5 gigawatts, and the growth seems likely to continue at a 30%-40% annual grow rate [Maycock 2007]. More manufacturing companies are needed; but also, each company must increase their production scale—from an annual capacity in the range of 10–100 MW to one in the range of 100–1000 MW—if solar is to be able to eventually meet terawatt levels of power [Zweibel, 2005].

Supply of raw materials. The shortage of essential polycrystalline silicon feedstock in recent years has hindered the growth of the silicon solar cell sector. Demand for silicon cells and modules exceeded supply because of this feedstock bottleneck. New sources of silicon, specifically dedicated for the solar industry rather than the semiconductor industry, are coming on line and will alleviate the shortfall. Shortages of other materials for solar cells could potentially occur in the future if production levels continue to ramp up. For example, certain relatively scarce elements used in some thin films could become in short supply, and new designs are already being considered to avoid such possible disruptions to the market. Additionally, worldwide competition for basic commodities, such as steel, also has an impact on overall technology costs.

Feasibility studies. Even a cursory examination confirms that the potential market for solar energy is huge. For example, the Western Governors' Association study [WGA 2006] on the solar resource and suitable available land in seven southwestern U.S. states (California, Arizona, Nevada, Utah, Colorado, New Mexico, and Texas) identifies the feasibility of generating up to 6,800 GW using CSP technologies. This is almost seven times the current electric generating capacity of the entire United States [Mehos 2008].

Business Issues

Various business-related issues confront solar energy development; three such issues are discussed below:

Investment climate. 2007 saw almost $1 billion of venture capital invested in U.S. solar businesses. This tremendous growth in solar start-up investment is encouraging technology improvements and pushing commercial products into a burgeoning new solar market. The obvious hope is for a preponderance of successful ventures, but some undoubtedly will not survive. Therefore, the investment and broader business communities must be prepared for some negative news, along with the more welcomed success stories.

Solar R&D is inherently a risk, especially when disruptive or revolutionary in nature. There is no guarantee that an innovative concept will actually lead to a breakthrough technology or financial success. But the rewards could be rich for those innovative technologies that find success in the market place.

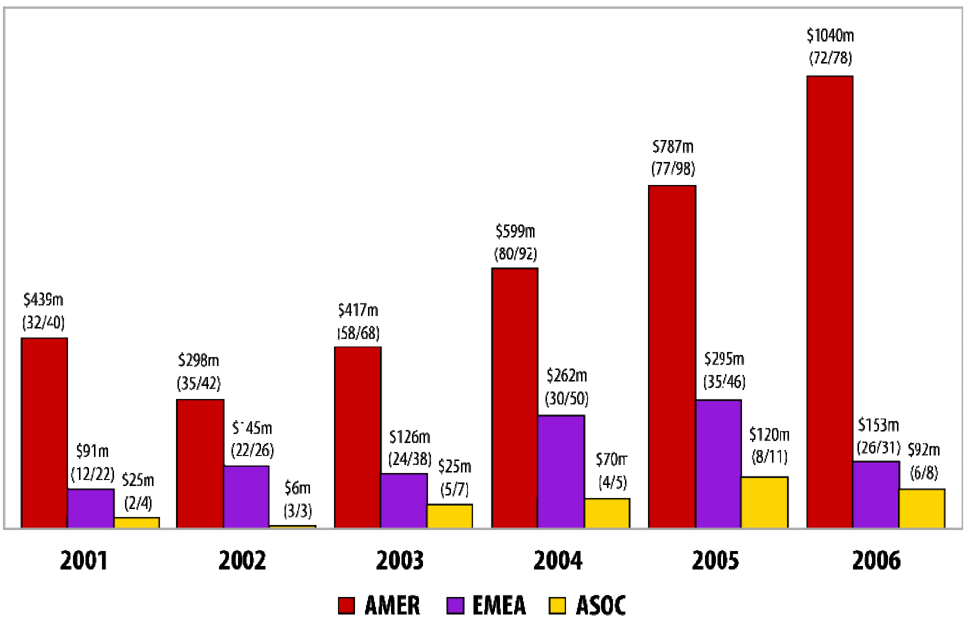


Figure 23. Total estimated venture capital investment by region, 2001–2006; AMER=the Americas, EMEA=Europe, Middle East, & Africa, and ASOC=Asia & Oceania [New Energy Finance 2007].

R&D timeframe. As in any kind of research, solar technologies must go through an incubation period before reaching a point of commercial viability. A concept may be attractive, but it must be proven as more than a mere theoretical construct. Likewise, a success at bench-scale in the laboratory must be translated into success in the industrial-scale manufacturing environment. Therefore, it may take 20–30 years to see a third-generation concept be transformed into a viable commercial product.

Predictable economics. Power purchase agreements (PPAs) can help companies interested in developing energy projects. For example, the Southwest Energy Service Provider's Consortium for Solar Development was formed with the goals of reducing solar energy costs and increasing efficiency through economies of scale. The consortium is issuing a Request for Proposal for a utility-scale (~250 MW) CSP plant in either Arizona or Nevada, to be owned by a third party, with consortium members each signing long-term PPAs. In another instance, Pacific Gas & Electric Company entered into a 177-MW CSP PPA with Ausra, Inc., for a plant using Compact Linear Fresnel Reflector technology, located in San Luis Obispo County, California [www.nrel.gov/csp/news/2007/550.html; www.nrel.gov/csp/news/2007/548.html].

VIII. Conclusions

Because of its vast resource, solar energy offers a means to significantly reduce greenhouse gas emissions associated with energy production and use. Solar can contribute to the reduction in fossil fuel use across all sectors—buildings, transportation, and industry—through both centralized and distributed generation of electricity and heat. Challenges related to cost, widespread market penetration, and policy implementation do exist. However, research, development, and demonstration programs on PV, CSP, and solar thermal technologies provide viable pathways to achieving commercialization and widespread application. Because solar is a truly global resource, solar technologies can provide secure and equitable energy worldwide, with less environmental impact than conventional energy resources and technologies.

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The possible role and contribution of geothermal energy to the mitigation of climate change

Ingvar B. Fridleifsson (United Nations University Geothermal Training Programme, Iceland), Ruggero Bertani (Enel S.p.A., Italy), Ernst Huenges (GFZ Potsdam, Germany), John W. Lund (Oregon Institute of Technology, USA), Arni Ragnarsson (ISOR, Iceland), and Ladislaus Rybach (Geowatt AG, Switzerland).

Abstract

Electricity is produced by geothermal in 24 countries, five of which obtain 15-22% of their national electricity production from geothermal energy. Direct application of geothermal energy (for heating, bathing etc.) has been reported by 72 countries. By the end of 2004, the worldwide use of geothermal energy was 57 TWh/yr of electricity and 76 TWh/yr for direct use. Ten developing countries are among the top fifteen countries in geothermal electricity production. Six developing countries are among the top fifteen countries reporting direct use. China is at the top of the latter list. It is considered possible to increase the installed world geothermal electricity capacity from the current 10 GW to 70 GW with present technology, and to 140 GW with enhanced technology. Enhanced Geothermal Systems, which are still at the experimental level, have enormous potential for primary energy recovery using new heat-exploitation technology to extract and utilise the Earth's stored thermal energy. Present investment cost in geothermal power stations is 2-4.5 million euro/MWe, and the generation cost 40-100 euro/MWh. Direct use of geothermal energy for heating is also commercially competitive with conventional energy sources. Scenarios for future development show only a moderate increase in traditional direct use applications of geothermal resources, but an exponential increase is foreseen in the heat pump sector, as geothermal heat pumps can be used for heating and/or cooling in most parts of the world. CO_2 emission from geothermal power plants in high-temperature fields is about 120 g/kWh (weighted average of 85% of the world power plant capacity). Geothermal heat pumps driven by fossil fuelled electricity reduce the CO_2 emission by at least 50% compared with fossil fuel fired boilers. If the electricity that drives the geothermal heat pump is produced from a renewable energy source like hydropower or geothermal energy the emission savings are up to 100%. The total CO_2 emission reduction potential of geothermal heat pumps has been estimated to be 1.2 billion tonnes per year or about 6% of the global emission. The CO_2 emission from low-temperature geothermal water is negligible or in the order of 0-1 g CO_2/kWh depending on the carbonate content of the water. Geothermal energy is available day and night every day of the year and can thus serve as a supplement to energy sources which are only available intermittently. Renewable energy sources can contribute significantly more to the mitigation of climate change by cooperating than by competing. Likely case scenarios are presented in the paper for electricity production and direct use of geothermal energy, as well as the mitigation potential of geothermal resources 2005-2050. These forecasts need to be elaborated on further during the preparation of the IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation.

Introduction

Although geothermal energy is categorised in international energy tables amongst the "new renewables", it is not a new energy source at all. People have used hot springs for bathing and washing clothes since the dawn of civilisation in many parts of the world. An excellent book has been published with historical records and stories of geothermal utilisation from all over the world (Cataldi et al., 1999).

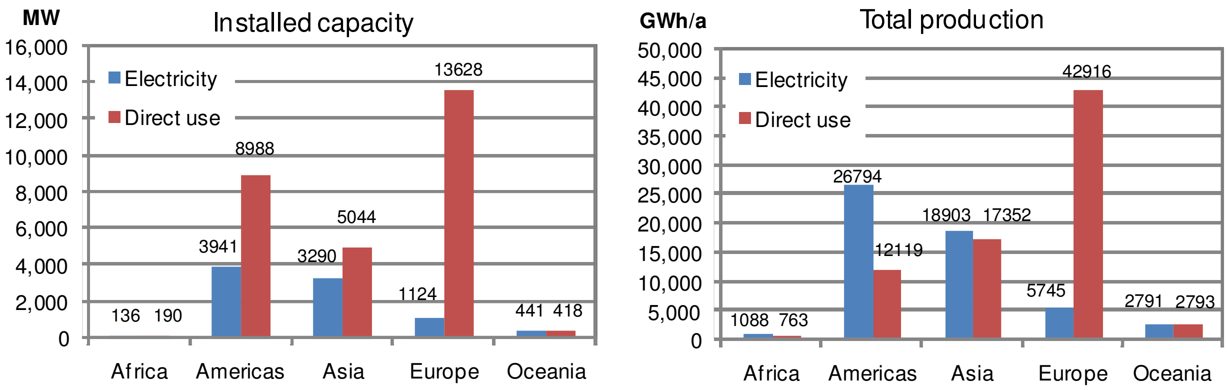

Figure 1. Installed capacity (left) and energy production (right) for geothermal electricity generation and direct use (heating) in the different continents (from Fridleifsson and Ragnarsson 2007, based on data from Bertani, 2005 and Lund et al., 2005). The Americas include North, Central and South America.

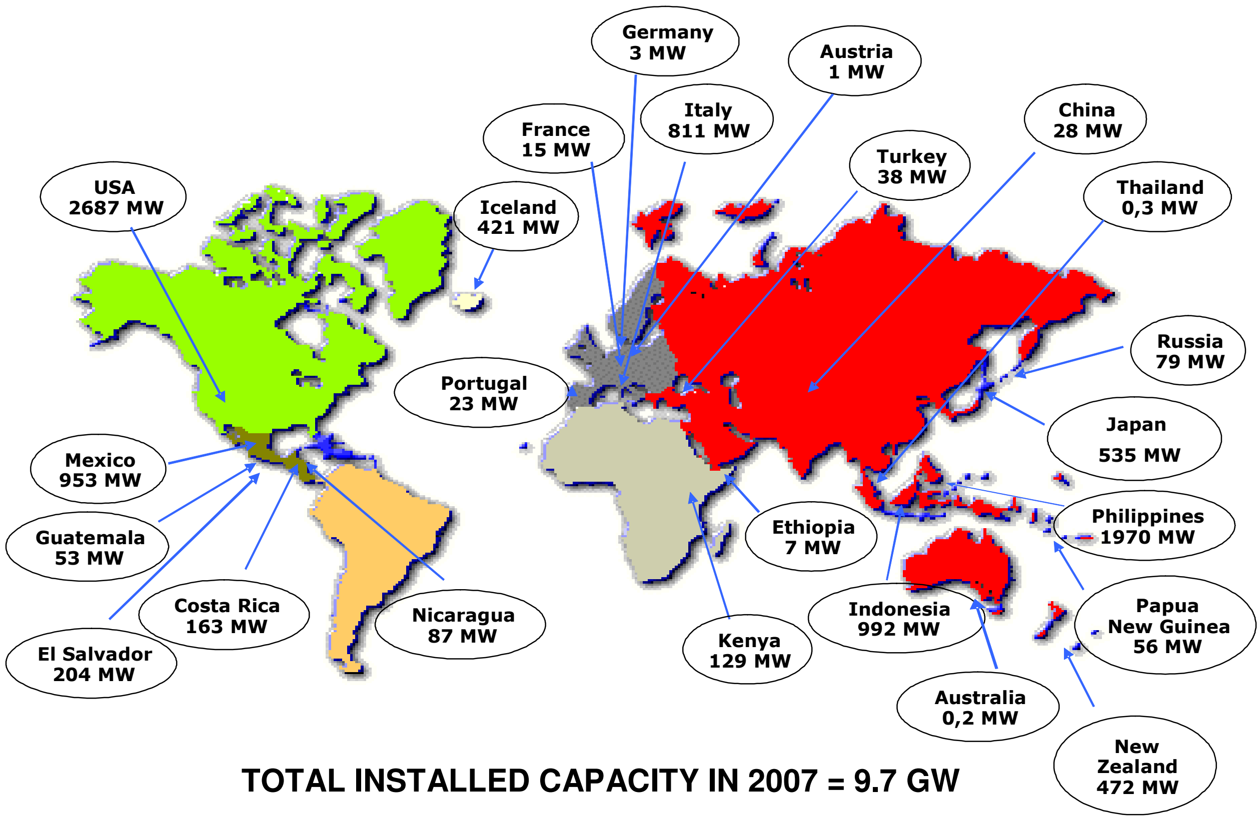

Figure 2. Installed capacity for electricity production in 2007 in different countries (Bertani, 2007).

Electricity has been generated commercially by geothermal steam since 1913, and geothermal energy has been used on the scale of hundreds of MW for five decades both for electricity generation and direct use. The utilisation has increased rapidly during the last three decades. Geothermal resources have been identified in some 90 countries and there are quantified records of geothermal utilisation in 72 countries. Summarised information on geothermal use in the individual countries for electricity production and direct use (heating) is available in Bertani (2005) and Lund et al. (2005), respectively. Electricity is produced by geothermal energy in 24 countries. Five of these countries obtain 15-22% of their national electricity production from geothermal (Costa Rica, El Salvador, Iceland, Kenya and the Philippines).

In 2004, the worldwide use of geothermal energy was about 57 TWh/yr of electricity (Bertani, 2005), and 76 TWh/yr for direct use (Lund et al., 2005). The installed electric capacity in 2004 was 8,933 MWe (Bertani, 2005). The installed capacity for direct applications in 2004 was 28,268 MWth (Lund et al., 2005). Figure 1 shows the installed capacity and the geothermal energy in the different continents in 2004. Figure 2 shows the installed capacity for electricity production in 2007 in different countries.

The world geothermal electricity production increased by 16% from 1999 to 2004 (annual growth rate of 3%). Direct use increased by 43% from 1999 to 2004 (annual growth rate of 7.5%). Only a small fraction of the geothermal potential has been developed so far, and there is ample opportunity for an increased use of geothermal energy both for direct applications and electricity production.

The installed electrical capacity achieved an increase of about 800 MWe in the three year term 2005-2007, following the rough standard linear trend of approximately 200/250 MWe per year (Figure 3, from Bertani, 2007).

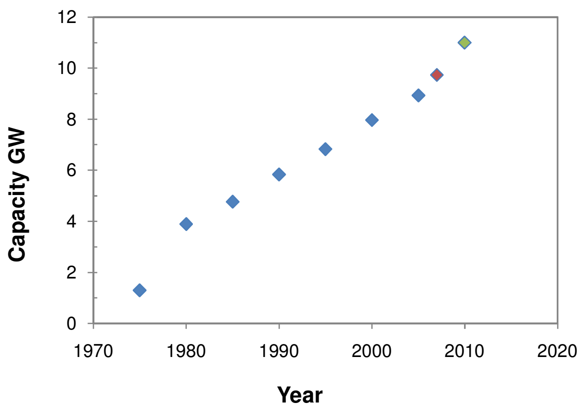

Figure 3. Installed capacity for electricity production from 1975 up to end of 2007 (red) and forecast to 2010 (green) (Bertani, 2007).

Of the total electricity production from renewables of 2968 TWh in 2001 (WEA 2004), 91% came from hydropower, 5.7% from biomass, 1.8% from geothermal sources and 1.4% from wind. Solar electricity contributed 0.06% and tidal 0.02%. A comparison of the renewable energy sources at that time (data from the UN World Energy Assessment Report update (WEA 2004)) showed the electrical energy cost to be 2-10 UScents/kWh for geothermal energy and hydro, 4-8 UScents/kWh for wind, 3-12 UScents/kWh for biomass, 25-160 UScents/kWh for solar photovoltaic and 12-34 UScents/kWh for solar thermal electricity. Heat from renewables is also commercially competitive with conventional energy sources. The UN World Energy Assessment Report update (WEA 2004) showed the cost of direct heat from biomass to be 1-6 UScents/kWh, geothermal energy 0.5-5 UScents/kWh, and solar heating 2-25 UScents/kWh (WEA 2004). It is recommended that a table similar to Table 7 of the 2004 update of the World Energy Assessment Report (WEA, 2004) be prepared for the IPCC Special Report on Renewable Energy and Climate Change Mitigation.

Table 1 shows the installed capacity and electricity production in 2005 for renewable energy sources, namely hydro, biomass, wind, geothermal, and solar energy. The data for the table is compiled from "Tables" in the 2007 Survey of Energy Resources (WEC, 2007). It should be noted that the installed capacity for biomass is not given in the "Tables", but reported as "In excess of 40 GW" in the text. The capacity factor for biomass is thus uncertain. No figures are given for the installed capacity and electricity production of tidal energy in the 2007 Survey of Energy Resources (WEC, 2007). Tidal energy is therefore absent from Table 1.

The table clearly reflects the variable capacity factors of the power stations using the renewable sources. The capacity factor of 73% for geothermal is by far the highest. Geothermal energy is independent of weather conditions contrary to solar, wind, or hydro applications. It has an inherent storage capability and can be used both for base load and peak power plants. However, in most cases, it is more economical to run the geothermal plants as base load suppliers. The relatively high share of geothermal energy in electricity production compared to the installed capacity (1.8% of the electricity with only 1% of the installed capacity) reflects the reliability of geothermal plants which can be (and are in a few countries) operated at capacity factors in excess of 90%.

	Installed capacity		**Production per year**		Capacity factor (%)
	GWe	%	TWh/yr	%	
Hydro	778	87.5	2,837	89	42
Biomass	40*	4.5	183	5.7	52*
Wind	59	6.6	106	3.3	21
Geothermal	8.9	1.0	57	1.8	73
Solar	4	0.4	5	0.2	14
Total	890	100	3,188	100	41**

Table 1. Electricity from renewable energy resources in 2005.

Compiled from Tables in 2007 Survey of Energy Resources (WEC, 2007)

*The installed capacity for Biomass is not given in the WEC 2007 Survey of Energy Resources, but said "In excess of 40 GW" in the text. The capacity factor is thus uncertain.

**Weighted average.

It should be stressed that Table 1 is not published here in order to diminish the importance of wind or solar energy. On the contrary, the table shows that geothermal energy is available day and night every day of the year and can thus serve as a supplement to energy sources which are only available intermittently. It is most economical for geothermal power stations to serve as a base load throughout the year, but they can also, at a cost, be operated to meet seasonal variations and as peak power. This applies both to electricity production (Table 1) and direct utilisation for heating/cooling.

Geothermal energy has until recently had a considerable economic potential only in areas where thermal water or steam is found concentrated at depths less than 3 km in restricted volumes, analogous to oil in commercial oil reservoirs. This has changed in the last two decades with the development of power plants that can economically utilise lower temperature resources (around 100°C) and the emergence of ground source heat pumps using the earth as a heat source for heating or as a heat sink for cooling, depending on the season. This has made it possible for all countries to use the heat of the earth for heating and/or cooling, as appropriate. It should be stressed that heat pumps can be used basically everywhere.

Geothermal Resources

Geothermal energy, in the broadest sense, is the natural heat of the Earth. Immense amounts of thermal energy are generated and stored in the Earth's core, mantle and crust. At the base of the continental crust, temperatures are believed to range from 200 to 1,000°C, and at the centre of the earth the temperatures may be in the range of 3,500 to 4,500°C. The heat is transferred from the interior towards the surface mostly by conduction, and this conductive heat flow makes temperature rise with increasing depth in the crust on average 25-30°C/km. Geothermal production wells are commonly more than 2 km deep, but rarely much more than 3 km at present. With an average thermal gradient of 25-30°C/km, a 1 km well in dry rock formations would have a bottom temperature near 40°C in many parts of the world (assuming a mean annual air temperature of 15°C) and a 3 km well 90-100°C.

The total heat content of the Earth is of the order of 12.6×10^{24} MJ, and that of the crust the order of 5.4×10^{21} MJ (Dickson and Fanelli, 2004). This huge number should be compared to the world electricity generation in 2005, 6.6×10^{13} MJ. The thermal energy of the Earth is therefore immense, but only a fraction can be utilised. So far our utilisation of this energy has been limited to areas in which geological conditions permit a carrier (water in the liquid or vapour phases) to "transfer" the heat from deep hot zones to or near the surface, thus giving rise to geothermal resources.

It is difficult to estimate the overall worldwide potential, due to the presence of too many uncertainties. Nevertheless, it is possible to identify a range of estimations, taking also into consideration the possibility of new technologies, such as permeability enhancements, drilling improvements, special Enhanced Geothermal Systems (EGS) technology, low temperature electricity production, and the use of supercritical fluids.

Bertani (2003) presents a compilation of data on geothermal potential published by different authors. The data is strongly scattered, but according to a method that seems to be realistic the expected geothermal electricity potential is estimated to be between a minimum of 35-70 GW and a maximum of 140 GW (Figure 4). The potential may be estimated orders of magnitude higher based on enhanced geothermal systems (EGS)-technology. The MIT-study (Tester et al., 2006) indicates a potential of more than 100 GW for USA alone or 35 GW for Germany alone (Paschen et al., 2003). Stefansson (2005) concluded that the most likely value for the technical potential of geothermal resources suitable for electricity generation is 240 GWe. Theoretical considerations, based on the conditions in Iceland and the USA, reveal that the magnitude of hidden resources is expected to be 5-10 times larger than the estimate of identified resources. If this is the case for other parts of the world, the upper limit for electricity generation from geothermal resources is in the range of 1-2 TWe. Furthermore, the frequency distribution of the temperature of geothermal resources in Iceland and the USA indicates that the magnitude of low-temperature geothermal resources in the world is about 140 EJ/yr of heat. For comparison, the world energy consumption is now about 420 EJ/yr.

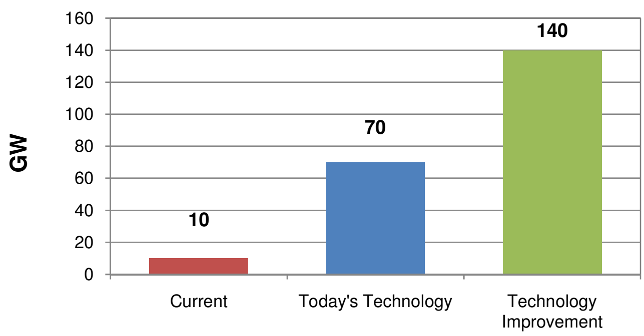

Figure 4. Estimated World geothermal electricity potential with present technology (blue) and with technology improvement (green). The current installed capacity is also shown (red).

It is considered possible to produce up to 8.3% of the total world electricity with geothermal resources, serving 17% of the world population. Thirty nine countries (located mostly in Africa, Central/South America, and the Pacific) can potentially obtain 100% of their electricity from geothermal resources (Dauncey, 2001).

Exploitable geothermal systems occur in a number of geological environments. They can be divided broadly into two groups depending on whether they are related to young volcanoes and magmatic activity or not. High-temperature fields used for conventional power production (with temperatures above 180°C) are mostly confined to the former group, but geothermal fields utilised for direct application of the thermal energy can be found in both groups. The temperature of the geothermal reservoirs varies from place to place depending on the geological conditions.

High-temperature fields (> 180 °C)

Volcanic activity takes place mainly along so called plate boundaries (Figure 5). According to the plate tectonics theory, the Earth's crust is divided into a few large and rigid plates which float on the mantle and move relative to each other at average rates counted in centimetres per year (the actual movements are highly erratic). The plate boundaries are characterised by intense faulting and seismic activity and in many cases volcanic activity. Geothermal fields are very common on plate boundaries, as the crust is highly fractured and thus permeable to water, and sources of heat are readily available. In such areas magmatic intrusions, sometimes with partly molten rock at temperatures above 1000°C, situated at a few km depth under the surface, heat up the groundwater. The hot water has lower density than the surrounding cold groundwater and therefore flows up towards the surface along fractures and other permeable structures.

Figure 5. World map showing the lithospheric plate boundaries (red dots = active volcanoes).

Most of the plate boundaries are below sea level, but in cases where the volcanic activity has been intensive enough to build islands or where active plate boundaries transect continents, high temperature geothermal fields are commonly scattered along the boundaries. A spectacular example of this is the "ring of fire" that circumscribes the Pacific Ocean (the Pacific Plate) with intense volcanism and geothermal activity in New Zealand, Indonesia, the Philippines, Japan, Kamchatka, Aleutian Islands, Alaska, California, Mexico, Central America, and the Andes mountain range. Other examples are Iceland, which is the largest island on the Mid-Atlantic Ridge plate boundary, the East African Rift Valley with impressive volcanoes and geothermal resources in e.g. Djibouti, Ethiopia, and Kenya, and "hot spots" such as Hawaii and Yellowstone.

Low-temperature fields (< 180 °C)

Geothermal resources unrelated to volcanoes can be divided into four types: a) Resources related to deep circulation of meteoric water along faults and fractures; b) Resources in deep high permeability rocks at hydrostatic pressure; c) Resources in high porosity rocks at pressures greatly in excess of hydrostatic (i.e. "geopressured"); and d) Resources in hot but dry (low porosity) rock formations. These four types are in fact end members, with most natural systems displaying some intermediate characteristics. All these, with the exception of type c), can also be associated with volcanic activity. Types c) and d) are not commercially exploited as yet. A comprehensive description of the nature of geothermal systems is given (with diagrams) on the homepage of the International Geothermal Association (http://iga.igg.cnr.it).

Type a) is probably the most common type for warm springs in the world. These can occur in most rock types of all ages, but are most obvious in mountainous regions where warm springs appear along faults in valleys. Warm springs of this type are of course more numerous in areas with a high regional conductive heat flow (with or without volcanic activity), but are also found in areas of normal and low heat flow. The important factor here is a path for the meteoric water to circulate deep into the ground and up again. Areas of young tectonic activity, such as Turkey and the Balkan Peninsula, Iceland, Japan, The Western USA, SE-China etc. are commonly rich in this type of geothermal springs.

Type b) is probably the most important type of geothermal resources that is not associated with young volcanic activity. Many regions throughout the world are characterized by deep basins filled with sedimentary rocks of high porosity and permeability. If these are properly isolated from surface ground water by impermeable strata, the water in the sediments is heated by the regional heat flow. The age of the sediments makes no difference, so long as they are permeable. The geothermal reservoirs in the sedimentary basins can be very extensive, as the basins themselves are commonly hundreds of km in diameter. The temperature of the thermal water depends on the depth of the individual aquifers and the geothermal gradient in the area concerned, but is commonly in the range 50 to 100°C (in wells less than 3 km deep) in areas that have been exploited (such as the Paris basin in France, the Pannonian basin in Hungary, the Williston Basin in Montana, North Dakota, USA and several areas in China). Geothermal resources of this type are rarely seen on the surface, but are commonly detected during deep exploration drilling for oil and gas. The widespread low-temperature geothermal resources of China are divided between types a) and b).

Geothermal Utilisation

Geothermal utilisation is commonly divided into two categories, i.e. electricity production and direct application. Conventional electric power production is commonly limited to fluid temperatures above 180°C, but considerably lower temperatures can be used with the application of binary fluids (outlet temperatures commonly about 70°C). The ideal inlet temperatures into buildings for space heating is about 80°C, but by application of larger radiators in houses/or the application of heat pumps or auxiliary boilers, thermal water with temperatures only a few degrees above the ambient temperature can be used beneficially.

As mentioned in the Introduction, geothermal resources have been identified in some 90 countries and there are quantified records of geothermal utilisation in 72 countries. Electricity is produced from geothermal energy in 24 countries. The top fifteen countries producing geothermal electricity and using geothermal energy directly in the world in 2005 (in GWh/yr) are listed in Table 2. It is of great interest to note that among the top fifteen countries producing geothermal electricity, there are ten developing countries. Among the top fifteen countries employing direct use of geothermal energy, there are six developing and transitional countries. China is on top of the list of countries on direct use (Table 2). Some 55% of the annual energy use of geothermal energy in China is for bathing and swimming, 14% for conventional district heating, and 14% for geothermal heat pumps used for space heating (Zheng et al., 2005).

Geothermal electricity production		Geothermal direct use	
	GWh/yr		GWh/yr
USA	17,917	China	12,605
Philippines	9,253	Sweden	10,000
Mexico	6,282	USA	8,678
Indonesia	6,085	Turkey	6,900
Italy	5,340	Iceland	6,806
Japan	3,467	Japan	2,862
New	2,774	Hungary	2,206
Zealand	1,483	Italy	2,098
Iceland	1,145	New	1,968
Costa Rica	1,088	Zealand	1,840
Kenya	967	Brazil	1,752
El Salvador	271	Georgia	1,707
Nicaragua	212	Russia	1,443
Guatemala	105	France	1,222
Turkey	102	Denmark	1,175
Guadeloupe		Switzerland	
(France)			

Table 2. Top fifteen countries utilising geothermal energy in 2005.
Data on electricity from Bertani (2005) and on direct use from Lund et al. (2005).

Figure 6 shows the top fourteen countries with the highest % share of geothermal energy in their national electricity production. Special attention is drawn to the fact that El Salvador, Costa Rica and Nicaragua are among the six top countries, and Guatemala is in eleventh place. Central America is one of the world´s richest regions in geothermal resources. Geothermal power stations provide about 12% of the total electricity generation of Costa Rica, El Salvador, Guatemala and Nicaragua, according to data provided by the countries for the World Geothermal Congress in 2005 (Bertani, 2005). The geothermal potential for electricity generation in Central America has been estimated to be some 4,000 MWe (Lippmann 2002).

Only a small portion of the geothermal resources in the region has been harnessed so far (under 500 MWe). The electricity generated in the geothermal fields is in all cases replacing electricity generated by imported oil.
This clearly demonstrates how significant geothermal energy can be in the electricity production of countries and regions rich in high-temperature fields which are associated with volcanic activity. Kenya is the first country in Africa to utilise its rich geothermal resources and can in the foreseeable future produce most of its electricity with hydropower and geothermal energy. Several other countries in the East African Rift Valley may follow suit. Indonesia is probably the world´s richest country in geothermal resources and can in the future replace a considerable

part of its fossil fuelled electricity by geothermal energy. Most commonly electricity generation takes place in conventional steam turbines (see Figure 7). The steam, typically at a temperature above 150°C, is piped directly from dry steam wells or after separation from wet wells through a turbine which drives the electric generator (Dickson and Fanelli, 2003). After that it is lead to a condenser where vacuum conditions are maintained by cooling water. The unit sizes are commonly 20-110 MWe, but both larger and smaller turbines are produced pressure at low temperatures, compared with steam. The fluid passes through a turbine in a similar way as steam in conventional cycles. Binary plants are usually constructed in small modular units of up to a few MWe capacity which are linked together. Kalina is a relatively new binary fluid cycle which utilises a water-ammonia mixture as working fluid to allow more efficient power production. This makes it an interesting option for combined heat and power generation.

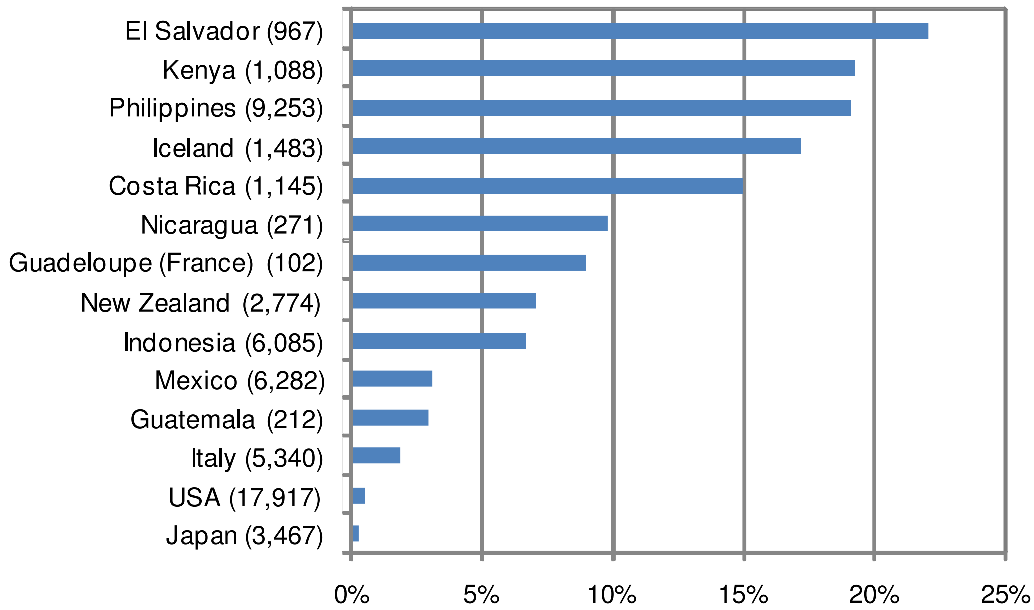

Figure 6. The fourteen countries with the highest % share of geothermal energy in their national electricity production (Fridleifsson, 2007). Numbers in parenthesis give the annual geothermal electricity production in GWh in 2004 (Bertani, 2005Electricity generation

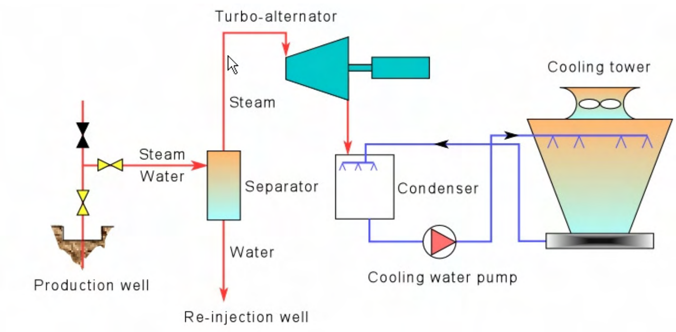

Figure 7. A schematic diagram of a geothermal condensing power plant

Binary plants (organic Rankine cycle) have been gaining popularity in recent years. They utilise geothermal fluids at lower temperatures than conventional plants or in the range 74-170°C. They use a secondary working fluid, usually an organic fluid that has a low boiling point and high vapour

A 2-MWe Kalina pilot plant has been in operation in Husavik, North Iceland, since 2000. An idealised diagram of the Husavik plant including cascaded uses of the geothermal resource is shown in Figure 7.

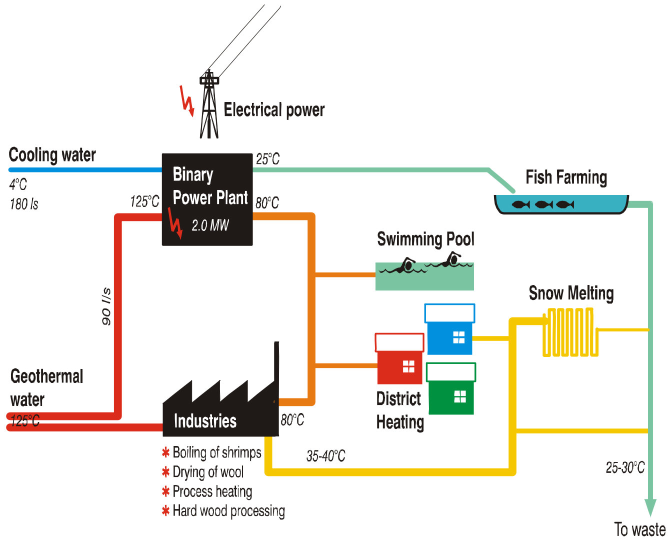

Figure 8. An idealized diagram showing cascaded uses of geothermal energy.

The efficiency of geothermal utilisation is enhanced considerably by cogeneration plants (combined heat and power plants), compared with conventional geothermal plants. A cogeneration plant produces both electricity and hot water which can be used for district heating as well as other direct uses. A necessary condition for the operation of a cogeneration power plant is that a relatively large market for hot water exists at a distance not too far from the plant. Iceland, where three geothermal cogeneration plants are in operation, is an example of this. There the distance of the plants to the towns is 12-25 km. The longest geothermal water pipeline in the world is in Iceland, 63 km

Direct utilisation

The main types of direct applications of geothermal energy are space heating 52% (thereof 32% using heat pumps), bathing and swimming (including balneology) 30%, horticulture (greenhouses and soil heating) 8%, industry 4%, and aquaculture (mainly fish farming) 4% (Lund et al., 2005). Figure 9 shows the direct applications of geothermal energy worldwide by percentage of total energy use. The main growth in the direct use sector has during the last decade been the use of geothermal (ground-source) heat pumps. This is due, in part, to the ability of geothermal heat pumps to utilise groundwater or ground-coupled temperatures anywhere in the world.

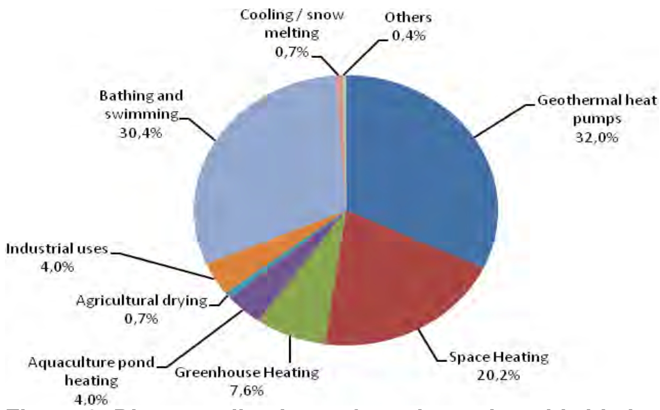

Figure 9. Direct applications of geothermal worldwide in 2004 by percentage of total energy use (data from Lund et al. 2005).

Space heating, of which more than 80% are district heating, is among the most important direct uses of geothermal energy. Preferred water delivery temperature for space heating is in the range 60-90°C and commonly the return water temperature is 25-40°C. Conventional radiators or floor heating systems are typically used, but air heating systems are also possible. If the temperature of the resource is too low for direct application, geothermal heat pumps can be used, as will be discussed below. Space cooling can also be provided by geothermal systems; geothermal heat pumps can heat and cool with the same equipment.

Open loop (single pipe) distribution systems are used for both private users and district heating systems. In that case geothermal water is used directly for heating and the spent water from radiators is discharged at the surface to waste. This type of system is only possible where the water quality is good and recharge into the geothermal system adequate. More commonly closed loop (double pipe) systems are used. Then heat exchangers are used to transfer heat from the geothermal water to a closed loop that circulates heated freshwater through the radiators. This is often needed because of the chemical composition of the geothermal water. The spent water is disposed of into wells which are called reinjection wells. Closed loop systems are more flexible than open loop systems and they allow substitution of the geothermal energy with other energy sources. Both of these two main types of district heating systems are shown schematically in Figure 10.

In Iceland, the geothermal water is commonly piped 10-20 km from the geothermal fields to the towns. Transmission pipelines are mostly of steel insulated by rock wool (surface pipes) or polyurethane (subsurface). However, several small villages and farming communities have successfully used plastic pipes (polybutylene) with polyurethane insulation as transmission pipes. The temperature drop is insignificant in large diameter pipes with a high flow rate, exemplified by a 1°C drop in a 27 km steel pipeline with 800 mm diameter and a flow of 1500 l/s and (Gunnlaugsson, personal communication 2008), and 3.5 °C in a 10 km steel pipeline with 200 mm diameter and a flow of 45 l/s (Baldursson, personal communication 2008).

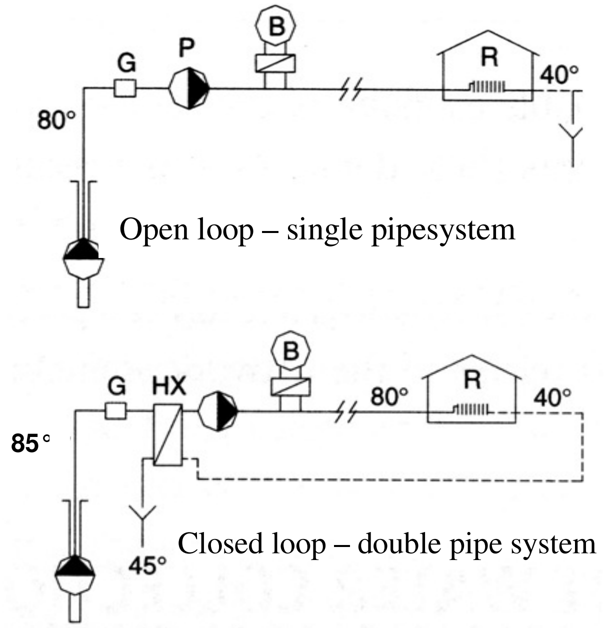

Figure 10. Two main types of district heating systems. G=gas separator, P=pump, B=boiler, R=radiation heating, HX=heat exchanger (Dickson and Fanelli, 2003).

Heat pump applications

Geothermal heat pumps (GHPs) are one of the fastest growing applications of renewable energy in the world today (Rybach, 2005). They represent a rather new but already well-established technology, utilising

the immense amounts of energy stored in the earth´s interior. This form for direct use of geothermal energy is based on the relatively constant ground or groundwater temperature in the range of 4°C to 30°C available anywhere in the world, to provide space heating, cooling and domestic hot water for homes, schools, factories, public buildings and commercial buildings.

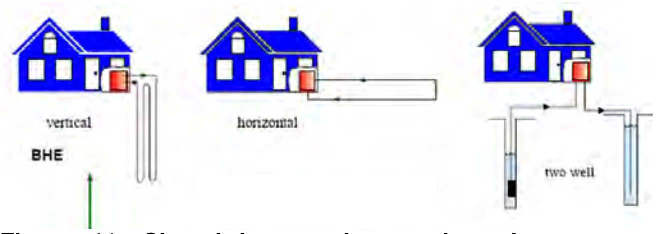

Figure 11. Closed loop and open loop heat pump systems. The green arrow indicates the most common system, with borehole heat exchangers (BHE). The heat pump is shown in red. (Modified from Geo-Heat Center, 2008).

There exist mainly two types of geothermal heat pumps (Figure 11). In ground-coupled systems a closed loop of plastic pipe is placed in the ground, either horizontally at 1-2 m depth or vertically in a borehole down to 50-250 m depth. A water-antifreeze solution is circulated through the pipe. Thus heat is collected from the ground in the winter and optionally heat is rejected to the ground in the summer. An open loop system uses groundwater or lake water directly as a heat source in a heat exchanger and then discharges it into another well, a stream or lake or even on the ground. In essence heat pumps are nothing more than refrigeration units that can be reversed. In the heating mode the efficiency is described by the coefficient of performance (COP) which is the heat output divided by the electrical energy input. Typically this value lies between three and four (Rybach, 2005).

Due to the rapidly growing GHP development, statistical data can provide only snapshots of the current situation. Table 3 shows the number of GHPs and the installed capacity in EU countries in 2005 and 2006. Table 4 shows the estimated number of installed GHP units per year in EU countries and Switzerland in 2007. In the USA, over 800,000 units have been installed at a rate of 50,000 GHP units annually with a capacity of over 9,600 MWth (Lund - personal communication, 2007). The growth is illustrated in Figure 12, where the increase of new GHP installations in some European countries is shown for year 2006. (Note that the references for Figure 12 and Table 4 are different, and the numbers not exactly the same). It is evident that GHP development is increasing significantly, albeit with quite different intensity from country to country.

Countries	2005		2006	
	Number	Capacity (in MW_{th})	Number	Capacity (in MW_{th})
Sweden	230094	2070.8	270111	2431.0
Germany	61912	681.0	90517	995.7
France	63830	702.1	83856	922.4
Denmark	43252	821.2	43252	821.2
Finland	29106	624.3	33612	721.9
Austria	32916	570.2	40151	664.5
Netherlands	1600	253.5	1600	253.5
Italy	6000	120.0	7500	150.0
Poland	8100	104.6	8300	106.6
Czech Republic	3727	61.0	5173	83.0
Belgium	6000	64.5	7000	69.0
Estonia	3500	34.0	5000	49.0
Ireland	1500	19.6	1500	19.6
Hungary	230	6.5	350	15.0
United Kingdom	550	10.2	550	10.2
Greece	400	5.0	400	5.0
Slovenia	300	3.4	420	4.6
Lithuania	200	4.3	200	4.3
Slovakia	8	1.4	8	1.4
Latvia	10	0.2	10	0.2
Portugal	1	0.2	1	0.2
Total EU 25	493236	6158.0	599511	7328.3

Table 3. Estimated number of GHP units and total installed capacity in EU countries (Geothermal Energy Barometer, 2007) Source: EurObserv'ER 2007

Country	2003	2004	2005	2006
Sweden	31564	39359	34584	40017
Germany	7349	9593	13250	28605
France	9000	11700	13880	20026
Austria	3633	4282	5205	7235
Finland	2200	2905	3506	4506
Estonia	n.a.	1155	1310	1500
Czech Republic	n.a.	600	1027	1446
Belgium	n.a.	n.a.	1000	1000
Poland	n.a.	n.a.	100	200
Slovenia	n.a.	35	97	120
Hungary	n.a.	n.a.	80	120
Total	53746	69629	74039	104775
Switzerland	3558	4380	5128	7130

Source: EurObserv'ER 2007

Table 4. Estimated number of installed GHP units per year in EU countries and Switzerland (Geothermal Energy Barometer, 2007

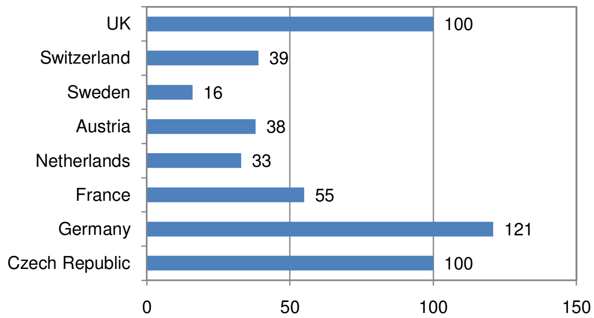

Figure 12. Increase of the number of GHP installations (in %) in European countries in 2006. (Source: European Heat Pump Association, EHPA).

Worldwide data on geothermal heat pump applications were presented at the World Geothermal Congress held in Antalya, Turkey, in 2005 (WGC-2005). According to that data GHP‘s account for 54.4% of the worldwide geothermal direct use capacity and 32% of the energy use. The installed capacity is 15,384 MWth and the annual energy use is 87,503 TJ/yr, with a capacity factor of 0.18 in the heating mode. Based on the size of a typical heat pump unit of 12 kW and the total installed capacity the total number of installations were estimated to be 1.3 million in 2005, which is over double the number of units reported in 2000 (Curtis et al., 2005). Figure 13 shows the rapid growth in the worldwide use of geothermal heat pumps as well as the leading countries as reported at and after WGC-2005.

Until recently, almost all of the installations of the ground source heat pumps have been in North America and Europe, increasing from 26 countries in 2000 to 33 countries in 2005 (Lund et al., 2005). China is, however, the most significant newcomer in the application of heat pumps for space heating. According to data from the Geothermal China Energy Society in February 2007, space heating with ground source heat pumps expanded from 8 million m^2 in 2004 to 20 million m^2 in 2006, and to 30 million m^2 in 2007 (Keyan Zheng, personal communication 2008). Conventional geothermal space heating in the country had grown from 13 million m^2 in 2004 to 17 million m^2 in 2006. The numbers reflect the policy of the Chinese government to replace fossil fuels where possible with clean, renewable energy. The “Law of Renewable Energy of China” came into implementation in 2006.

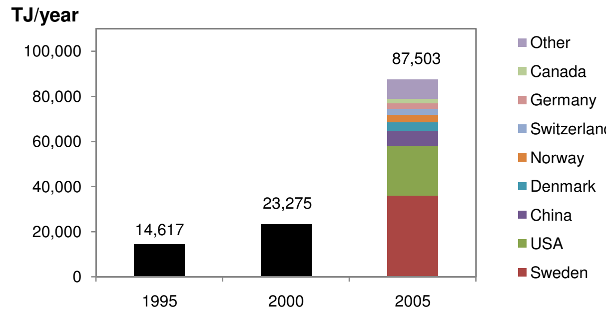

Figure 13. Worldwide growth of ground source heat pump applications and the leading GHP countries. Data from Lund et al. (2005).

Enhanced Geothermal Systems (EGS)

The principle of Enhanced Geothermal Systems (EGS) is simple: in the deep subsurface where temperatures are high enough for power generation (150-200 °C) an extended fracture network is created and/or enlarged to act as new pathways. Water from the deep wells and/or cold water from the surface is transported through this deep reservoir using injection and production wells, and recovered as steam/hot water. Injection and production wells as well as further surface installations complete the circulation system. The extracted heat can be used for district heating and/or for power generation.

While conventional geothermal resources cover a wide range of uses for power production and direct uses in profitable conditions, a large scientific and industrial community has been involved for more than 20 years in promoting Enhanced Geothermal Systems, the so-called EGS concept (Ledru et al., 2007). The enhancement challenge is based on several conventional methods for exploring, developing and exploiting geothermal resources that are not economically viable yet. This general definition embraces different tracks for enlarging access to heat at depth:

- stimulating reservoirs in Low Permeability Systems and enlarging the extent of productive geothermal fields by enhancing/stimulating permeability in the vicinity of naturally permeable rocks

- improving thermodynamic cycles in order to ensure power production from water resources at medium temperature (from 80°C)
- improving exploration methods for deep geothermal resources
- improving drilling and reservoir assessment technology
- defining new targets and new tools for reaching supercritical fluid systems, especially high-temperature down-hole tools and instruments

A recent publication, "The Future of Geothermal Energy – Impact of Enhanced Geothermal Systems (EGS) on the United States in the 21th Century", determined a large potential for the USA: recoverable resources > 200,000 EJ, corresponding to 2,000 times the annual primary energy demand (Tester et al., 2006). An EGS power generation capacity of >100,000 MWe could be established by the year 2050 with an investment volume of 0.8 - 1 billion USD. The report presents marketable electricity prices, based on economic models that need to be substantiated by EGS realisations.

The original idea calls for general applicability, since the temperature increases with depth everywhere. But still a number of basic problems need to be solved for the realisation of EGS systems, mainly that the techniques need to be developed for creating, characterising, and operating the deep fracture system (by some means of remote sensing and control) that can be tailored to site-specific subsurface conditions. Some environmental issues like the chance of triggering seismicity also need detailed investigation.

There are several places where targeted EGS demonstration is underway: Australia can claim a large-scale activity, through several stock market-registered enterprises (e.g. Geodynamics, Petratherm, Green Rock Energy, Geothermal Resources, Torrens Energy, and Eden Energy). A real boom can be observed: with 19 companies active in 140 leases (a total of 67,000 km^2 in four states), with an investment volume of 650 million USD. The project developers plan to establish the first power plants (with a few MWe capacity) in the coming years (Beardsmore, 2007). The EU project "EGS Pilot Plant" in Soultz-sous-Forêts/France (started in 1987), has ordered a power plant (1.5 MWe) to utilise the enchanced fracture permeability at 200°C (low fracture permeability was enhanced). In Landau Germany, the first EGS-plant with 2.5 to 2.9 MWe went into operation in fall 2007 (Baumgärtner, 2007). Another approach is made for deep sediments in the in situ geothermal laboratory in Groß Schönebeck using two research wells (Huenges et al., 2007). One of the main future demonstration goals in EGS will be to see whether and how the power plant size could be upscaled to several tens of MWe. The U.S. plans to include an R&D component as part of a revived EGS program.

EGS plants, once operational, can be expected to have great environmental benefits (CO_2 emissions zero). The potential impact of EGS in the future, and also the environmental benefits like avoiding additional CO_2 emission, cannot yet be satisfactorily quantified.

To achieve high levels of CO_2 emissions reduction using renewables, it will be necessary to have large sources of carbon-free, base load electricity that are dispatchable on a wide scale in both developed and developing countries. Geothermal is a proven technology for providing highly reliable base load electricity with capacity factors above 90% for many of the hydrothermal plants in operation today. Widespread deployment of geothermal would have a very positive impact on our energy security, on our environment, and on global economic health. However, there is an inherent limitation on a global scale in that the world's high grade hydrothermal systems are too localized and relatively small in number. Through EGS approach, it could be possible for geothermal energy to achieve high levels of CO_2 reduction or offset by exploiting the massive resource characterized by high temperature but low permeability and lack of natural fluid circulation.

New developments - Drilling for higher temperatures

Production wells in high-temperature fields are commonly 1.5-2.5 km deep and the production temperature 250-340°C. The energy output from individual wells is highly variable depending on the flow rate and the enthalpy (heat content) of the fluid, but is commonly in the range 5-10 MWe and rarely over 15 MWe per well. It is well known from research on eroded high-temperature fields that much higher temperatures are found in the roots of the high-temperature systems. The international Iceland Deep Drilling Project (IDDP) is a long-term program to improve the efficiency and economics of geothermal energy by harnessing deep unconventional geothermal resources (Fridleifsson et al., 2007). Its aim is to produce electricity from natural supercritical hydrous fluids from drillable depths. Producing supercritical fluids will require drilling wells and sampling fluids and rocks to depths of 3.5 to 5 km, and at temperatures of 450-600°C. The central science team participants are from Iceland, USA, Japan, New Zealand, Italy, Germany and France. Other scientists and geothermal experts involved are from Russia, Spain, Norway, UK, Luxembourg, Greece, Turkey and Portugal. Some 40-50 research proposals have been put forward and 100-150 scientists and their students are currently active in the project.

The current plan is to drill and test at least three 3.5-5 km deep boreholes in Iceland within the next few years (one in each of the Krafla, Hengill, and Reykjanes high-temperature geothermal systems). Beneath these three developed drill fields temperatures should exceed 550-650°C, and the occurrence of frequent seismic activity below 5 km, indicates that the rocks are brittle and therefore likely to be permeable. Modelling indicates that if the wellhead enthalpy is to exceed that of conventionally produced geothermal steam, the reservoir temperature must be higher than 450°C. A deep well producing 0.67 m^3/sec steam (~2400 m^3/h) from a reservoir with a temperature significantly above 450°C could yield enough high-enthalpy steam to generate 40-50 MW of electric power. This exceeds by an order of magnitude the power typically obtained from conventional geothermal wells (Fridleifsson et al., 2007). This would mean that much more energy could be obtained from presently exploited high-temperature geothermal fields from a smaller number of wells. Further information on the IDDP can be obtained on the webpage www.iddp.is.

Environmental issues

Geothermal fluids contain a variable quantity of gas, largely nitrogen and carbon dioxide with some hydrogen sulphide and smaller proportions of ammonia, mercury, radon and boron. The amounts depend on the geological conditions of different fields. Most of the chemicals are concentrated in the disposal water which is routinely reinjected into drillholes and thus not released into the environment. The concentration of the gases is usually not harmful and they can be vented to the atmosphere. Removal of hydrogen sulphide released from geothermal power plants is a requirement in the USA and Italy.

The range in CO_2 emissions from **high-temperature geothermal fields** used for electricity production in the world is variable, but much lower than that for fossil fuels. USA is the leading producer of electricity from geothermal fields in the world with a generation of 18,000 GWh/yr in 2005. Bloomfield et al. (2003) compared the average values for all geothermal capacity in the USA, including binary power plants. In Figure 14 the CO_2 emission from geothermal power plants is compared to that from fossil fuel plants. CO_2 emission values for coal, oil and natural gas plants are calculated using data from DOE´s Energy Information Administration. The CO_2 emission of the geothermal plants in the USA was reported as: CO_2 91 g/kWh by Bloomfield et al. (2003).

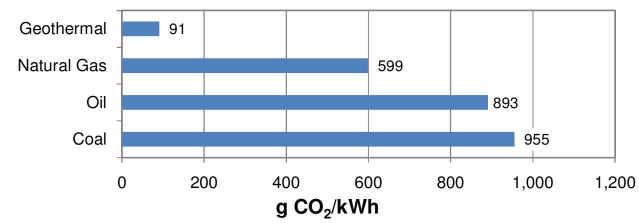

Figure 14. Comparison of CO2 emission from electricity generation from different energy sources in the USA. Data from Bloomfield et al. (2003).

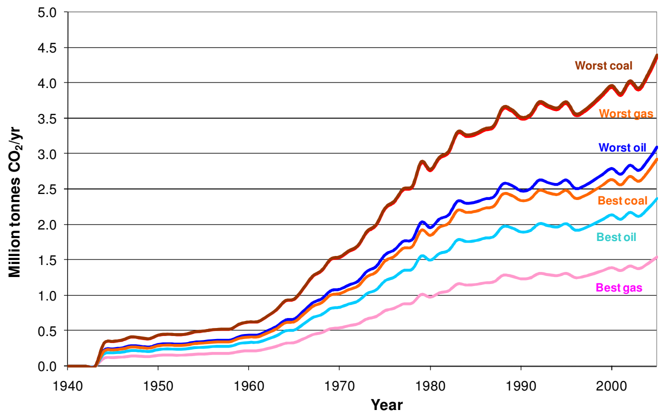

Figure 15. CO_2 savings using geothermal water in Reykjavik (Iceland) compared to other energy sources 1940-2006. Total avoidance 90 million to 110 million tonnes of CO_2 emissions depending on the type of fossil fuel(s) replaced by geothermal resources (Gunnlaugsson, personal communication 2008).

Bertani and Thain (2002) reported on CO2 emission data obtained in 2001 from 85 geothermal power plants operating in 11 countries around the world. These plants had an operating capacity of 6,648 MWe which constituted 85% of the world geothermal power plant capacity at the time. In the survey, details were obtained of the MWe output of the respective power plants together with their steam flow rate per MWe and % weight of CO2 contained in the geothermal steam. From this data, the MWe weighted CO2 emission rate in g/kWh of generation was calculated. (In the case of the Larderello plants in Italy, the data was provided on a summated basis for a group of plants operating in this field). The collected data showed a wide spread in the overall CO2 emission rates from the plants included in the survey. The actual range was from 4 g/kWh to 740 g/kWh with the weighted average being 122 g/kWh. This compares fairly well with the value of 91 g/kWh reported for the USA plants by Bloomfield et al. (2003). From the collected data, the average CO2 content was 90.46% of the non condensable gases (Bertani and Thain, 2002). Where there is a high natural release of CO2 from the geothermal fields prior to development, any measurable decrease in this natural emission resulting from the power development should be subtracted from the measured plant emission rate.

The gas emissions from **low-temperature geothermal resources** are normally only a fraction of the emissions from the high-temperature fields used for electricity production. The gas content of low-temperature water is in many cases minute, like in Reykjavik (Iceland), where the CO_2 content is lower than that of the cold groundwater. In sedimentary basins, such as the Paris basin, the gas content may cause scaling if it is released. In such cases the geothermal fluid is kept under pressure within a closed circuit (the geothermal doublet) and reinjected into the reservoir without any de-gassing taking place. Conventional geothermal schemes in sedimentary basins commonly produce brines which are generally reinjected into the reservoir and thus never released into the environment (zero CO_2 emission). No systematic collection has been made of CO_2 emission data from geothermal district heating systems in the world. The CO_2 emission from low-temperature geothermal water can be regarded negligible or in the range of 0-1 g CO_2 /kWh depending on the carbonate content of the water. As an example, for Reykjavik District Heating, the CO_2 emission from low-temperature areas is about 0.05 mg CO_2 /kWh (5 times 10^{-5} g CO_2/kWh). The data from geothermal district heating systems in China (Beijing, Tianjin and Xianyang) is limited, but is less than 1 g CO_2/kWh (Gunnlaugsson, personal communication 2007). The district heating system in Klamath Falls, Oregon, USA has zero emission as all the geothermal water is used and reinjected in a closed system.

Thanks to geothermal district heating, Reykjavik (Iceland) is one of the cleanest capitals in the world. There is no smoke from chimneys. Heating with polluting fossil fuels has been eliminated, and about 100 million tonnes of CO_2 emissions have been avoided by replacing coal and oil heating by geothermal (see Figure 15). Almost 90% of all houses in Iceland are currently heated by geothermal water, and the remainder is heated by electricity generated by hydropower (83%) and geothermal energy (17%). Geothermal utilisation has reduced CO_2 emissions in Iceland by some two million tonnes annually compared to the burning of fossil fuels. The total release of CO_2 in Iceland in 2004 was 2.8 million tonnes. The reduction has significantly improved Iceland's position globally in this respect. Many countries could reduce their emissions significantly through the use of geothermal energy.

The home page of the Clinton Climate Initiative gives an interesting bird´s eye view on the best practices in 40 cities, including Reykjavik in the top ten examples of best practices in renewables http://www.c40cities.org/bestpractices/renewables/reykjavik_geothermal.jsp.

Another good example (although on a smaller scale) of replacing fossil fuels by geothermal water is in Galanta, Slovakia. A district heating system using natural gas with about 9,000 GJ/yr heat production was modified. The natural gas was replaced as a heat source by carbonate rich geothermal water. The replacement resulted in the reduction of CO_2 emission by about 5,000 tonnes annually (Galantaterm, 2007). Although this geothermal water is rich in carbonate, its CO_2 emission is negligible (about 0.3 g CO_2/kWh).

Similar geothermal water is common in many countries in Central and Eastern Europe, but is as yet only used on a very limited scale. The largest user there is Hungary in the Pannonian basin with very wide spread geothermal resources and a long tradition for geothermal utilisation (Lund et al., 2005; Arpasi, 2005). Another substantial user of geothermal resources in Europe is France, which started considerable geothermal development with geothermal district heating systems in Paris and several other localities in the vast Paris basin in the 1970s as a response to the first oil crises. During 1978-1987, over seventy geothermal district heating systems were constructed in France, providing space heating and hot water for around 200,000 housing units. There was very little new activity in France during the period of low energy prices in the 1990s. Several geothermal district heating systems were in fact converted to natural gas. Following the Kyoto Agreement (since 1998), France has resumed an active policy for energy management and the development of renewable energy sources, including geothermal (Laplaige et al., 2005).
Kaltschmitt (2000) published figures of 4-16 tons CO_2-equivalent /TJ based on life cycle analysis of low-temperature district heating systems. There is a very large potential for replacing fossil fuels by conventional geothermal resources in the space heating (and hot tap water) sector in many European countries. With the application of heat pumps, all European countries can obtain a significant proportion of their space heating (and hot tap water) sector from geothermal heat. The limiting factor may, however, be the way in which the electricity (providing 25-30% of the energy coming from the heat pumps) is produced. If the electricity is produced from low emission resources, then the road is clear.

CO2 emission reduction by heat pumps

Geothermal heat pumps (GHP) are environmentally benign and represent a large potential for reduction of CO_2 emission. This can be demonstrated by comparing the CO_2 emission related to heating of buildings using different energy sources. The emission rates depend on the energy efficiency of the equipment as well as the fuel mix and the efficiency of electricity generation. The heat pump needs auxiliary power to accomplish the temperature rise needed in the system. In most cases, heat pumps are driven by electric power resulting in an amount of CO_2 emission that depends on the type of energy source used for electricity generation (zero emission if the electricity is generated from renewables). The average CO_2 emission associated with generation of electricity in Europe has been estimated to be 0.55 kg CO_2/kWh. With proper system design, seasonal performance coefficients in the heating mode of 4.0 (heating energy supplied by the GHP system/electricity input for heat pumps and circulation pumps) can be reached. The results show that the electrically driven heat pump reduces the CO_2 emission by 45% compared with an oil boiler and 33% compared with a gas fired boiler. Kaltschmitt (2000) published data for heat pumps driven systems of 50-56 tonnes CO_2-equivalent/TJ based on life cycle analysis. If the electricity that drives the heat pump is produced from a renewable energy source like hydropower or geothermal energy, the emission savings are even higher. The total CO_2 reduction potential of heat pumps has been estimated to be 1.2 billion tonnes per year or about 6% of the global emission (ISEO webpage: www.uniseo.org/heatpump .html).

The European Heat Pump Association (EHPA) has recently published a vision for the year 2020 (EPHA webpage: ehpa.fiz-karlsruhe.de). There it is pointed out that heating and cooling consume at least 40% of all primary energy consumed within the EU and that replacement of oil and gas boilers as well as electrical heating with heat pumps could contribute significantly to the renewable energy strategy of the EU. It is concluded that widespread installation of heat pumps would result in nearly 70 million installed heat pumps in 2020 and that they would contribute 20.5% of the EU's GHG reduction goal for 2012 and 21.5% to this goal for 2020. They conclude further that heat pumps would produce about 30% of the EU´s target for renewable energy in 2020.

Possible contribution of geothermal energy to the mitigation of climate change

One of the major concerns of mankind today is the ever increasing emission of greenhouse gases into the atmosphere and the threat of global warming. It is internationally accepted that a continuation of the present way of producing most of our energy by burning fossil fuels will bring on significant climate changes, global warming, rises in sea level, floods, droughts, deforestation, and extreme weather conditions. And the sad fact is that the poorest people in the world, who have done nothing to bring on the changes, will suffer most. One of the key solutions to these difficulties is to reduce the use of fossil fuels and increase the sustainable use of renewable energy sources. Geothermal energy can play an important role in this aspect in many parts of the world.

In the **geothermal direct use sector**, the potential is very large as space heating and water heating are significant parts of the energy budget in large parts of the world. In industrialised countries, 35 to 40% of the total primary energy consumption is used in buildings. In Europe, 30% of energy use is for space and water heating alone, representing 75% of total building energy use. The recent decision of the Commission of the European Union to reduce greenhouse gas emissions by 20% by 2020 compared to 1990 in the member countries implies a significant acceleration in the use of renewable energy resources. Most of the EU countries already have some geothermal installations. The same applies to the USA and Canada where the use of ground source heat pumps is widespread both for space heating and cooling. The largest potential is, however, in China. Due to the geological conditions, there are widespread low-temperature geothermal resources in most provinces of China which are already widely used for space heating, balneology, fish farming and greenhouses during the cold winter months and for tap water also in the summer.

To estimate the future development of the worldwide geothermal utilisation, three scenarios have been prepared. They include the installed capacity in heat pump applications and other direct use applications separately, as well as the annual energy production for the same. The scenario that is considered to be the most likely case is shown in Table 5 and Figures 16 and 17. They show that while only a moderate increase is expected in direct use applications, an exponential increase is foreseen in the heat pump sector. The reason is that geothermal heat pumps (GHPs) can be used for heating and/or cooling in most parts of the world. The most critical issue here is the source of electricity providing 25-30% of the energy supplied by the heat pumps. As previously mentioned, results show that an electrically driven heat pump reduces the CO_2 emission by 45% compared with an oil boiler and 33% compared with a gas fired boiler.

Year	Average annual growth rate from 2005		Direct Use other than GHP		Geothermal Heat Pumps (GHP)		Total	
	Direct Use (%)	GHP (%)	MW_{th}	TJ/yr	MW_{th}	TJ/yr	MW_{th}	TJ/yr
2005			12,855	185,869	15,384	87,503	28,239	273,372
2010	7	22	18,000	260,000	41,500	236,000	59,500	496,000
2020	6	16	30,900	446,000	143,000	811,000	173,000	1,260,000
2030	5	12.5	43,600	630,000	292,000	1,660,000	336,000	2,290,000
2040	4	10	50,800	734,000	476,000	2,710,000	527,000	3,444,000
2050	3.5	9	60,500	874,000	744,000	4,230,000	804,000	5,100,000

Table 5. Likely case scenario for direct use of geothermal from 2005 to 2050.

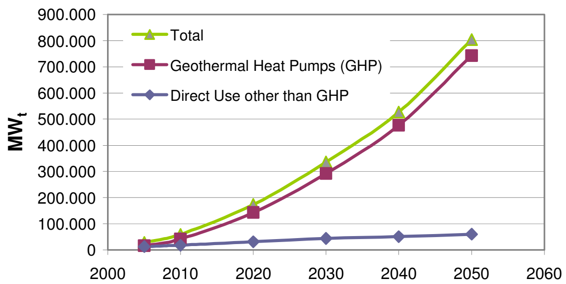

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Figure 16. Likely case scenario for growth in direct use and GHP installed capacity.

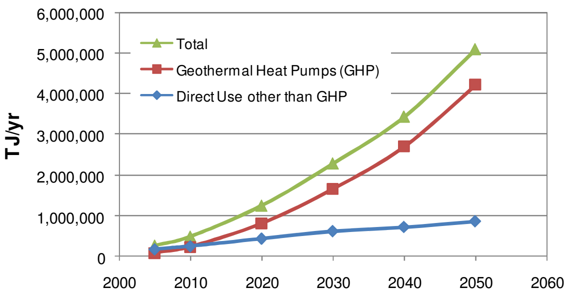

Figure 17. Likely case scenario for growth in direct use and GHP energy production.

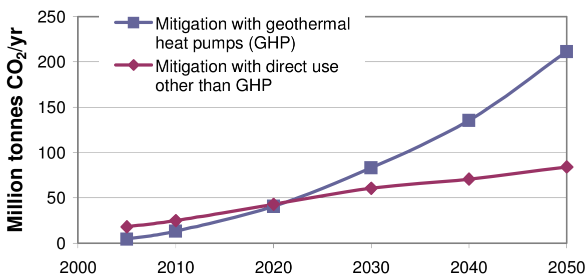

Figure 18. Mitigation potential of geothermal direct heating use in the world based on data in Table 5. The blue line shows the estimated mitigation from Geothermal Heat Pumps (GHP) assuming an emission of 50 tonnes CO_2-equivalent/TJ for GHP. The red line shows the estimated mitigation from direct heating use (other than GHP) assuming an emission of 4 tonnes CO_2-equivalent/TJ for direct use (without GHP). Both estimates are based on an emission of 100 tonnes CO_2-equivalent/TJ for fossil heat provision based on the life cycle analysis of Kaltschmitt (2000)

The mitigation potential of CO2 for the heat provision is large for GHPs as long as GHPs substitute fossil energy. Nevertheless, in the case of fossil provided electricity to drive the heat pump a production of 200 Million tons CO2/yr has to be taken into account to fulfil the 2050 goal of 4 Million TJ/yr GHP heat provision (see Figure 18). A scenario of a heat provision of nearly 1 Million TJ/yr by direct use of geothermal systems brings a mitigation potential of 100 Million tons CO2/yr with very low self emissions of CO2.

In the electricity sector, the geographical distribution of suitable high-temperature hydrothermal fields is more restricted and mainly confined to countries or regions on active plate boundaries or with active volcanoes. As mentioned earlier, geothermal power stations provide about 12% of the total electricity generation of the four countries Costa Rica, El Salvador, Guatemala and Nicaragua. Hydropower stations provide 48% of the electricity for the four countries, and wind energy 1%. With an interconnected grid, it would be easy to provide all the electricity for the four countries by renewable energy. The geothermal potential for electricity generation in Central America has been estimated at some 4,000 MWe (Lippmann 2002), and less than 500 MWe have been harnessed so far. With the large untapped geothermal resources and the significant experience in geothermal energy as well as hydropower development in the region, Central America may become an international example of how to reduce the overall emissions of greenhouse gases in a large region. Similar development can be foreseen in the East African Rift Valley, as well as in several other countries and regions rich in high-temperature geothermal resources.

As mentioned before, it is difficult to estimate the overall world-wide potential. With the present engineering solutions it is possible to increase from the extrapolated value of 11 GW for year 2010 up to a maximum of 70 GW. The gradual introduction of the aforesaid new developments may boost the growth rate with exponential increments after 10-20 years, thus reaching the global world target of 140 GW for year 2050 (Figure 4).

It should be pointed out that some of these "new technologies" are already proven and are currently spreading fast into the market, like the binary plant ("low temperature electricity production"), whereas the EGS are just entering the field demonstration phase to prove their viability.

The electricity production from geothermal sources is strongly related to the plant capacity factor. Since 1995, it has been continuously increasing from the initial value of 64% to the present one of 73%. Better technical solutions for the power plants improve their performances; the most advanced approaches for the resource development (reinjection, inhibitors against scaling/corrosion, better knowledge of the field performances and parameters using advanced geophysical surveys) will increase the capacity factor linearly to the limit of 90%, presently already reached by many geothermal fields in operation. The forecast for capacity, capacity factor and energy is presented in Table 6 and Figures 19 and 20.

Year	Installed Capacity (GW)	Electricity Production (GWh/yr)	Capacity Factor (%)
1995	6.8	38,035	64
2000	8.0	49,261	71
2005	8.9	56,786	73
2010	11	74,669	77
2020	24	171,114	81
2030	46	343,685	85
2040	90	703,174	89
2050	140	1,103,760	90

Table 6. World installed capacity, electricity production and capacity factor of geothermal power plants 1995-2005 and forecasts for 2010-2050.

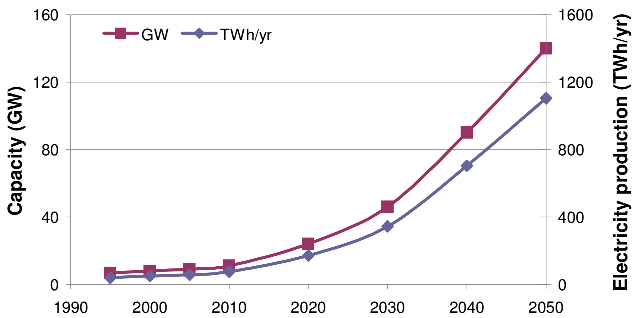

Figure 19. Installed Capacity and Electricity production 1995-2005 and forecasts for 2010-2050.

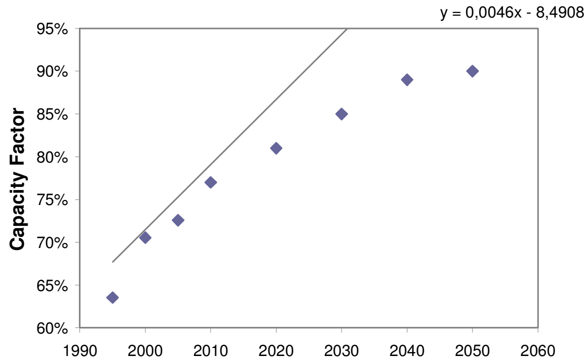

Figure 20. Capacity Factor of geothermal power plants in the world 1995-2005 and forecasts for 2010-2050

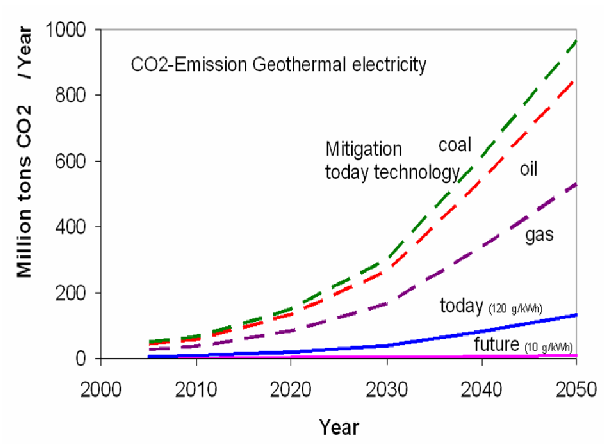

Figure 21. Mitigation potential of geothermal power plants in the world based on data of Table 6 and assumptions for emission of 120 g CO_2/ kWh for today and 10 g CO_2/ kWh for future technology.

Geothermal electricity production of about 100 TWh/yr in 2050 will mitigate (depending on what is substituted) hundreds of million tons CO_2/yr as given in Figure 21. Present technology with dominant open systems and release of emissions will produce some tens of million tons CO_2/yr, whereas future technology including reinjection will result in negligible emissions.

Geothermal sustainability

Geothermal energy is generally classified as a renewable resource, where "renewable" describes a characteristic of the resource: the energy removed from the resource is continuously replaced by more energy on time scales similar to those required for energy removal (Stefansson, 2000). Consequently, geothermal production is not a "mining" process. Geothermal energy can be used in a "sustainable" manner, which means that the production system applied is able to sustain the production level over long times. The longevity of production can be secured and sustainable production achieved by using moderate production rates, which take into account the local resource characteristics (field size, natural recharge rate, etc.).

It appears natural to define the term "sustainable production" as production which can be maintained for a very long time. In Iceland, a reference period of 100 – 300 years has been proposed (Axelsson et al., 2005), while in New Zealand production for a period longer than 100 years is considered sustainable (Bromley et al., 2006). Much longer time scales, such as time scales comparable to the lifetimes of geothermal resources, are considered unrealistic in view of the time scale of human endeavours.

The production of geothermal fluid/heat continuously creates a hydraulic/heat sink in the reservoir. This leads to pressure and temperature gradients, which in turn – after termination of production – generate fluid/heat inflow to re-establish the pre-production state. The regeneration of geothermal resources is a process, which occurs over various time scales, depending on the type and size of the production system, the rate of extraction, and on the attributes of the resource. This nature of recovery, or re-establishment, characterising geothermal resources contributes to their potential for sustainable use.

Time scales for re-establishing the pre-production state following the cessation of production have been determined using numerical model simulations for: 1) heat extraction by geothermal heat pumps, 2) the use of doublet systems on a hydrothermal aquifer for space heating, 3) the generation of electricity on a high enthalpy, two-phase reservoir, and 4) an enhanced geothermal system (for details see Rybach and Mongillo, 2006; Axelsson et al., 2005). The results show that after production stops, recovery driven by natural forces like pressure and temperature gradients begins. The recovery typically shows an asymptotic behaviour, being fast at the start and then slowing down subsequently, and theoretically taking an infinite amount of time to reach its original state. However, practical replenishment (e.g. 95%) will occur much earlier, generally on time scales of the same order as the lifetime of the geothermal production systems (Axelsson et al., 2005).

A good example of what appears to be (after 64 years of continuous production) a sustainable use of a low-temperature geothermal field is the Reykir field (Mosfellssveit), which has been used for district heating of Reykjavik, the capital of Iceland, since 1943 (Gunnlaugsson, 2003). Prior to drilling, the artesian flow of thermal springs was estimated about 120 l/s of 70-83 °C water. After drilling, about 200 l/s of 86 °C water was piped to Reykjavik for heating buildings (15 km). After 1970, the field was redeveloped with deep rotary drilling of large diameter wells and the installation of down-hole pumps. The yield from these wells then increased to 2000 l/s of 85-100 °C water. Figure 22 shows the production (in Gigaliters) and the water level in well MG-28 from 1983 to 2007. The water level was steadily decreasing until 1990, when it became possible to reduce pumping from the field as an additional geothermal field for Reykjavik started operation. Immediately after the reduction of production, the pressure built up and the water level rose again. Changes in the chemistry and temperature of the geothermal fluid have only been observed at the southeastern boundary of the field (Gunnlaugsson et al., 2000). This is the main production field for Reykjavik (see also Figure 15), which is the largest single geothermal district heating system in the world.

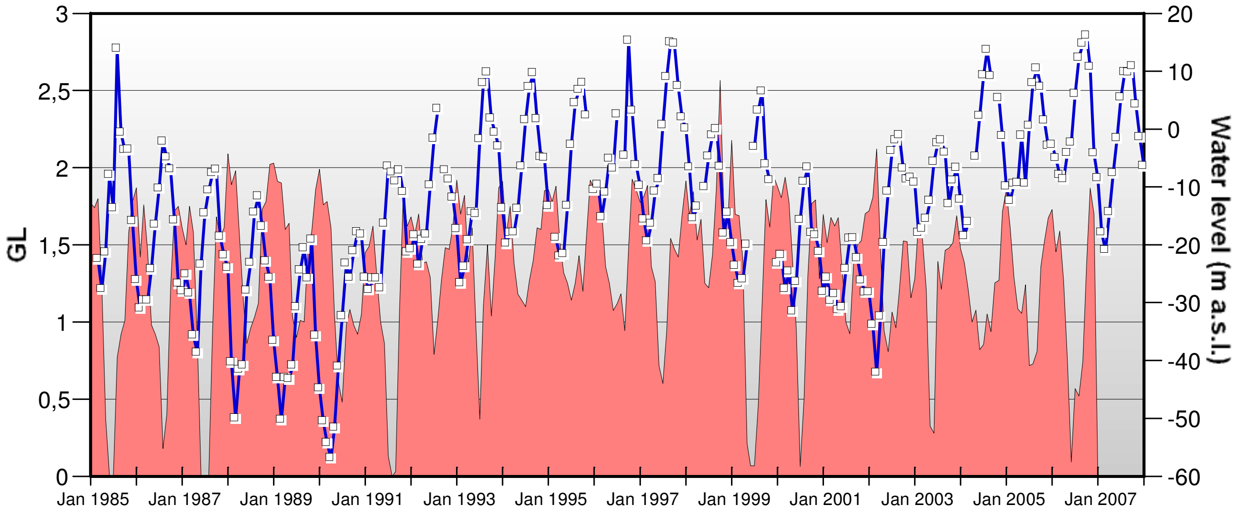

Figure 22. Production in Gigaliters (in red) from the Reykir low-temperature field and the water level (black line with data points) in well MG-28 (observation well) from 1985 to 2007 (Ivarsson, 2007).

There are similar examples of the sustainable use of hydrothermal systems in different geological environments in many countries (including large fields in sedimentary formations in China, where sustainability is only maintained by re-injection of the same amount of water as is being produced). Numerical model simulations have been carried out for the application of down-hole heat exchangers and heat pump applications.

Discussion of geothermal energy and other renewables

Renewable energy, which includes production from geothermal, wind, solar, biomass, hydroelectric and tide/wave/ocean sources, is gaining interest from politicians and developers due to global warming predictions and the high cost of oil. Putting geothermal energy in perspective with the other renewables, helps in the appraisal of its place in the market along with strengths and weaknesses of each renewable resource.

The overall consumption of different energy sources in the world is described by the Total Primary Energy Supply (TPES). It refers to the direct use at the source, or supply to users without transformation, that is energy that has not been subjected to any conversion or transformation process. The world TPES in 2005 was 11,435 Mtoe (million tonnes of oil equivalents, 1 Mtoe = 41,868 GJ), of which 12.7% came from renewable energy sources. The share of the different energy sources in the world renewable primary energy supply was as follows in 2004: Biomass 79.4%, hydropower 16.7%, geothermal energy 3.2%, wind energy 0.5% and solar/tide/ocean energy 0.3%. Since 1990, renewable energy sources have grown at an average annual rate of 1.9%, as compared to the world TPES of 1.8% per annum. Wind energy has had the highest growth rate of 24.4%; albeit, from a small base in 1990. The second highest growth rate was from non-solid biomass combustible renewables and waste, such as renewable municipal waste, biogas and liquid biomass, averaging 8.1% annually since 1990.

Looking at world electricity generation on its own the picture is quite different. This can be seen in Table 7, which shows the fuel shares in the world electricity generation 2004. That year the renewable energy share was 18.6% (mainly hydropower). This is a slightly lower share of the total electricity generation than in 1990. Since 1990 renewable electricity generation has grown on average 2.1% per annum worldwide which is lower than the total electricity generation growth rate of 2.8%. The growth of developing countries is expected to produce a doubling of the global electricity demand over the next 25 years, from 18,235 TWh in 2005.

The most important renewable energy source with respect to electricity generation is hydropower, which represents almost 89% of the total generation. This share is similar for all the continents except Europe, where wind energy plays a considerable role. Hydropower also has a significant share in the total electricity generation worldwide or 16.5%, with a growing rate of 2-5%. The largest markets are in the USA, Canada, Brazil, Norway and China.

Wind energy provides about 0.5% of world global electricity generation, with the most important countries being in Europe (Germany, Spain, and Denmark) and USA. A very aggressive growth rate of 15-20% is expected, mainly in the UK, China, India and Australia.

Geothermal Energy provides approximately 0.3% of the world global electricity generation, with a stable long-term growth rate of 5%. At present the largest markets are in the USA, Philippines, Mexico, Indonesia, Italy and Iceland. Future developments are limited to certain areas worldwide, particularly under current technologies.

Solar energy plays a very limited role in global electricity generation, but it has a very high growth rate of 25-30%, especially in the USA, Spain, China, Australia and India.

	GWh	%
Coal	6,944,328	39.61
Gas	3,418,676	19.50
Nuclear	2,738,012	15.62
Oil	1,170,152	6.67
Other sources	2,292	0.01
Non-renewables total	14,273,460	81.42
Hydro power	2,889,094	16.48
Biomass	149,811	0.85
Waste	77,471	0.44
Wind energy	82,259	0.47
Geothermal energy	55,896	0.32
Solar thermal energy	1,608	0.01
Solar PV energy	840	0.00
Tide, Wave, Oceanenergy	551	0.00
Renewables total	3,257,530	18.58
Total world generation	17,530,990	100.00

Table 7. Fuel shares in world electricity generation 2004 (International Energy Agency).

The present installed geothermal capacity of 10 GW is expected to increase up to 11 GW in 2010. Its investment costs are close to average, depending on the quality of the resource (temperature, fluid chemistry and thermodynamics phase, well productivity etc.), ranging from approximately 2 to 4.5 million euro/MWe, and its generation costs are very attractive, from 40 to 100 euro/MWh. It is a resource suitable for base load power. Geothermal electricity generation can be considered as broadly cost-competitive, despite its relatively high capital costs up front for development of the geothermal field (resource evaluation, mining risk, drilling and piping). Its availability is very high and the energy production stable. The next generation is expected to see the implementation of Enhanced Geothermal System (EGS) and an intensive increase in low-to-medium temperature applications through binary cycles and cascade utilisations. The potential of geothermal energy has barely been exploited, but its base-load capability is a very important factor for its success. The utilisation of binary plants and the possibility of production from enhanced geothermal systems (to be considered as possible future developments) can expand its availability on a worldwide basis

Among the other renewable energy resources, with hydro potential considered as already known utilised and without an important growth margin, only wind energy can be considered as a realistic competitor to geothermal energy. But they should not be considered as opponents, both resources can be developed where more convenient and where their presence has been assessed. Wind energy is more widely distributed, but it is not generally even throughout the day and its production is not easily predictable, especially considering the very fast climate changes worldwide.

Estimates for the future indicate a major growth in wind and solar electricity generation, and a slower growth in geothermal energy, hydroelectricity and biomass. Tide/ocean/wave energy is in its infancy with unknown growth. By 2010 the expected electrical generation capacity for wind energy is 74 GW, solar energy 20 GW and geothermal energy 11 GW. Hydroelectricity generation will primarily grow in non-OECD countries such as China, India, and in Latin America. Biomass growth will be strong, especially in OECD countries.

Each of the respective renewables has certain limitations; some are better suited for electric energy production and others for direct heating. Solar panels and wind mills can be easily installed and in a short period of time, whereas hydro power and geothermal energy tend to be more time consuming, especially large projects. Solar energy obviously depends on daytime sun light and night-time storage, wind can be intermittent and also depends on storage, hydropower is subject to drought and limited site, biomass depends on a supply of fuel and can contribute to greenhouses gases and particulate emission, tide and ocean energy is limited to areas where sufficient oscillations are available and where it does not interfere with navigation, and even though geothermal energy is base load for power and can supply the full load for heating, it is site specific. The development of the various renewable energy sources is not only dependent upon the technical aspects mentioned above, but are also influenced by the support (or lack of) from government policies and financial incentives. Thus, all renewables have limitations, but must be supported as they can complement each other. It is very important for the proponents of the various types of renewable energy to work together in order to find the optimal use of energy resources in the different regions of the world.

Conclusions

Geothermal energy is a renewable energy source that has been utilised economically in many parts of the world for decades. A great potential for an extensive increase in worldwide geothermal utilisation has been proven. This is a reliable energy source which serves both direct use applications and electricity generation. Geothermal energy is independent of weather conditions and has an inherent storage capability which makes it especially suitable for supplying base load power in an economical way, and can thus serve as a partner with energy sources which are only available intermittently. The renewable energy sources can contribute significantly to the mitigation of climate change and more so by working as partners rather than competing with each other.

Presently, the geothermal utilisation sector growing most rapidly is heat pump applications. This development is expected to continue in the future making heat pumps the major direct utilisation sector. The main reason for this is that geothermal heat pumps can be installed economically all over the world.

One of the strongest arguments for putting more emphasis on the development of geothermal resources worldwide is the limited environmental impact compared to most other energy sources. The CO_2 emission related to direct applications is negligible and very small in electricity generation compared to using fossil fuel.

The geothermal exploitation techniques are being rapidly developed and the understanding of the reservoirs has improved considerably over the past years. Combined heat and power plants are gaining increased popularity, improving the overall efficiency of the geothermal utilisation. Also, low-temperature power generation with binary plants has opened up the possibilities of producing electricity in countries which do not have high-temperature fields. Enhanced Geothermal Systems (EGS) technologies, where heat is extracted from deeper parts of the reservoir than conventional systems, are under development. If EGS can be proven economical at commercial scales, the development potential of geothermal energy will be limitless in many countries of the world.

A project for drilling down to 5 km into a reservoir with supercritical hydrous fluids at 450-600°C is under preparation (IDDP). If this project succeeds, the power obtained from conventional geothermal fields can be increased by an order of magnitude. This would mean that much more energy could be obtained from presently producing high-temperature geothermal fields from a smaller number of wells.

Likely case scenarios are presented in the paper for electricity production and direct use of geothermal energy, as well as the mitigation potential of geothermal resources 2005-2050. These forecasts need to be elaborated on further during the preparation of the IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation.

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The possible role and contribution of hydropower to the mitigation of climate change

Richard Taylor

Executive Director, International Hydropower Association (IHA)

Abstract

This keynote paper covers the current and potential roles of hydropower in climate change mitigation (and adaptation).

Introduction

This keynote paper covers the current and potential roles of hydropower in climate change mitigation (and adaptation). The paper includes brief descriptions on:

- Hydropower typology
- Market position
- Realistic potential
- Costs and financing
- Ongoing technical developments
- Current issues
- Building on the IPCC Fourth Assessment Report
- Key messages

Three additional sections are annexed, providing further background on recent developments relating to osmotic power, the greenhouse-gas status of freshwater reservoirs, and hydropower sustainability assessment.

I. Scope of application

The primary role of hydropower is electricity generation (although very small units can be used to drive machinery directly). Hydro powerplants can operate in isolation and supply independent systems, but most are connected to a transmission network.

Hydroelectricity is also used for space heating and cooling in several regions. Most recently hydroelectricity has also been used in the electrolysis process for hydrogen fuel production.

All scales of hydropower use the same fundamental processes of drawing energy from water. The technology is the same regardless of the size of the equipment. Compartmentalization into small and large tends to be for non-technical reasons.

The capacity of individual hydropower units ranges from 0.1 kW to 700 MW; annual generation ranges from 1000 kWh from the smallest of units, to the world record of 93.4 billion kWh delivered by the Itaipu powerplant (Brazil/Paraguay) in 2000.

The largest hydro powerplant in terms of capacity is the Three Gorges powerplant (China), nearing completion with 32 turbines totalling 22.4 million kW.

The typology of hydropower goes beyond scale. There is a range of 'head' and 'discharge' parameters determining the turbine design best suited to a particular site. Low-head sites will be utilized as 'run-of-river' schemes, exploiting the daily flow in a river. Often these flows are regulated by a storage reservoir upstream. Run-of-river schemes tend to operate continuously, providing 'base' load in much the same way as thermal plants.

Storage schemes manage water retained in a reservoir for a number of purposes, releasing water according to the demand, with the associated hydro plant generating base load and/or simply generating at times of peak demand. In addition, reservoirs can regulate flows for:

- downstream run-of-river hydro generation
- agricultural irrigation
- urban and industrial water supply
- environmental flows
- navigation

By managing a stock of water, reservoirs can provide security through drought seasons. Also, reservoirs can mitigate the impacts of floods by drawing down the operating level at the beginning of the flood season, thereby creating a retention capacity to store the peak flows of an incoming flood in order to attenuate the downstream impact. This will become an increasingly important service in the mitigation of the growing intensity of hydrological events associated with climate change in many areas. UNEP highlights that more dams will be needed in to help deal with water resource and agricultural needs in the future as the world faces environmental, developmental and energy crises (UNEP, 2007).

II. Market penetration

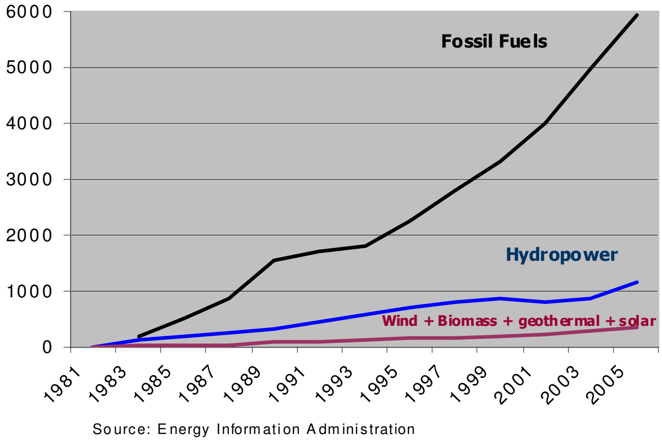
The world total of hydro generation in 2005 was 2,836 TWh, with an installed capacity of 778 GW (WEC, 2007). Some 30 GW of new capacity has been added in 2006/07 and this could be expected to bring the total up to around 3,000 TWh/year (Wilmington Media, 2007).

Hydropower, therefore, currently provides about 7% of global primary energy and 16% of total electricity supply. By capacity, hydro provides 87% of global renewable energy power generation. It is noted that the market share of fossil fuels continues to increase. Figure 1a below shows the growth in electricity generation over the last two decades. Figure 1b shows the growth in hydropower relative to the remaining set of renewable technologies.

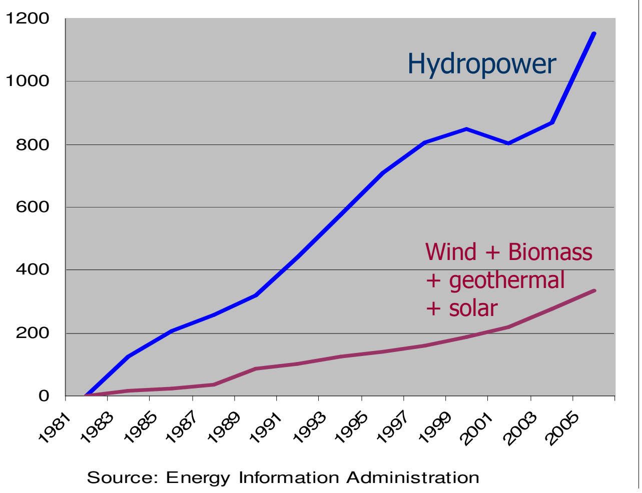
It is important to take into account more than just *capacity* and *annual generation* in assessing the value of a powerplant. The *plant factor* indicates the ratio of (full-capacity) hours that a plant operated against the total (8760) hours in a year. The *availability* indicates the proportion of time that a plant was capable of generating, if needed.

Figure 1: Growth in global electricity generation (TWh) (EIA, 2007)

a) Relative to fossil fuel generation



b) Relative to other renewables



If hydropower is playing a supporting role, backing up generation from other sources, it is likely to have a near 95% availability, but the plant factor may be as low as 10%.

Power markets offer a premium for the delivery of power when it is needed. Peak power demand and unexpected loss of supply from other sources require flexibility of operation. Hydropower units can be switched from standstill to full supply in very short periods of time, so they can be used to meet sudden demand. In a mixed system, thermal stations can be utilized to operate in a steady state (base load), at their best point of efficiency and, thus, minimum emissions per unit of power. Hydropower capacity is then dispatched to follow peaks in the demand. When there is a lack of 'pure' hydro in the system, pumped storage can be utilized. These schemes recycle all, or part of, the water utilized for generation (see below).

Hydropower can also provide the firming capacity for wind power. By storing potential energy in reservoirs, the inherent intermittent supply from wind power schemes can be supported by hydropower.

Hydro generation can also be managed to provide ancillary services such as voltage regulation and frequency control. With recent advances in 'variable-speed' technology, these services can even be provided in the pumping mode of reversible turbines.

There is currently a major effort in the hydro sector, especially in OECD countries, to increase storage capacity through new projects and the modification of existing schemes.

The growth rate of new hydro development in non-OECD countries continues to be around 10%. Hydro equipment manufacturing companies are reporting unprecedented volumes of orders. Figure 3 shows that the fastest growth in capacity is being seen in Asia, with Central and South America also seeing rapid growth.

Figure 2: Use of hydropower in mixed energy systems

Pumped storage in a mixed system with a thermal station [left]

Hydropower providing firming capacity for wind power [right].

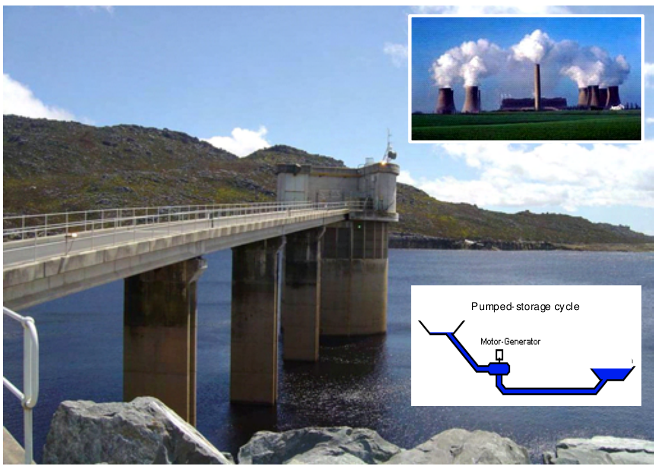
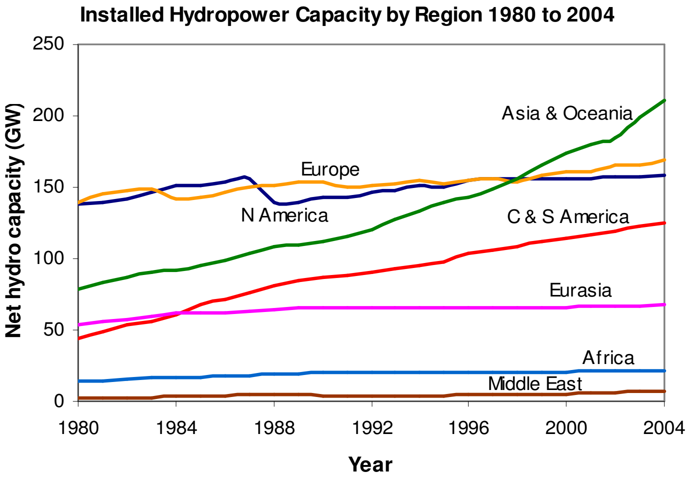


Figure 3: Growth in hydropower capacity by region (EIA, 2007)

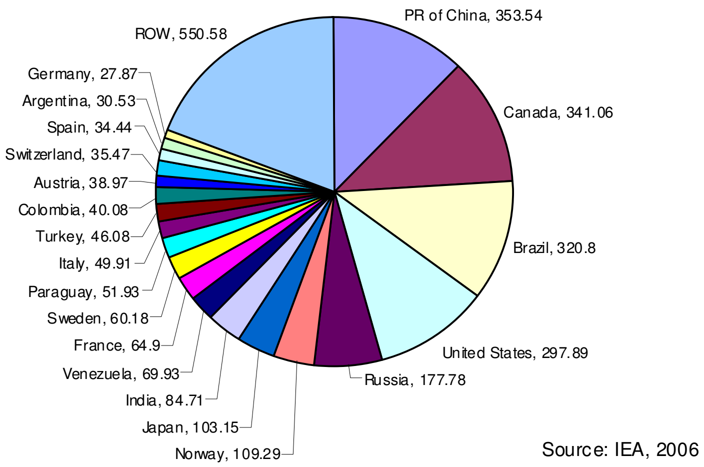


III. Potential, by region

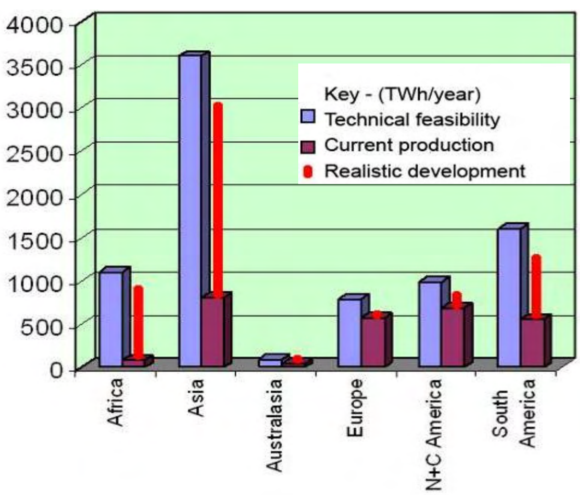
Hydro provides some level of power generation in 159 countries. Five countries make up more than half of the world's hydropower production: China, Canada, Brazil, USA and Russia.

Figure 4: Hydro generation and potential

a) Hydro generation, by country (2889 TWh in 2005) (IEA 2006)



b) Realistic future hydropower development, by region (IHA, 2007)



Taking Europe as a benchmark (current supply, plus ongoing development, versus technical potential), it is possible to establish a realistic potential. IHA estimates that only one-third of the global realistic potential has been developed.

Using this approach, it would be reasonable to expect a ten-fold increase of hydro in Africa, a three-fold increase in Asia, a doubling in South America, and an increase of about 10 to 15% in North America.

For North America, this would equate to an additional 16 GW of new capacity, of which 11 GW is identified in Canada. While this expansion will be determined by the needs of the North American market, future development in many less developed regions will rely more heavily on finding long-term funding mechanisms and appropriate partnerships. Figure 5 shows clearly that the bulk of the remaining realistic potential remains in the developing world. These are regions where increasing energy supply and access is vital for development, for example in Africa (WWF, 2006).

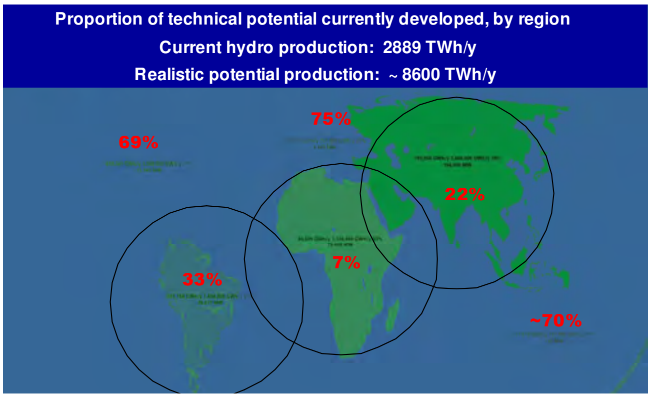


Figure 5: Proportion of technical potential currently developed, by region (IHA, 2007)

IV. Costs

A recent survey of hydropower developers confirmed that the costing of hydro development is quite site-specific. Low-head schemes tended to have higher costs than high-head developments. Economies of scale and the availability of national contractors and equipment suppliers also influence costs considerably. Installation costs tend to be in the range of US$ 1 million to >5 million per MW, with an average of <2 million/MW.

The methodology of calculating operating costs (including consideration of the cost of financing and depreciation), coupled with fluctuations in exchange rates, leads to uncertainty, but operating costs are estimated at US$ 3 to 10 per MWh. An approximation for annual operational costs is 0.8 to 2% of the installation cost.

Figure 6: Costs of hydropower development (IHA, 2007)

Project size (MW)	Development cost (US$ million/MW)	Operational cost (US$/MWh)
< 10	1 to >5	3 to 10
10 to 100	1 to 3	3 to 7
> 100	1 to 2.5	3 to 7

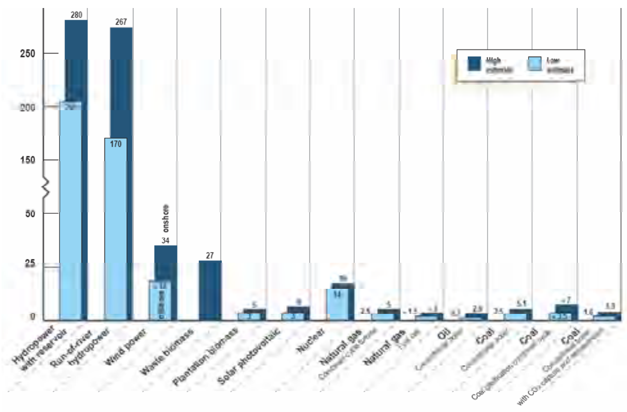
Different analyses have provided different cost ranges for hydropower, due to varying discount rates and other underlying assumptions (IPCC, 2007b)

V. Financing

Many economically feasible hydropower projects are financially challenged. High up-front costs are a deterrent for investment, despite zero fuel costs. The structural elements of a hydropower project tend to make up about 70% of the initial investment cost (UNWWAP, 2006). Also, hydro tends to have lengthy lead times for planning, permitting, and construction.

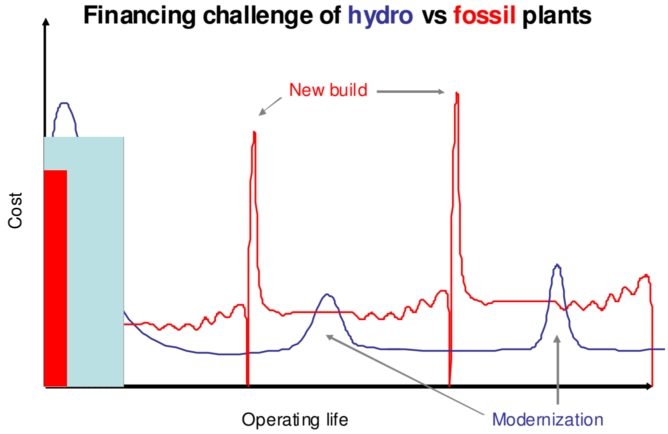
The operating life of a reservoir is normally expected to be in excess of 100 years. Equipment modernization would be expected every 30 to 40 years. In the evaluation of life-cycle costs, hydro often has the best performance by comparison with other generation technologies. This is due to annual operating costs being a fraction of the capital investment and the energy pay-back ratio being extremely favourable because of the longevity of the powerplant components (Figure 7).

Figure 7: Energy payback ratio of electricity generation technologies.



The development of more appropriate financing models is a major challenge for the hydro sector, as is finding the optimum roles for the public and private sectors. Figure 8 below provides a schematic interpretation of the contrast in required financial modelling between hydro and typical fossil-fuelled powerplants.

Figure 8: Financing challenge of hydro vs fossil plants (IHA, 2007)



The main challenges for hydro relate to creating private-sector confidence and reducing risk, especially prior to project permitting. Green markets and trading in emissions reductions will undoubtedly give incentives. Also, in developing regions, such as Africa, interconnection between countries and the formation of power pools are building investor confidence in these emerging markets. Feasibility and impact assessments carried out by the public sector, prior to developer tendering, will ensure greater private-sector interest in future projects.

VII. Relevant technical development

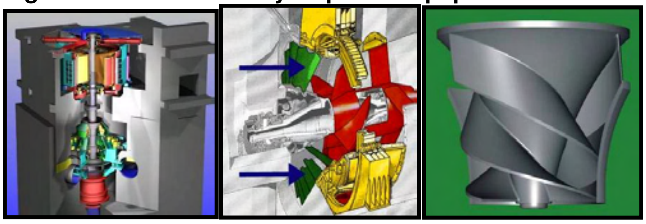
With hydropower technology, the challenge is to improve by continuously pushing the envelope in terms of operational range (head and discharge), environmental performance, materials, efficiency and costs.

Effort is also being applied to develop equipment to operate with even greater flexibility and in more difficult conditions/constraints. Some examples are shown in Figure 8 below.

From the smallest to the largest, all hydro developments have a footprint, especially when account is taken of the cumulative impact of a set of small schemes. Strategic planning and assessment are needed to optimize benefits and minimize impacts (UNEP, 2007). Smaller-scale hydro plays an important role in remote areas, community developments, and in maximizing the value of multi-purpose infrastructure. Larger schemes continue to be best suited to powering industrial and urban centres.

The least-cost option for producers desiring additional capacity is almost always to modernize existing plants, when this is an option. Equipment with improved performance can be retrofitted, often to accommodate market demands for more flexible, peaking modes of operation. Most of the ~800 GW of hydro equipment in operation today will need to be modernized in the next three decades.

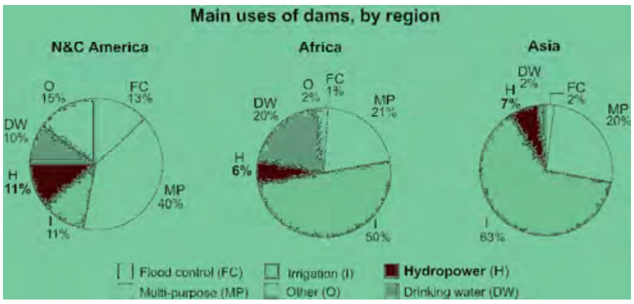
Figure 8: Advances in hydropower equipment



From left to right: variable speed technology; Straflo/Matrix technology, combining the turbine runner and generator rotor (courtesy of Andritz Hydro); and a 'fish-friendly' turbine concept (courtesy of the Alden Laboratories, USA).

There are many recent cases of incremental hydropower, both adding to current capacity and re-working existing water infrastructure to include entirely new hydropower facilities. There are 45,000 large dams in the world and the majority does not have a hydro component. While this is not always an economic option, there is a significant market niche in this area. For example, an initial study has indicated some 20 GW could be made available in the USA by adding hydropower capacity to 2,500 dams that currently have none (UNWWAP, 2006).

Figure 9: Main uses of dams, by region (ICOLD, 2003)



In addition, many hydropower companies are looking to develop expertise in ocean technologies such as wave, tidal and marine-current. It is assumed that these technologies will be covered separately. However it is worth mentioning the potential of technologies at the ocean/hydro interface; these include osmotic power (see Annex 1) and seawater pumped storage.

Special effort is also focused on refining the synergies between other renewables, as well as optimizing the performance of the existing stock of thermal powerplants, not just with wind but other renewable technologies, such as geothermal power generation (see Figure 11 below).

Figure 10: Ocean / hydro interface technologies

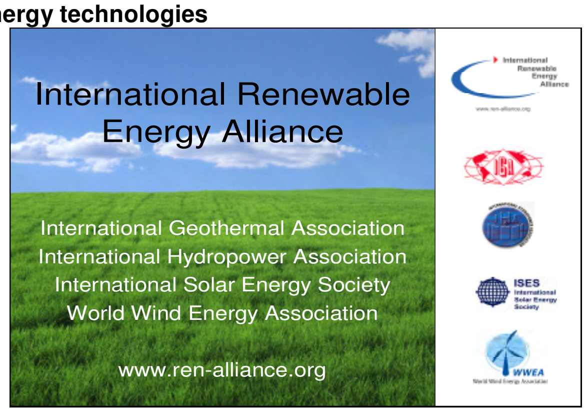
Norway's proposed prototype osmotic plant [top] & Japan's Okinawa pumped storage scheme.

Figure 11: Hydro and thermal power synergies in Iceland

The Háganga hydropower reservoir in the highlands of Iceland. Peaking operation of the hydro powerplants support baseload generation from the country's geothermal power stations. The example in the foreground [top] is the 60 MW Krafla plant in northern Iceland.

Work in collaboration with partner organizations dealing with a portfolio of renewables is seen as an essential step forward in the optimization of the contribution of renewables working in unison.

Figure 12: Promoting synergies between renewable energy technologies



VIII. Mitigation economics

Hydropower is clearly a key climate change mitigation technology.

compares the external costs of emissions per kWh for different power generation technologies. While the analysis also considers non-GHG emissions, the impact of GHGs causes the largest part of the external costs for the fossil fuel technologies (EU, 2005). By comparison, hydropower is shown to have the least emission costs out of all the technologies. This is based on a study of alpine hydropower plants, so may not apply to hydropower in other regions (see Annex 2).

Figure 13: External costs of electricity systems associated with operational and fuel-supply chain emissions (IPCC, 2007b).

Note: 'Rest' is the external cost related to the fuel cycle.

The IPCC (2007b) suggests that by 2030, hydropower could realistically lead to the avoidance of at least 0.87 $GtCO_2$ in global emissions by displacing fossil-fuel power generation. This would be at a maximum cost of US\$41/tCO_2 where mitigation is by new build in non-OECD countries. In contrast, 85% of the mitigation potential of hydropower in OECD countries by 2030 could be taken up at a profit of between 0 and US\$16/tCO_2.

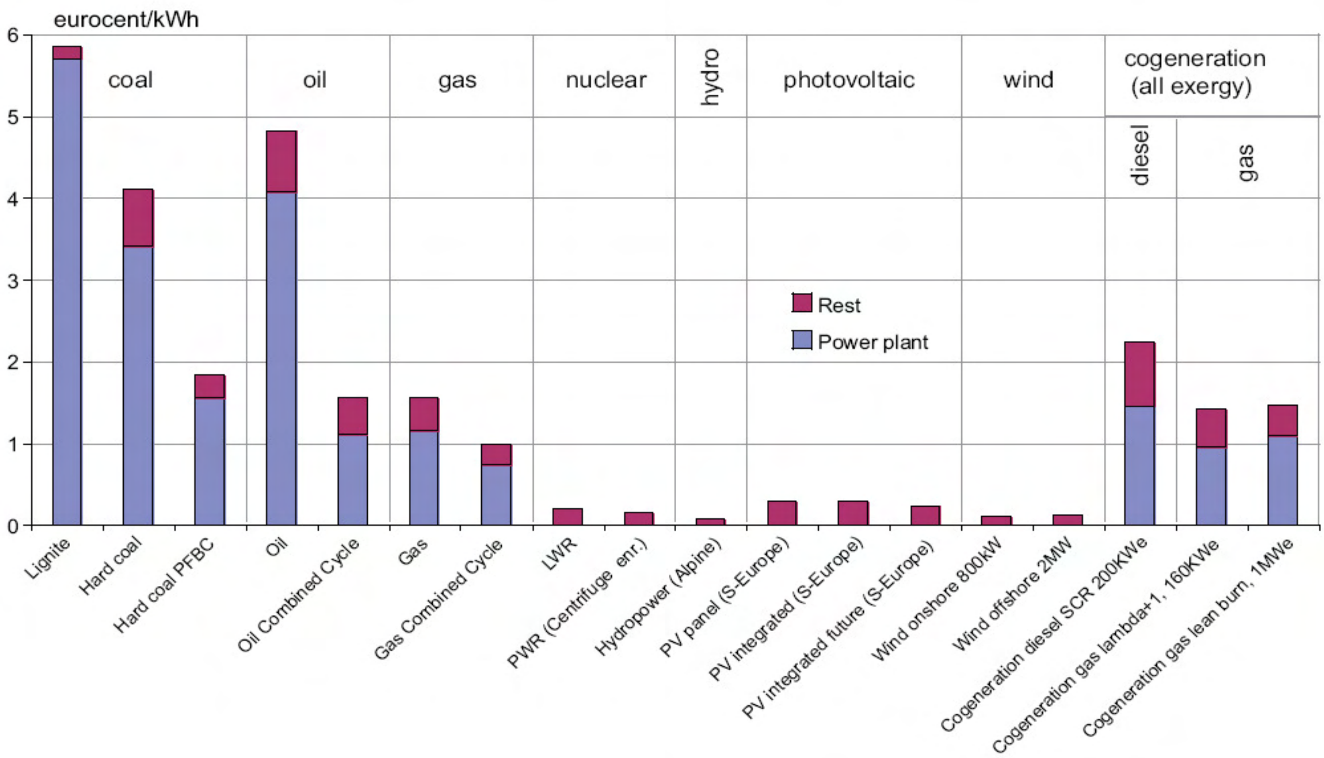
IX. Current issues

For hydropower the current issues under investigation are:

a) River-basin assessment of the impact of climate change on the established hydrological patterns. There has been some analysis at a regional level using macro hydrological models. For example, it was projected that by the 2070s there will have been an overall average decrease of 7 to 12% in hydropower production potential of Europe's currently existing capacity (IPPC, 2007a). There has been some analysis at a river basin level, but for limited areas and with varying results. For example, different models for the St Lawrence River projected differing outcomes associated with 2°C global warming: ranging from a 25-35% decline in hydropower generation to a 3% increase (IPCC, 2007a).

b) The greenhouse gas (GHG) footprint of freshwater reservoirs (in relation to the natural carbon cycle, see Annex 2).

c) Sustainability assessment of existing schemes and proposed new developments (see Annex 3).



X. Building on IPCC AR4

The main aspects that could complement the Fourth Assessment Report are:

d) Reduced uncertainty of the estimated renewables resource, including the impacts of climate change on these resources.
e) Further investigation of synergies between renewable technologies.
f) Greater understanding of the qualitative practicalities of supply.
g) Better understanding of offsetting (not all kWs are created equal).
h) An inclusive approach to energy pollution (not just considering GHGs).
i) Further analysis of the GHG footprint of each renewable technology.
j) Capacity building for accelerated renewables development in developing countries.

XI. Key messages

Currently, hydropower offsets the fossil-fuel equivalent of 13 million barrels of oil each day. It offsets several types of air pollution (not just GHG emissions). By working in unison, hydro can also directly reduce emissions from fossil-fuelled powerplants.

Hydro storage reservoirs provide reliability, flexibility of operation and energy storage, all of which are fundamental to modern power systems.
Where necessary, water can be recycled (by pumped storage) between reservoirs to capitalize on the flexibility of hydro generation.

Hydro can be developed in synergy with the complete family of renewables, thereby greatly improving the aggregate quality and security of supply.

Despite high upfront costs, hydro offers low and predictable operational costs.

Although it is not a panacea, hydro has significant untapped resources (only one third of the realistic potential has been developed).

The sector is investigating a sustainability standard, with guidelines established (IHA, 2006) (see Annex 3).
Hydropower does not consume the water it uses; by managing freshwater, it can make it available for multiple purposes. In this way it can contribute to adaptation to climate change (IPCC, 2007a).

Hydro also offers security against drought and protection against flood, thereby offering further climate change mitigation services.

Much of the remaining hydropower potential is in regions where new development is needed with a sense of urgency.

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Annex 1. – Osmotic power

Power production based on the osmotic pressure difference between waters with varying salt gradients

Osmotic power stands out as a promising, and yet unexploited, renewable energy source. It is considered possible to develop the necessary membrane technology and the building of the first osmotic power prototype plant is planned for 2008. There is a wide R&D programme involving research centres and commercial developers on three continents.

Background

Osmotic power is a relatively new energy conversion concept even though osmosis has been known for several hundred years. Only 30 to 35 years ago, Prof. Sidney Loeb and his team at UCLA proposed methods for the utilisation of osmotic pressure in power generation using membranes.

All the basic technology components necessary for efficient osmotic power production are available in principle. New and more energy efficient membrane technology has been developed during the last few years.

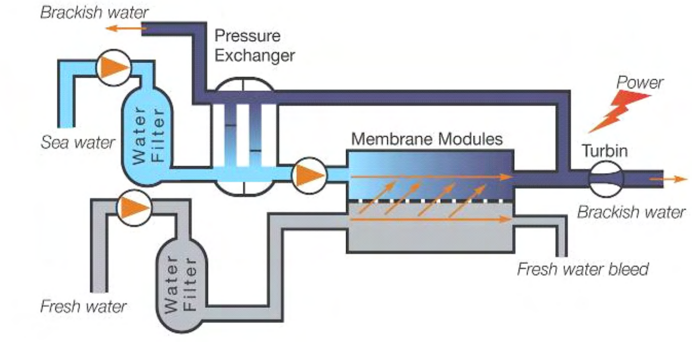
The commercial potential of osmotic power is identified and Statkraft, a North European electricity generator, is now planning to build an osmotic power plant prototype to further verify the osmotic power system.

The power of osmotic power

The principle of osmotic power is utilising the entropy of mixing water with different salt gradients. In this process water is transported spontaneously through a semi-permeable membrane (i.e. a membrane that retains the salt ions but allows water through) from the freshwater side to the water with the higher salt concentration, creating pressure due to osmotic forces. The increased pressure can be utilised in various forms, in this case to drive a turbine. Given a fixed volume compartment on the saltier side, the pressure will increase towards a theoretical maximum of 26 bars based on Atlantic sea water. This pressure is equivalent to a 270 metre high water column. We have found that pressure retarded osmosis (PRO) is the most promising method for production of this energy. The principle of a PRO osmotic power plant is sketched in figure below.

Given sufficient control of the pressure on the salty water side, approximately half the theoretical energy can be transformed to electrical power, making osmotic power a significant new source of renewable energy.

Figure 14: A simplified PRO osmotic power process diagram



The osmotic power process

In the PRO process, water with no or low salt gradient is fed into the plant (greyish) and filtered before entering the membrane modules. Such modules could contain spiral wound or hollow fibre membranes. In the module, 80 – 90 % of the water with low salt gradient is transferred by osmosis across the membrane into the pressurised salty water (bluish). The osmotic process increases the volumetric flow of high pressure water and is the key energy transfer in the power production process. This requires membranes with particularly high water flux and excellent salt retention properties.

- Osmotic power annex contributed by Jon Dugstad, Statkraft Development AS.

Annex 2. – GHG status of freshwater reservoirs

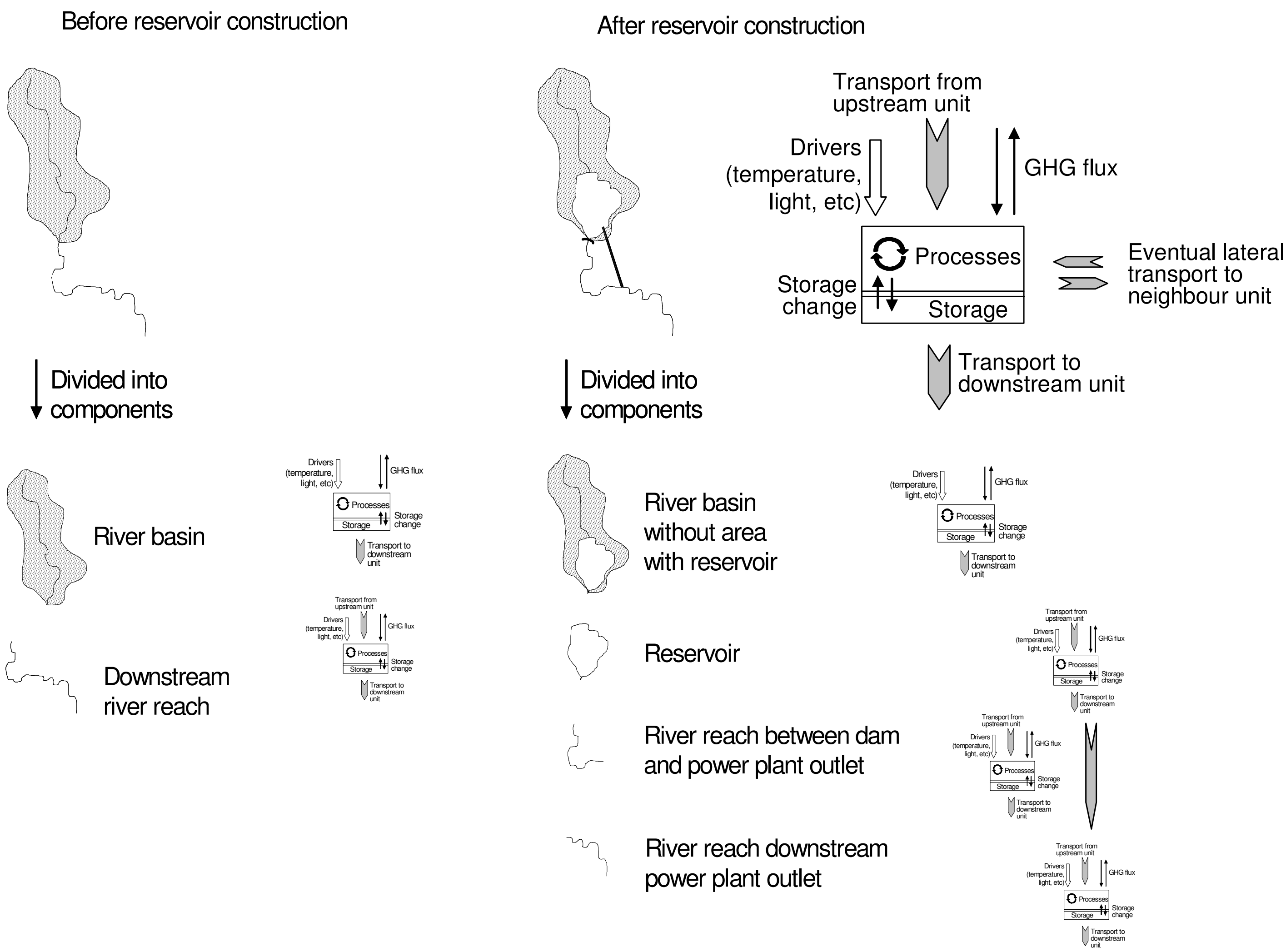
Research over the past two decades has determined that inland water bodies tend to play an important role in the natural carbon cycle. Water draining through catchments transports carbon which collects in rivers and lakes. Human activities, including agriculture, industry and urban areas, can add significantly to the carbon loading in a catchment. The introduction of a reservoir into a river basin could influence the natural exchange of carbon by changing the processes, leading to the carbon being returned to the atmosphere (and in what molecular format) and/or retained in sediment.

In cool and temperate climates, the level of GHG fluxes from the surface of inland water bodies is generally not considered to be significant. In tropical areas the natural processes are more active, with significantly higher natural carbon loading. Studies on some tropical reservoirs have indicated high levels of emissions from water surfaces, including both carbon dioxide and methane. There appears to be a correlation between carbon loading, water residence time and 'gross' GHG emissions. The challenge is the determination of any increment in the total emissions in the river basin as a result of the reservoir.

In collaboration with UNESCO, a scientific working group has been established to review the GHG status of freshwater reservoirs. Following two international workshops (2006 and 2007), the working group has been convened to produce a scoping report on the current understanding and to propose further steps to improve capability to evaluate the GHG footprint of freshwater reservoirs.

A schematic of a potential predictive model under consideration is shown in Figure 15 below.

Figure 15: Potential predictive model for GHG impact of reservoirs



Annex 3. – Hydropower sustainability assessment

With the collaboration of various civil-society organizations, government bodies and financing agencies, the International Hydropower Association has established the Hydropower Sustainability Assessment Forum. A summary of this initiative is given below.

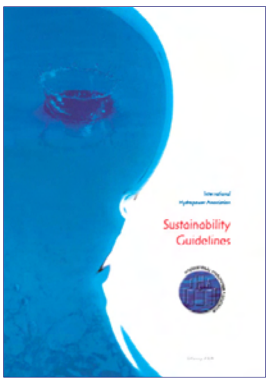
Goal:

Within a two-year period, establish a broadly endorsed sustainability assessment tool to measure and guide performance in the hydropower sector.

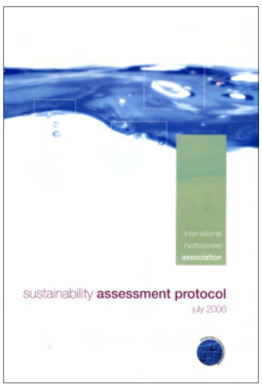
Process:

The Hydropower Sustainability Assessment Forum will carry out an expert appraisal of the ***Hydropower Sustainability Guidelines*** and ***Assessment Protocol***, as developed by the International Hydropower Association (IHA), with a view towards a future sustainability standard for the sector. Experts on environmental, social and economic/financing aspects will participate, along with representatives of developed and developing countries involved in hydropower. The membership of the Forum will be kept to a sufficiently small number to make its operations practical and focused; there will be two members for each category, including two IHA Officers. During its deliberations, the Forum will incorporate feedback from the current IHA reference group, and call on the networks of other Forum members, external expertise, including people affected by hydropower, to consult on specific issues. By seeking to operate by consensus, the goal of the first phase is to deliver an enhanced Protocol that can be endorsed by a range of key stakeholder organizations, and to make recommendations on pathways toward a sustainability standard.

IHA Sustainability Guidelines and Protocol



Adopted in 2004



Adopted in 2006

Output:

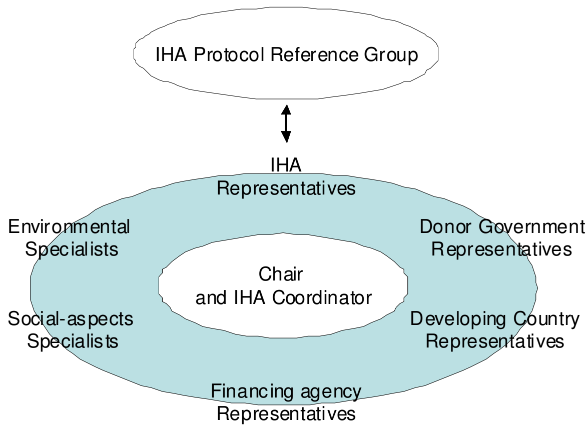
1. to deliver an enhanced Protocol that can be endorsed by a range of key stakeholder organizations, and
2. to make recommendations on pathways towards a sustainability standard for the hydropower sector.

Categories:

Six stakeholder categories will be represented in the Forum:

Environment
Civil Society
Finance/Economics
Developing country policy
Developed country policy
Hydropower sector

Hydropower Sustainability Assessment Forum



Ocean Energy: Position paper for IPCC

Hans Chr. Soerensen[1, 2] and Alla Weinstein[2]

[1] *Spok ApS, Wave Dragon ApS & Wave Dragon Ltd*
Blegdamsvej 4, DK 2200 Copenhagen N, Denmark
E-mail: hsorensen @eu-oea.com or hcs@wavedragon.net

[2] *European Ocean Energy Association*
Renewable Energy House, Rue d'Arlon 63-65, B-1040 Brussels, Belgium
E-mail: aweinstein@eu-oea.com

Abstract

This Paper summarise the state of the art for ocean energy used for electricity world wide.

Ocean Energy (OE) represents one of the largest renewable resources available on the planet. OE is an emerging industry that has a potential to satisfy world-wide demand for electricity, water and fuels, when coupled with secondary energy conversation principles.

OE represents a number of energy conversion principles:

- Wave energy is represented by surface and subsurface motion of the waves;
- Hydrokinetic energy that harvests the energy of ocean currents and tides;
- Ocean thermal energy conversion uses the temperature differential between cold water from the deep ocean and warm surface water;
- Osmotic energy is the pressure differential between salt and fresh water.

The OE generating potential has not been reported by IPCC in prior reports.

I. Energy Potential

The theoretical global resource is estimated to be in the order of:

- 8,000 - 80,000 TWh/year for wave energy;
- 8,800 TWh/year for tidal current energy;
- 2,000 TWh/year for osmotic energy;
- 810,000 TWh/year for ocean thermal energy

This has to be compared to the Worlds electricity consumption of 16,000 TWh/year

I.

II. State of the Art

OE is an emerging industry. To date there are few operational OE systems around the world. The primary example of an OE generating facility is the tidal barrage system at La Rance, France that has an installed capacity rating of 240 MW and produces on average 600 GWh/year without any impact on climate change since 1966. Other operational systems are much smaller (5 MW China, 20 MW Canada).

The state of the art of the OE sector has advanced significantly over the last 5 years. A number of large scale test installations are either developed or under development today.

Considering the harsh marine environment, design of OE systems has to address significant technical challenges, those to achieve high reliability, low cost and safety.

At present there is no commercially leading technology amongst ocean energy conversion systems. In contrary to wind it is expected that different principle of energy conversion will be utilised at various locations to take advantage of the variability of ocean energy resource.

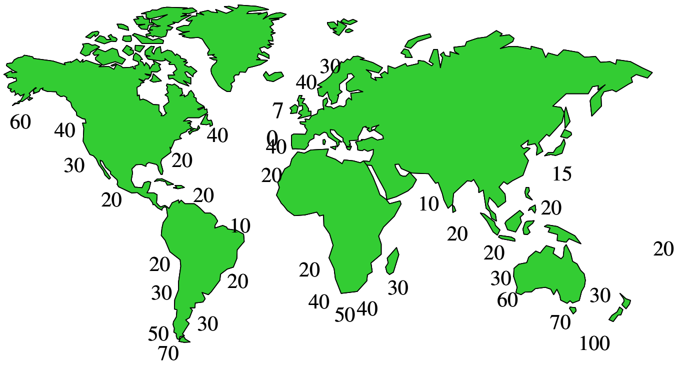


Figure 1: The highest wave activity (kW/m) is found between the latitudes of ~30° and ~60° on both hemispheres.

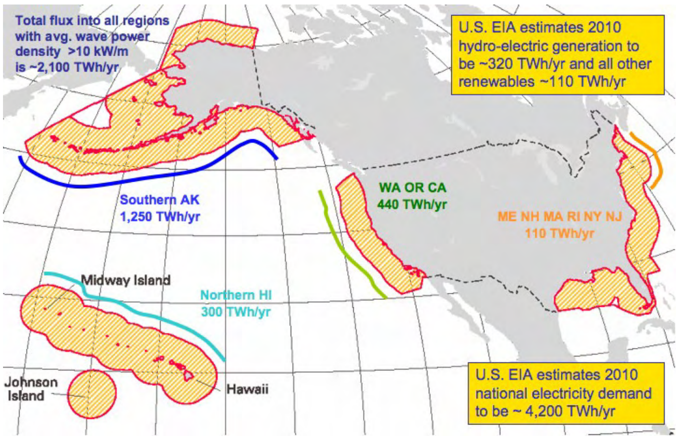


Figure 2: The wave energy potential expressed in potential electricity production (TWh) at the coasts of US.

Figure 3: The tidal range in meters.

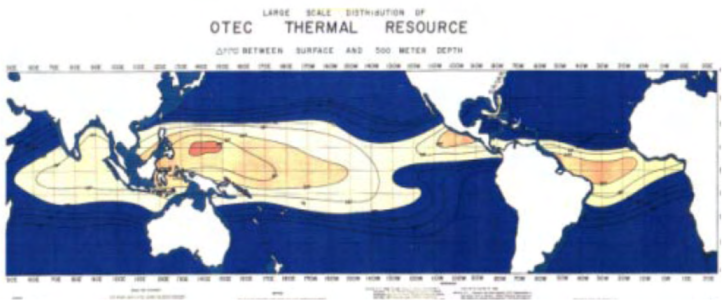


Figure 4: Ocean Thermal world-wide resource.

Wave Energy Installations:

- 0.4 MW and 0.5 MW Oscillating Water Column plants off the islands of Pico and Islay;
- 0.2 MW AquaBuOY of the coast of Oregon, USA;
- 2.25 MW Pelamis of the coast of Portugal by 2008;
- 7 MW Wave Dragon of Wales coast by 2008-2009;

Tidal:

- Barriers: 240 MW La Range by 1966, 20 MW Canada, 5 MW China
- Current: 1 MW MCT of North Ireland by 2007-2008

Ocean Thermal:

- • 0.2 MW Hawaii 1993 -1998

III. Wave Energy

Among different types of ocean energy, wave energy represents the highest density resource. Processes in the ocean concentrate solar and wind energy that in turn create waves as winds blow across the oceans. This energy transfer provides a natural storage of wind energy in the water near the surface. Once created, surface waves travel thousands of kilometres with little energy losses, unless they encounter head winds. Nearer the coastline the wave energy intensity decreases due to interaction with the seabed. Energy dissipation near shore can be compensated by natural phenomena as refraction or reflection, leading to energy concentration ("hot spots").

Ocean waves encompass two forms of energy: the kinetic energy of the water particles, which in general follow circular paths; and the potential energy of elevated water particles. On the average, the kinetic energy in a linear wave equals its potential energy. The energy flux in a wave is proportional to the square of the amplitude and to the period of the motion. The average power in long period, large amplitude waves commonly exceeds 40-50 kW per meter width of oncoming wave.

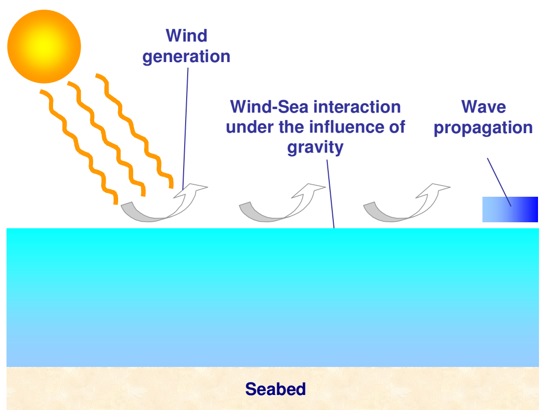


Figure 5: Ocean waves are generated by the wind.

As most forms of renewables energy sources, wave energy is unevenly distributed over the globe. Increased wave activity is found between the latitudes of ~30° and ~60° on both hemispheres, induced by the prevailing western winds blowing in these regions. Particularly high resources are located along the Western European coast, off the coasts of Canada and the USA and the south-western coasts of Australia, New Zeeland, South America and South Africa.

Situated at the end of the long fetch of the Atlantic, the wave climate along the western coast of Europe is highly energetic. Higher wave power levels are found only in the southern parts of South America and in the Antipodes. Resource studies assign for the area of the north-eastern Atlantic (including the North Sea) available wave power resource of about 290 GW and for the Mediterranean 30 GW. The similar figure for the west coast of United States is 150 GW.

Principles and Aspects of Wave Energy Conversion

In contrast to other renewable energy sources the number of concepts for wave energy conversion is very large. Although over 4,000 wave energy conversion techniques have been patented worldwide, the apparent large number of concepts for wave energy converters can be classified by its basic principles of energy conversion:

- Oscillating Water Columns are partially submerged, hollow structures open to the seabed below the water line. The heave motion of the sea surface alternatively pressurizes and depressurises the air inside the structure generating a reciprocating flow through a turbine installed beneath the roof of the device.
- Overtopping devices, floating or fixed to the shore, that collect the water of incident waves in an elevated reservoir to drive one or more low head turbines.
- Heaving devices (floating or submerged) mechanical and/or hydraulic convert up and down motion of the waves into linear or rotational motion to drive electrical generators.
- Pitching devices consist of a number of floating bodies hinged together across their beams. The relative motions between the floating bodies are used to pump high-pressure oil through hydraulic motors, which drive electrical generators.
- Surging devices exploit waves' horizontal particle velocity to drive a deflector or to generate pumping effect of a flexible bag facing the wave front.

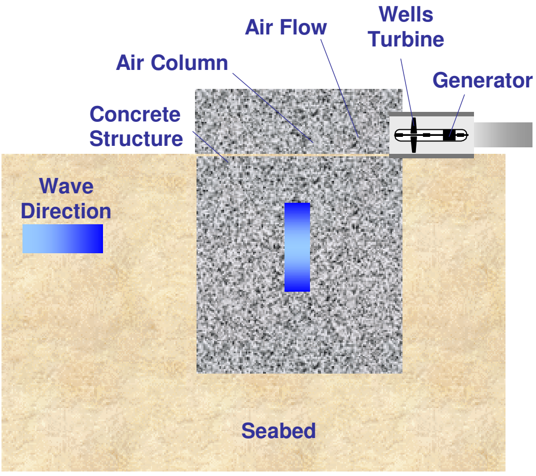


Figure 6: Oscillating water column type of wave device.

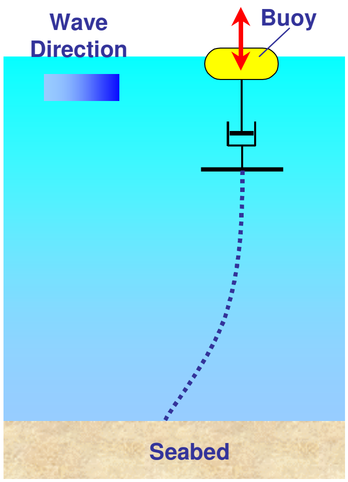


Figure 7: Buoy type of wave device.

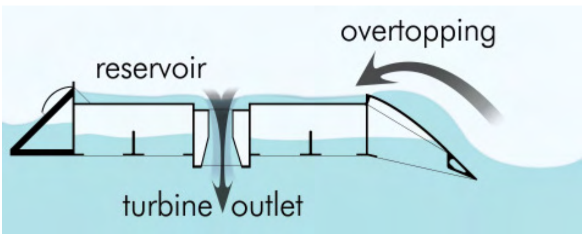


Figure 8: Overtopping type of wave device

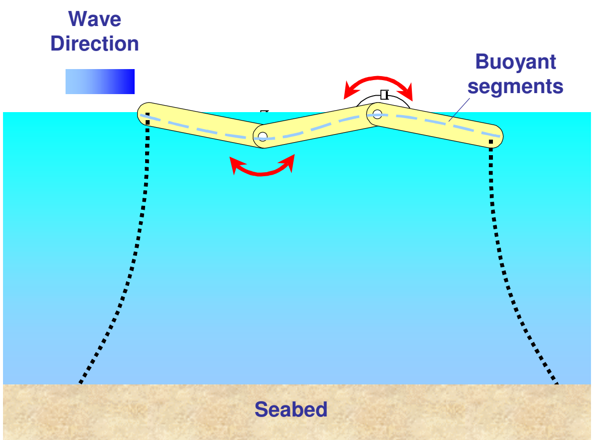


Figure 9: Pitching type of wave device

It is important to appreciate the challenges facing wave power developments:

- Irregularity in wave amplitude, phase and direction makes it difficult to obtain maximum efficiency over the entire range of excitation frequencies.
- The structural loading in the event of extreme weather conditions, such as hurricanes, may be as high as 100 times the average loading.
- The coupling of the irregular, slow motion (~0.1 Hz) of a wave to electrical generators typically requires a 500 times increase is frequency.

Obviously the design of a wave power converter has to be highly sophisticated to be reliable and safe on the one hand, and economically feasible on the other. The abundant resource and the high-energy fluxes in the waves prescribe economically viable energy production. One of the important advantages of wave energy technologies is their environmental compatibility, as wave energy conversion is generally free of green house emissions. Also, the low visual and acoustic impact, particular of offshore or submerged devices, provides a significant advantage.

The negligible demand of land use is an important aspect. As for most renewable energy sources, the in-situ exploitation of wave energy implies diversification of employment and security of energy supply in remote regions. Furthermore, the large-scale implementation of wave power technologies will stimulate declining industries, e.g. shipyards, and promote job creation in small and medium-sized enterprises.

Wave Energy Development Status

Wave energy conversion is being investigated in a number of countries, particularly in the member States of the European Union, Canada, China, India, Japan, Russia, the USA and others. Although the first patent on wave energy conversion was issued as early as 1799, the significant research and development of wave energy conversion began after the oil crisis of 1973.

In the last five years there has been a resurgent interest in wave energy, especially in Europe. Nascent wave energy companies have been highly involved in the development of new wave energy converters such as the Pelamis, the Archimedes Wave Swing, AquaBuOY, Oceanlinx or the Wave Dragon.
The predicted electricity generating costs from wave energy converters have improved significantly in the last twenty years. It is projected that energy generated by wave energy installation can reach an average price below 10 c€/kWh by 2020. Compared, e.g., to the

average electricity price in the European Union, which is approx. 4 c€/kWh, the electricity price produced from wave energy is still high, but it is forecasted to decrease further with the development of the technologies.

Wave energy installation will consist of farms of wave energy converters, interconnected together to reach the desired farm capacity. Modularity of systems allows for gradual build-out of wave energy farms.

IV. Tidal Energy

Tidal energy conversion techniques exploit the natural rise and fall of the level of the oceans caused principally by the interaction of the gravitational fields in the planetary system of the Earth, the Sun and the Moon. The main periods of these tides are diurnal at about 24 h and semidiurnal at about 12 h 25 min. During the year, this motion is being influenced by the positions of the three planets with respect to each other. Spring tides occur when the tide-generating forces of the Sun and the Moon are acting in the same directions. In this situation, the lunar tide is superimposed to the solar tide. Some coastlines, particularly estuaries, accentuate this effect creating tidal ranges of up to ~17 m. Neap tides occur when the tide-generating forces of the sun and the moon are acting at right angles to each other.

The vertical water movements associated with the rise and horizontal water motions termed tidal currents accompany fall of the tides. It has therefore to be distinguished between:

- <u>Tidal range energy</u>, make use of the potential energy from the difference in height (or head) between high and low tides, and
- <u>Tidal current energy</u>, the kinetic energy of the water particles in a tide or in an marine current.

Tidal currents have the same periodicities as the vertical oscillations, being thus predictable, but tend to follow an elliptical path and do not normally involve a simple to-and-fro motion. Where tidal currents are channelled through constraining topography, such as straits between islands, very high water particle velocities can occur. These relatively rapid tidal currents typically have peak velocities during spring tides in the region of 2 to 3 m/s or more.

Currents are also generated by winds, and temperature and salinity differences. The term “marine currents”, often met in literature, encompasses several types of ocean currents. Wind driven currents affect the water at the top of the oceans, down to about 600-800 m. Currents caused by thermal and salinity gradients are normally slow, deep water currents, that begin in the icy waters around the north polar ice. Wind driven currents appear to be less suitable for power generation than marine currents, as they are in general slower. Usually, tidal currents exhibit their maximum speed at fairly shallow waters, making them accessible for large engineering works.

The global tidal range energy potential is estimated to be about 3 TW, about 1 TW being available at comparably shallow waters. Within the European Union, France and the United Kingdom have sufficiently high tidal ranges of over 10 metres. Beyond the European Union, Canada, the CIS, Argentina, Western Australia and Korea have potentially interesting sites, which have been periodically investigated. Some regions with exceptional tidal range are shown on Figure 3 1 (annual average tidal range in meters).

Recent studies indicate that marine currents have the potential to supply a significant portion of future electricity needs. The resource potential of the European marine current is estimated to exceed 12,000 MW of installed capacity. Locations with especially intense currents are found around the British Islands and Ireland, between the Channel Islands and France, in the Straits of Messina between Italy and Sicily, and in various channels between the Greek islands in the Aegean. Other large marine current resources can be found in regions such as South East Asia, both the east and west coasts of Canada and certainly in many other places around the Globe.

Tidal Range Energy

The principle of conversion of tidal range into electricity is very similar to the technology used in traditional hydroelectric power plants. The first requirement is a dam or "barrage" across a tidal bay or estuary. At certain points along the dam, gates and turbines are installed. When there is an adequate difference in the elevation of the water on the different sides of the barrage, the gates are opened. The "hydrostatic head" that is created, causes water to flow through the turbines, turning an electric generator to produce electricity.

Tidal range energy conversion technology is considered mature, but, as with all large civil engineering projects, technical and environmental risks require attention. Some environmental impacts are associated with the changes of water levels that would modify currents, the sediment transport and deposits. However, there are regional development benefits as well, for example the La Rance plant in France, the only commercial sized tidal range conversion scheme so far, includes a road crossing linking two previously isolated communities and has allowed further development of the distribution network for raw materials and developed products.

Tidal Current Energy

Tidal currents can be harnessed using technologies similar to those used for wind energy conversion, i.e. turbines of horizontal or vertical axis ("cross flow" turbine). Some other techniques have either been abandoned or are at an early stage of development.

Several types of tidal current conversion devices, particularly fully submerged devices, are subject to the corrosive effects of seawater. Maintenance requires divers to access submerged machinery. While placing the drive train above water can minimize the need for divers, maintenance costs would remain higher than e.g. in wind turbines.

In contrast to atmospheric airflows the availability of tidal currents can be predicted very accurately, as their motion will be tuned with the local tidal conditions. Because the density of water is some 850 times higher than that of air, the power intensity in water currents is significantly higher than in airflows. Consequently, a water current turbine can be built considerably smaller than an equivalent powered wind turbine.

Tidal current devices are projected to have limited environmental impact. Their installation requires minimal land use, and fully submerged devices will not affect optically or acoustically their surroundings. Their effects on flora or fauna have not been studied extensively yet, but it is unlikely that they will be of significance. Finally, submerged marine current converters are considered to operate in safe environment: disturbances caused by extreme weather conditions are significantly attenuated to the depths of about 20-30 metres where the devices will normally operate.

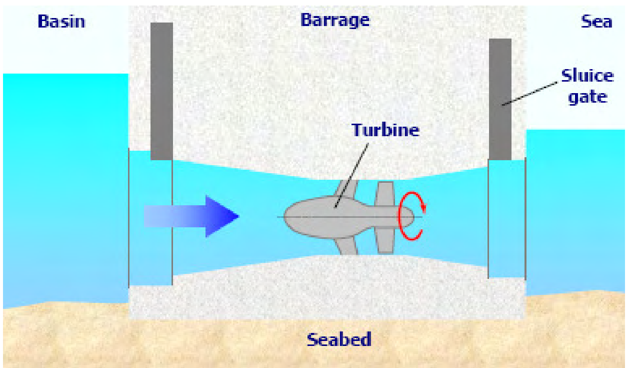


Figure 9: Tidal barrage type of tidal device.

V. Ocean Thermal Energy

A process called Ocean Thermal Energy Conversion (OTEC) uses the heat energy stored in the Earth's oceans to generate electricity.

OTEC works best when the temperature difference between the warmer, top layer of the ocean and the colder, deep ocean water is about 20°C (36°F). These conditions exist in tropical coastal areas, roughly between the Tropic of Capricorn and the Tropic of Cancer. To bring the cold water to the surface, OTEC plants require an expensive, large diameter intake pipe, which is submerged a mile or more into the ocean's depths.

Some energy experts believe that if it could become cost-competitive with conventional power technologies, OTEC could produce billions of watts of electrical power.

History

OTEC technology is not new. In 1881, Jacques Arsene d'Arsonval, a French physicist, proposed tapping the thermal energy of the ocean. But it was d'Arsonval's student, Georges Claude, who in 1930 actually built the first OTEC plant in Cuba. The system produced 22 kilowatts of electricity with a low-pressure turbine. In 1935, Claude constructed another plant aboard a 10,000-ton cargo vessel moored off the coast of Brazil. Weather and waves destroyed both plants before they became net power generators. (Net power is the amount of power generated after subtracting power needed to run the system.)
In 1956, French scientists designed another 3-megawatt OTEC plant for Abidjan, Ivory Coast, West Africa. The plant was never completed, however, because it was too expensive.

The United States became involved in OTEC research in 1974 with the establishment of the Natural Energy Laboratory of Hawaii Authority. The Laboratory has become one of the world's leading test facilities for OTEC technology.

In 2004 Japan moved away from their work in the field of wave energy and directed all their research and development efforts to OTEC. While wave energy resources are marginal, Japan has a good OTEC resource.

The types of OTEC systems include the following:

Closed-Cycle

These systems use fluid with a low-boiling point, such as ammonia, to rotate a turbine to generate electricity. Warm surface seawater is pumped through a heat

exchanger where the low-boiling-point fluid is vaporized. The expanding vapor turns the turbo-generator. Cold deep-seawater—pumped through a second heat exchanger—condenses the vapor back into a liquid, which is then recycled through the system.
In 1979, the Natural Energy Laboratory and several private-sector partners developed the mini OTEC experiment, which achieved the first successful at-sea production of net electrical power from closed-cycle OTEC. The mini OTEC vessel was moored 1.5 miles (2.4 km) off the Hawaiian coast and produced enough net electricity to illuminate the ship's light bulbs and run its computers and televisions.
In 1999, the Natural Energy Laboratory tested a 250-kW pilot OTEC closed-cycle plant, the largest such plant ever put into operation.

Open-Cycle

These systems use the tropical oceans' warm surface water to make electricity. When warm seawater is placed in a low-pressure container, it boils. The expanding steam drives a low-pressure turbine attached to an electrical generator. The steam, which has left its salt behind in the low-pressure container, is almost pure fresh water. It is condensed back into a liquid by exposure to cold temperatures from deep-ocean water.
In 1984, the Solar Energy Research Institute (now the National Renewable Energy Laboratory) developed a vertical-spout evaporator to convert warm seawater into low-pressure steam for open-cycle plants. Energy conversion efficiencies as high as 97% were achieved.
In May 1993, an open-cycle OTEC plant at Keahole Point, Hawaii, produced 50,000 watts of electricity during a net power-producing experiment.

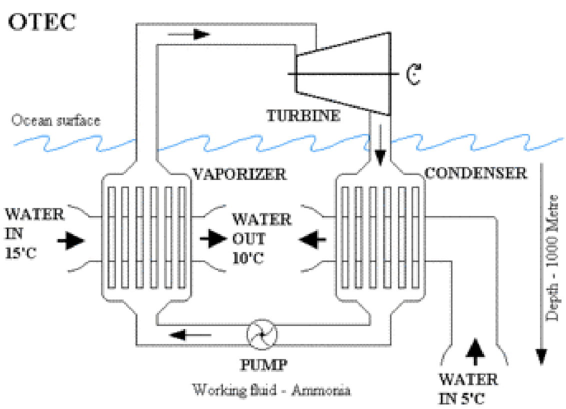


Figure 10: Diagram of a closed cycle Ocean Thermal Energy Conversion plant

Hybrid

These systems combine the features of both the closed-cycle and open-cycle systems. In a hybrid system, warm seawater enters a vacuum chamber where it is flash-evaporated into steam, similar to the open-cycle evaporation process. The steam vaporizes a low-boiling-point fluid (in a closed-cycle loop) that drives a turbine to produce electricity.

VI. Ocean Osmotic Energy

Exploiting the pressure difference at the boundary between freshwater and saltwater can capture energy. This is called Osmotic Energy. The difference of potential between freshwater and salt water is called the Salinity Gradient. The potential for osmotic energy exists wherever a stream or river enters the ocean.

Most people are familiar with reverse osmosis where freshwater is obtained from saltwater. Reverse osmosis consumes energy and produces freshwater from seawater. Osmosis consumes freshwater in the presence of seawater and produces energy (the freshwater becomes saltwater).

The principle of salinity gradient energy is the exploitation of the entropy of mixing freshwater with saltwater. The potential energy is large, corresponding to 2.6 MW m3/sec when freshwater is mixed with seawater.
Several methods have been proposed to extract this power. Among them are the difference in vapor pressure above freshwater and saline water and the difference in swelling between fresh and saline waters by organic polymers. However, the most promising method is the use of semi-permeable membranes. The energy can then be extracted as pressurized brackish water by pressure retarded osmosis (PRO) or direct electrical current by reverse electro dialysis (RED).

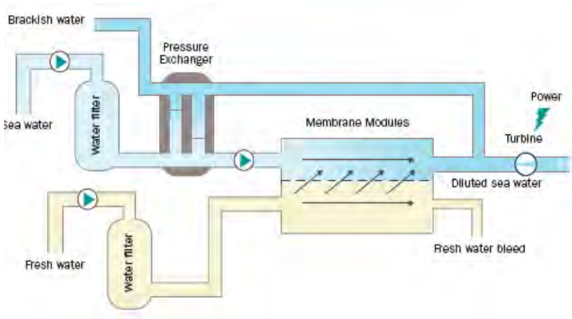


Figure 11: Diagram of pressure retarded osmosis (PSO) process using salinity gradients.

With the RED method, ion selective membranes are used in alternate chambers with freshwater and seawater, where salt ions migrate by natural diffusion through the membranes and create a low voltage direct current. With the PRO method, another type of membrane, similar to reverse osmosis membranes used for sea water desalination, is used. These PRO method membranes are much more permeable to water than to salt. If fresh and saltwater are separated by such membranes, natural osmosis will force the freshwater through the membrane to the saltwater side where hydrostatic pressure up to 26 bars can be created. The two methods are quite different in their working principles, but it is the same potential energy that is exploited.

Salinity power represents sufficiently large sources of renewable energy that is yet to be exploited. The resource potential world-wide is estimated to be 2,000 TWh annually. One of the reasons that this renewable source has not drawn more attention is that it is not readily evident to most people. Another reason is that considerable technological development is necessary to fully utilize this resource. Along with the lack of efficient and suitable plant components, some pessimistic cost forecasts have been issued. The potential cost of energy from this source is higher than most traditional hydropower, but is comparable to other forms of renewable energy that are already produced in full-scale plants.

VII. Socio Economic and Environment Impact

The creation of an ocean energy industry could lead to a significant increase in jobs that is estimated to be in the range of 10 – 20 jobs/MW in coastal regions.

Like any electrical generating facility, an OE power plant will affect the environment in which it is installed and operates. There is no actual environmental effects data available at this time, however a number of the Environmental Assessment documents have been written to provide a desktop assessment of potential impacts of wave and tidal energy. These assessments, and the follow-on consents for installation of wave and tidal ocean energy conversation devices have provided findings of no significant environmental impacts. These findings support the general opinion that ocean energy represents a fairly benign means of renewable energy generation.

Withdrawal of ocean energy will not present an impervious barrier to the ocean energy resources. Gaps between devices and less than 100% absorption efficiency allow ocean energy to maintain its strength and to pass through a plant. Undiminished ocean energy will spread into the lower-energy zone immediately behind the plant by diffraction.

For devices using close- circuit hydraulics, working fluid spills or leakage may be concern. For devices with equipment mountings on submerged hull surfaces, underwater noise is a concern. For devices with air turbines, atmospheric noise is a concern. These concerns can be mitigated to various extents through system design features.

Ocean energy devices represent low visual impacts as they are either below the surface, or two small to be visible from a distance.

Because of the high level of fishing activity in offshore shelf waters, floating devices will have to be appropriately marked as a navigation hazard. In addition to lights, sound signals, and radar reflectors, highly contrasting day-markers will be required. Day-markers that meet the Coast Guard requirement of being visible within one nautical mile (1.8 km) at sea are expected to have negligible visual impact when viewed from shore.

Potential conflicts for use of space may exist with marine protected areas; shipping, fishing, scientific research areas, and military warning area; telecommunication cable routes and dredge spoil disposal sites. Most of these can be avoided with appropriate research during site selection and early dialogue with groups that might be affected.

Wave energy can have a number of other benefits in both the environmental and social areas. For example, in remote coastal areas, including small islands, it can help reduce the reliance on auxiliary (diesel) power stations. In addition to the resultant reduction of the emission of combustion gases to the atmosphere, the transport of the fuel to the site, often by water, is largely eliminated, which in turn reduces the environmental risks associated with this means of transportation.

VIII. The Barriers for Ocean Energy

Ocean energy has a tremendous potential to make a significant contribution to the renewable energy generation. While developers work diligently on technology development, their ability to expand commercially may be significantly hindered unless non-technological barriers are addressed in earnest. The following is the list of barriers that would require political, public and financial will to overcome to allow commercial expansion of ocean energy generation.

Electrical Grid Access

Ocean energy is a coastal resource. National grids were designed to accommodate central generation, resulting in weak transmission lines available in coastal areas. Ocean Energy has a potential to generate electrical power in hundreds of megawatts. Except for coastal countries, like Portugal and the SW region of UK that have high voltage transmission lines available close to shore, coastal communities lack sufficient transmission lines capacity to provide grid access for any significant amount of electricity that can be generated from ocean energy.

The barrier to ocean energy commercialization thus lies in the answer to these questions – a) who will finance the grid expansion in coastal areas suitable for ocean energy generation; b) who will determine the energy mix and, hence, the grid access for ocean energy systems.

Regulatory Framework

Initial efforts in securing installation permits in a number of countries demonstrated that permitting is expensive, long, and intensive. Lack of field data to support environmental analysis makes it that much harder to provide permitting authorities with factual information vs. desk analysis. Furthermore, there is lack of coordination between permitting authorities, making it so much more difficult to obtain permits.
Governments can significantly impact licensing of ocean energy systems by creating one-stop permitting structures.
The European Ocean Energy Association will be working with the European governments to streamline permitting processes to facilitate greater number of installations of ocean energy systems.

Availability of Resource Data

Top-level analyses of the available ocean energy resources have been done and are widely available. Now, these top level analyses need to be overlaid with constraints that would prevent harvesting of ocean energy in specific areas, i.e. other uses of the sea, access to transmission lines, populations centres, etc.

Economic Incentives

In the history of new industry creation it is a known fact that artificial market conditions need to be created at the early stage of industry development to create a market pull and to incentivise early adapters. Such market pull can have three elements – incentives for investors (investment tax credits), incentives for end-users (investment and production tax credits) and feed-in tariffs that would make high-cost pre-commercial installations attractive to investors and the end-users.

Public Awareness

Ocean energy is lacking public awareness, as it is a developing industry. A public awareness campaign may provide similar benefits as was enjoyed by the wind industry in its early days.

IX. Recommendations

OE can become a major player in the world-wide renewable energy mix in fairly short time, provided that industry players have access to the same level of financial support and incentives as other emerging industries. In particular, governments and private investors have the necessary resources to propel OE from a demonstration stage to the commercial stage in less time that it took the wind industry to mature. The following are some of the recommendations that can stimulate the growth of this emerging industry:

- Permitting, licensing, consenting requirements needs to be simplified and coordinated;
- Market driven incentives drive innovation - let the developer take the technical risk;
- As demonstrated from other industries, long-term, fixed feed-in tariff become a major factor in attracting project financing;
- Infrastructure, like grid access, requires a long-term outlook and planning. Need to start now.
- Accept some unknown environmental impact on the sea in perspective of the positive climate impact; the only way to study is often to deploy
- Support baseline studies and follow up programs related to the environmental impact;
- Establish a better balance between funding of research and demonstration projects
- Ocean energy should be assessed in conjunction with other developing technologies to develop hybrid systems;

X. The EU-OEA

The European Ocean Energy Association was formed as an answer to the expressed need for an ocean energy 'umbrella' organization to draw all ocean energy actors together by providing a forum that facilitates the ongoing development and commercialisation efforts in the field of ocean energy.

The European Ocean Energy Association is officially established in the Renewable Energy House in Brussels beginning of 2007 and is a member of EREC.

Acknowledgements

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Status and Perspectives of Wind Energy

Prof. Arthouros Zervos
National Technical University of Athens
President, European Wind Energy Association
Chairman, Global Wind Energy Council

Abstract

This paper describes the present status of wind energy market and technology and looks into the challenges and perspectives of its future development.

Since the 1980s, when the first commercial wind turbines were deployed, their capacity, efficiency and visual design have all improved dramatically. A modern wind turbine annually produces 180 times more electricity at less than half the cost per unit (kWh) than its equivalent twenty years ago. The largest turbines being manufactured now are of more than 5 MW capacity, with rotor diameters of over 100 metres. Modern turbines are modular and quick to install, whilst wind farms vary in size from a few megawatts up to several hundred.

Wind power is now established as an energy source in over 60 countries around the world. Although the wind power industry has up to now been most dynamic in the countries of the European Union, this is changing. The United States and Canada are both experiencing a surge of activity, whilst new markets are opening up in Asia and South America. A new frontier for wind power development has also been established in the sea, with offshore wind parks beginning to make a contribution.

Despite the great progress made in the past 25 years, wind energy has a long way to go before it reaches its full potential in terms of the large-scale supply of electricity. While it can already be cost competitive with newly built conventional plant at sites with good wind speeds, significant further cost reductions are necessary through market development and R&D.

As the industry expands, large quantities of wind powered electricity will need to be integrated into the global grid network. The variability of the wind is not an issue which will hinder this development, however. The already established control methods and backup capacity available for dealing with variable demand and supply are more than adequate to handle the additional variable supply of wind power at penetration levels up to around 20%. Above that, some changes may be needed in power systems and their method of operation.

Existing Scenarios show that wind energy can make a major contribution towards satisfying the global need for clean, renewable electricity within the next 30 years and that its penetration in the supply system can be substantially increased.

I. Introduction

From an emerging power source twenty five years ago, wind energy has mushroomed into a mature and booming global business. Generation costs have fallen by 50 per cent over the last 20 years, moving closer to the cost of conventional energy sources. Modern wind turbines have improved dramatically in their power rating, efficiency and reliability.

The progress of wind energy around the world in recent years has been impressive. By the end of 2007 more than 94,000 MW of electricity-generating wind turbines were operating in sixty countries. Over the past ten years, global wind power capacity has continued to grow at an average cumulative rate of 29%. In 2007, more than 20,000 MW (Megawatts) of new capacity was installed around the world.

Europe, the United States and India have been the major driving forces behind wind energy's expansion so far, but the industry is now seeing development across dozens of countries around the world. Over 60 countries around the world contribute to the global total, and the number of people employed by the industry worldwide is estimated to be more than 200,000.Whilst the underlying motivation remains wind power's attraction as one of the leading carbon-free generation technologies, there are other economic bonuses.

Manufacturing wind turbines and their components offers major employment opportunities, often building on existing engineering skills and raw materials. In rural areas, wind energy can bring investment and jobs to isolated communities; hosting wind turbines provides farmers with a steady income while allowing them to continue grazing or cropping their land. In the developing world, stand-alone wind turbines offer a potential electricity supply to millions of people remote from a grid connection.

The future prospects of the global wind industry are very promising: even on a conventional scenario the total wind power installed worldwide could quadruple from 94 GW in 2007 to 360 GW by 2016. The next ten years will also see a broadening of the global wind energy market to engage a spread of new countries across all continents.

The impressive expansion rate of the global wind energy market has attracted major players from the conventional fossil fuel, power and finance sectors. Numerous international companies and institutional investors have chosen to invest in the wind sector in recent years, including General Electric, ABB, Siemens, Shell, BP, AES, Florida Power and Light, Bridgepoint, Allianz, Englefield Capital and Babcock & Brown.

II. Status of Wind Energy

The World Wind Resources

Few studies have been made of the world's wind resources, with the most detailed research confined to the continent of Europe and the US. However, those assessments which have been carried out confirm that the world's wind resources are extremely large and well distributed across almost all regions and countries. Lack of wind is unlikely to be a limiting factor on global wind power development. When specific analysis has been produced on individual countries or regions, this has often shown an even greater resource than the global picture suggests.

According to Grubb and Meyer (in Johansson, 1993), the world's wind resources have the capacity to generate 53,000 TWh of electricity per year. This is more than three times the International Energy Agency's (2007) figure for global electricity consumption in 2005 (15,016 TWh).

A study by the German Advisory Council on Global Change, WBGU (2003), calculated that the global technical potential for energy production from both onshore and offshore wind installations was 1,000EJ per year. The report then assumed that only 10–15% of this potential would be realisable in a sustainable fashion, and arrived at a figure of approximately 140EJ per year as the contribution from wind energy in the long term. This represented 35% of the 1998 figure for total world primary energy demand (402 EJ) used by the study.

The WBGU calculations of the technical potential were based on average values of wind speeds from meteorological data collected over a 14 year period (1979–1992). They also assumed that advanced multi-megawatt wind energy converters would be used. Limitations to the potential came through excluding all urban areas and natural features such as forests, wetlands, nature reserves, glaciers and sand dunes. Agriculture, on the other hand, was not regarded as competition for wind energy in terms of land use.
More recently, researchers from the Global Climate and Energy Project at Stanford University, California (Archer, 2005) estimated that the world's wind resources can generate more than enough power to satisfy total global energy demand. After collecting measurements from 7,500 surface and 500 balloon-launch monitoring stations to determine global wind speeds at 80 metres above ground level, they found that nearly 13% had an average wind speed above 6.9

metres per second (Class 3), more than adequate for power generation.
North America was found to have the greatest wind power potential, although some of the strongest winds were observed in Northern Europe, whilst the southern tip of South America and the Australian island of Tasmania also recorded significant and sustained strong winds.
The study did not take into account uncertainties such as long-term variations and climatic effects, or practical considerations such as site availability, access and transmission. Translated into electricity output, however, and using as little as 20% of the potential resource for power generation, the report

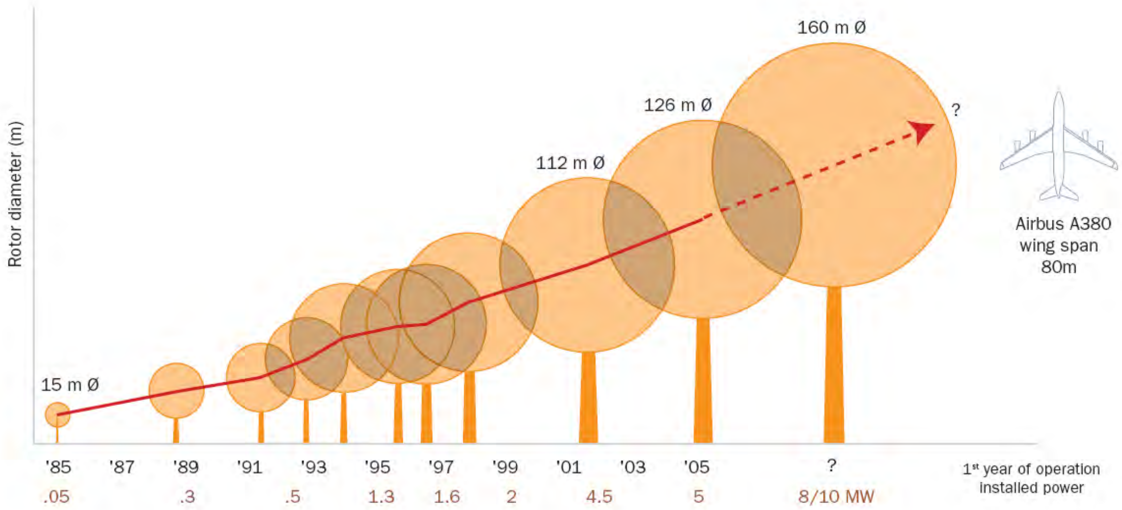


Figure 1. The size of wind turbines at market introduction
Source: Jos Beurskens, ECN

concluded that wind energy could satisfy the world's electricity demand seven times over.
Looking in more detail at the solar and wind resource in 13 developing countries, the SWERA (Solar and Wind Energy Resource Assessment) project, supported by the United Nations Environment Programme, has found the potential, among other examples, for 7,000 MW of wind capacity in Guatemala and 26,000 MW in Sri Lanka. Neither country has yet started to seriously exploit this large resource.

Turbine Technology

The evolution of modern wind turbines is a remarkable story of engineering and scientific skill coupled with a strong entrepreneurial spirit. In the last twenty years turbines have increased in size by a factor of 100, the cost of energy has reduced by a factor of more than 5, the industry has moved from an idealistic fringe activity to the edge of conventional power generation. At the same time the engineering base and computational tools have developed to match the machine size and volume.

This is a remarkable story but it is far from finished. Many technical challenges remain and even more spectacular achievements will result. Serious investment is needed to maximise potential through research and development and to avoid unnecessary failures which will impede progress.

Once the wind resource is established, the engineering challenge for the wind industry is to harness that energy and turn it into electricity. Compared with the traditional windmills common in the nineteenth century, a modern power-generating wind turbine is designed to generate high quality, network frequency electricity and to operate continuously for more than 20 years.

Most modern wind turbines have three blades controlled by stall or pitch regulation and either a gearbox or a direct drive system. Variable speed is an increasingly popular option, particularly because it improves compatibility with the grid. The blades are usually made from glass polyester or glass epoxy. Support structures are most commonly tubular steel towers which taper from their base to the nacelle at the top.

Over the last twenty years wind turbines have steadily increased in both size and energy output. From units of 20-60 kW in the 1980s, their capacity has increased to more than 6,000 kW today, and with rotor diameters of up to126 metres. The unit cost of turbines has also greatly reduced as a result of both technical improvements and volume production.

Some of the early turbine designs were noisy, both aerodynamically and mechanically, but mechanical noise has been practically eliminated and aerodynamic noise vastly improved. Wind turbines are now highly efficient, with less than 10 % thermal losses in the system transmission. In larger projects with proven medium sized turbines an availability of 98% is consistently achieved.

The potential offshore market is now the main driver for the development of larger turbines. Although there are still many challenges, including increased costs for both grid connection and foundations, there are major advantages in the higher mean wind speeds and reduced turbulence to be found out at sea.

Technology Trends

Turbines have grown larger and larger and hence the way in which the important design parameters change with size can be demonstrated and used in order to see how turbines may develop in the future. For various design parameters these trends can be used to establish key challenges for the industry.

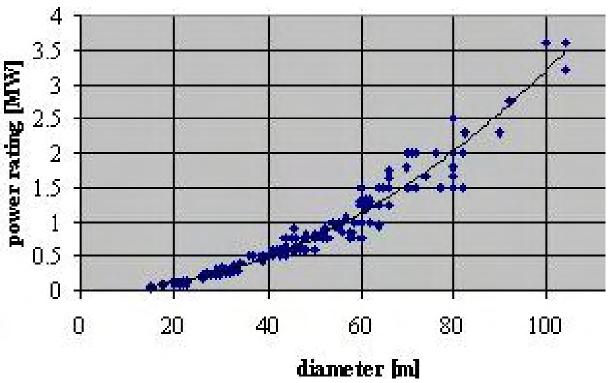


Figure 2. Rating vs diameter of wind turbine designs
Source: EWEA

Larger Diameters

Diameter in relation to power rating has generally increased in recent years. A remarkable increase from 65 m to 69 m to almost 77 m in average diameter of 1.5 MW turbines has taken place for the years 1997, 2000 and 2006 respectively. The diameter, or rather the square of the diameter determines how much energy a wind turbine can produce. The rating, the maximum power that the rotor is allowed to produce, plays an important part in the determination of the loads in the system. Balancing the diameter and the rating is therefore a key task in wind turbine design.

This is partly due to the optimisation of designs to maximise energy capture on comparatively low wind speed sites, but there is growing interest in better load management through more intelligent control systems as a means of realising relatively larger rotors and increased energy capture. Understanding, predicting, controlling and thereby limiting the loads is a vital part of wind turbine development.

Tip Speed - Offshore v Land Based Designs

The tip speed of a turbine is the product of the rotational speed and the radius of the blade. Noise increases very sharply with tip speed and hence high tip speed turbines are very much noisier than slow tip speed turbines. For a given power a fast turning turbine exhibits lower torque (drive train load) than a low speed turbine and hence has a lower drive train cost. There is therefore a trade-off between drive train load and noise to be made. For the onshore market the noise is the major constraint.

Pitch v Stall

There has been an enduring debate in the wind industry about the merits of pitch versus stall regulation. Until the advent of MW scale wind turbines in the mid 1990's, stall regulation predominated but pitch regulation is now the favoured option for the largest machines. This is due to a combination of factors. Overall costs are quite similar for each design type but pitch regulation offers potentially better output power quality (this has been perhaps the most significant factor in the German market), and pitch regulation with independent operation of each pitch actuator allows the rotor to be regarded as two independent braking systems for certification purposes.

Speed Variation

Operation at variable speed offers the possibility of increased "grid friendliness", load reduction and some minor energy benefits. It is thus an attractive option. It has become almost mandatory for MW scale turbines to have some degree of speed variation and that continuously variable speed is the predominant choice.

Hub Height

The choice of hub height is very site dependent. There is a trade-off between the benefits of the extra energy which may result from placing the rotor in the higher wind speeds to be found at higher levels above the ground against the extra cost of making the larger towers. Hub height equal to diameter is a good description of the average trend of the largest turbines. There is always great variation in tower height for any given size of rotor with high towers suiting low wind speed sites.

Rotor Mass

The rotor mass accounts for approximately 20% of the cost of the turbine. Blade manufacturers have naturally sought to reduce material volume and mass, especially in the largest blades. The way in which design principles change with blade size is therefore very important. If blade stress is kept constant as the size increases (a reasonable design assumption) then the blade loads and required blade strength will both scale as the cube of diameter, implying that geometric similar blades are feasible in a given material and that blade mass will then also scale as cube of diameter.

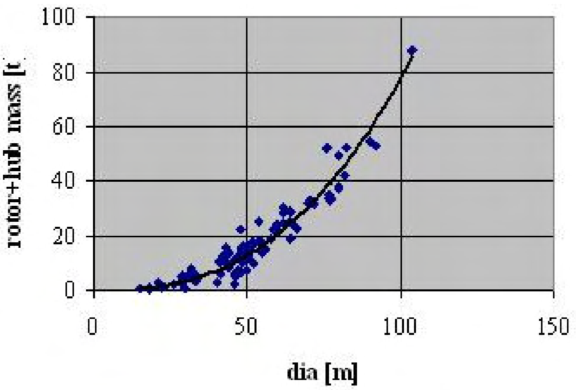


Figure 3. Rotor mass trends
Source: EWEA

Also the higher tip speeds of large offshore rotors imply reduced solidity (solidity is essentially ratio of blade projected area to rotor swept area) and hence slimmer blades. The reduced blade area will only allow reduced blade mass if materials of sufficiently high specific strength are available. Again, this fits in with a greater prominence of carbon fibre reinforcement in large blade design. As designs evolve with increasing attention to mass reduction an overall picture of rotor mass scaling as less than cubic is apparent (Figure 3).

It will be a challenge to maintain this trend (of less than cubic scaling through improved design concepts and materials) if rotors continue to get larger.

<u>Offshore Technology</u>
Offshore installations only constitute a very small part of the wind turbine market, but offshore wind is set to develop in a significant way and the potential offshore market is the main driver for large turbine technology development.

About 1000 MW of offshore wind has been installed in European waters and there are declared plans for about 4 GW of offshore wind up to a horizon of 2010. About 15 years ago, the technology started with a “toe in the water” approach to test turbine operation in the offshore environment. The turbines were “marinised” with some extra protection, in some cases de-humidified nacelle space, but otherwise were essentially the same as the land based technology.
The largest wind turbines now being designed primarily for offshore reveal design changes, mainly higher tip speeds and built –in handling equipment in the nacelle. With turbines now available of 2 MW rating and above and four projects of well over 100 MW capacity, the commercial offshore wind farm is at hand.

Figure 4. The Horns Rev 160 MW wind farm

The logistics involved in manufacture, transport, erection and maintenance of offshore multi-megawatt wind turbines is a severe challenge and at a commercial scale is likely to involve integrated dockyard assembly facilities. In the case of blades which may be more than 50 m length, direct access to the sea from the manufacturing plant is highly desirable if not essential.

<u>Overall Design Trends</u>
How has wind turbine technology evolved since the early 1980’s?

Although there has always been a wide variety of designs on the margins of commercial technology in the early days, the Danish, 3 bladed, single fixed speed, stall regulated turbine dominated the market at rated power levels generally less than 200 kW. Blades were almost invariably of glass-polyester resin manufacture.

In 2008, the focus of attention is on technology around and above 3 MW rating and commercial turbines now exist with a rotor diameter up to 126 m. Designs with variable pitch and variable speed predominate while direct drive generators are becoming more prevalent.

Epoxy based resin systems predominate blade manufacture and carbon fibre reinforcement is increasingly used in big blades. Some manufactures produce wholly carbon blades and many use carbon in cap spars. If the trend towards increasing use of carbon continues and the offshore market develops substantially, the wind industry could lead world demand for quality carbon fibre and drive further cost reduction of carbon fibres.

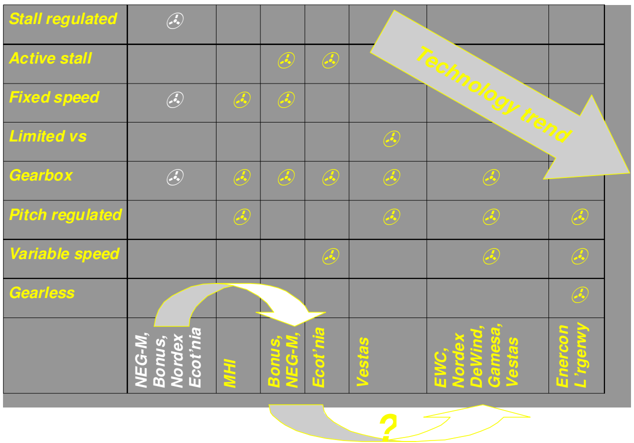


Figure 5. Technology trends
Source:EWEA

Figure 5 correlates key design features with representative manufacturers. It shows the evolution from the original mainstream architecture, stall regulated, fixed speed and with geared transmission to the present, pitch regulated, variable speed and with direct drive transmissions appearing.

These design changes are not in any significant degree a path to cost reduction. Variable speed may offer a little more energy capture but this is largely offset by added cost. The design changes have largely been driven by market demands - better acoustic noise regulation, better output power quality, avoidance of gearbox problems etc. Since the initial commercialisation of wind energy in the early 1980's, there has, of course, been huge cost reduction and this is a direct consequence of the huge growth in the market.

Thus modern wind turbines are more sophisticated and adaptable than their predecessors on account of technology development but much cheaper (discounting inflationary factors) on account of market expansion. Market expansion has of course promoted incremental technology improvements in design, materials, processes and logistics that have contributed very significantly to cost reduction. There are significant gains from technology advances but no significant cost reduction has come from the most visible changes in mainstream technology direction – variable speed, direct drive, predominant pitch regulation.

Variability and Grid Integration

Wind power is often described as an "intermittent" energy source, and therefore unreliable. In fact, wind turbines do not start and stop at irregular intervals. Their output is variable, just as the power system itself is inherently variable.

Electricity flows – both supply and demand - are influenced by a large number of planned and unplanned factors. Changing weather makes people switch their heating and lighting on and off, millions of consumers expect instant power for TVs and computers. On the supply side, when a large power station goes offline, whether by accident or planned shutdown, it does so instantaneously, causing an immediate loss of many hundreds of megawatts. By contrast, wind energy does not suddenly trip off the system. Variations are smoother because there are hundreds or thousands of units rather than a few large power stations, making it easier for the system operator to predict and manage changes in supply. There is little overall impact if the wind stops blowing in one particular place, because it is always blowing somewhere else.

Power systems have always had to deal with these sudden output variations from large power plants, and the procedures put in place can be applied to deal with variations in wind power production as well. The issue is therefore not one of variability in itself, but how to predict, manage and ameliorate this variability, and what tools can be used to improve efficiency.

The challenge in many parts of the world is that there is no regulatory or physical grid structure in place to allow the full exploitation of the vast global wind reserves. These will have to be developed at significant cost, although large investment would be involved whichever generation option was chosen.

In the present situation wind power is disadvantaged in relation to conventional sources, whose infrastructure has been largely developed under national vertically integrated monopolies which were able to finance grid network improvements through state subsidies and levies on electricity bills. But whilst a more liberalised market has closed off those options in some countries, numerous distortions continue to disadvantage renewable generators in the power market – from discriminatory connection charges to potential abuse of their dominant power by major companies.

Grid Integration

One of the biggest mistakes often made during public discussion about integrating wind energy into the electricity network is that it is treated in isolation. An electricity system is in practice much like a massive bath tub, with hundreds of taps (power stations) providing the input and millions of plug holes (consumers) draining the output. The taps and plugs are opening and closing all the time. For the grid operators, the task is to make sure there is enough water in the bath to maintain system security. It is therefore the combined effects of all technologies, as well as the demand patterns, that matter.

The present levels of wind power connected to electricity systems already show that it is feasible to integrate the technology to a significant extent. Experience with more than 50 GW installed in Europe, for example, has shown where areas of high, medium and low penetration levels take place in different conditions, and which bottlenecks and challenges occur.

For small penetration levels, grid operation will not be affected to any significant extent. The already established control methods and backup capacity available for dealing with variable demand and supply are more than adequate to handle the additional variable supply of wind power at penetration levels up to around 20% (EWEA, 2005). Above that, some changes may be needed in power systems and their method of operation.

The integration of large amounts of wind power is often dismissed as impossible, and many grid operators are reluctant to make changes to their long established procedures.In Denmark, however, 21% of total electricity consumption was met by wind power in 2004. In the western half of the country, up to 25% of demand is met by wind power and, on some occasions, it has been able to cover 100% of instantaneous demand.

Costs and Prices of Wind Energy

When looking at the economics of a wind energy investment, the first fact that strikes one's attention is the high share of the upfront/ capital costs as compared with the total cost of the project within its whole lifetime (around 80%).

This fact marks a fundamental difference with most other conventional electricity generation technologies, where the future cost of fuel is uncertain, but which require less financial effort in the initial stages of the project and has some consequences both in terms of bankability and risks for the wind energy investor and for society as a whole.

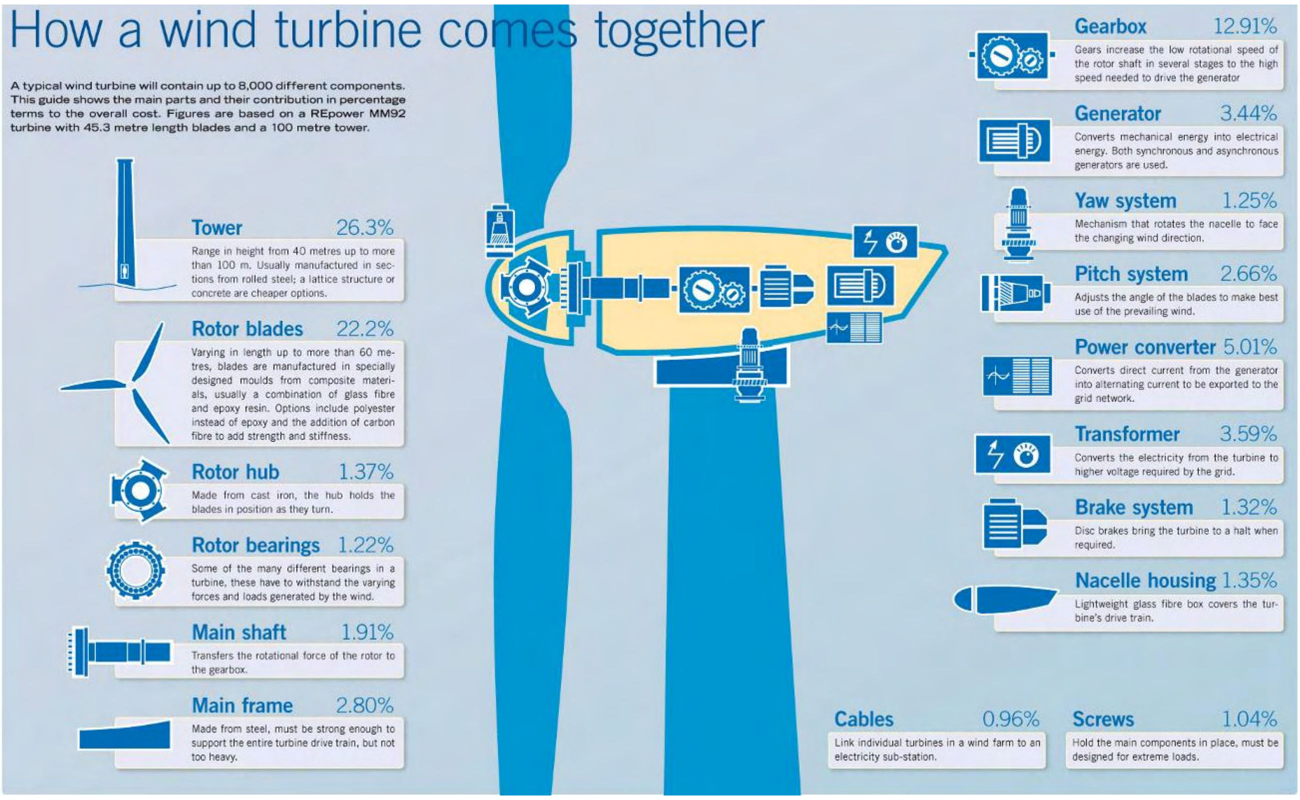


Figure 6. Example of the main components of a wind turbine and their share to the overall cost in the 5 MW RE Power machine

Source: *Wind Directions, January/February 2007*

Figure 6 illustrates the complexity of sub-components that make up a wind turbine, and helps to understand why it is the most expensive element of the whole investment. Note that the figure refers to a very large size wind turbine (5 MW). The relative weight of the sub-components will change with the model.

The wind turbine - comprising all sub-components; its transportation to the site and its installation- accounts for the lion share of the investment. Also the civil works (foundation; road construction; land preparation) and the grid connection constitute elements of importance.

After more than two decades of steady reductions, the upfront/ capital costs of a wind energy project have experienced a rise of around 20% in the past couple of years. Today they can be ranged at approx. 1,100 to 1,400 €/kW for newly-built projects.

The operation & maintenance of the machines make up the most uncertain category, because it can vary substantially from onshore to offshore models and because few wind turbines have achieved the end of their lifetime. The other variable costs (land rent, administration, insurance, etc.) explain around half of the total variable costs and differ substantially across countries.

Based on recent existing data from a variety of sources (BWEA, 2006; Erik, P. 2006; Milborrow, 2006; EWEA,2008) a prudent level of variable costs is between 1 and 2 €cent/kWh over the lifetime of the turbine. This would mean between 10% and 20% of the total cost: around 10% in pure O&M activities, and the rest in the remaining categories.

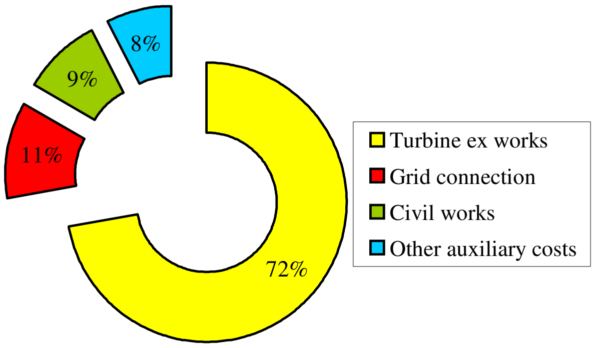


Figure 7. Estimated capital cost distribution of a wind project in Spain during 2007.
Source: Intermoney-AEE.

As with all other electricity-generating technologies, the production cost of wind energy cannot be presented with a single figure, rather as a range of values, depending on the characteristics of the site; the lifetime of the investment; the debt/equity ratio; the number of full working hours of the machines, etc.

Of all these, it is the capacity factor which matters the most, followed by the upfront/ capital costs and by the lifetime of the wind farm. With the latest information available, the generating cost of a kWh is in the range of 4.5 to 8.7 €cent/kWh for an onshore wind farm. This refers to a newly built project.

At present, only a limited number of wind farms have been put into operation. As a consequence, the uncertainty of cost calculation in the case of offshore wind is higher than for onshore wind. Recent works use an average cost of 2,000 €/kW installed. Broader ranges of between 1,800 and 2,500 €/kW can be used. This entails generation costs of 6 to 11.1 €cent/kWh.

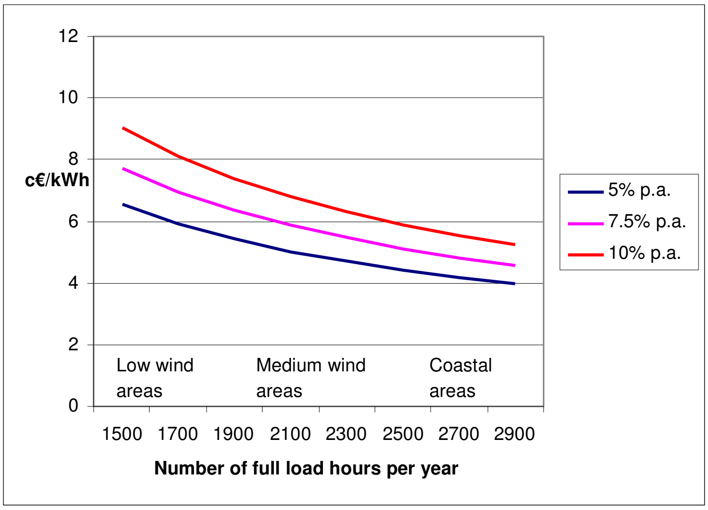


Figure 8. The costs of wind-produced power as a function of wind speed (number of full load hours) and discount rate.
Source: EWEA

The different situations regarding distance to the shore; water depth; and grid construction and connection largely explain such a wide range. In general, the higher energy production due to better wind conditions than onshore does not compensate for the higher initial upfront/ capital costs and O&M costs. Therefore, offshore wind power is more expensive than onshore wind power.

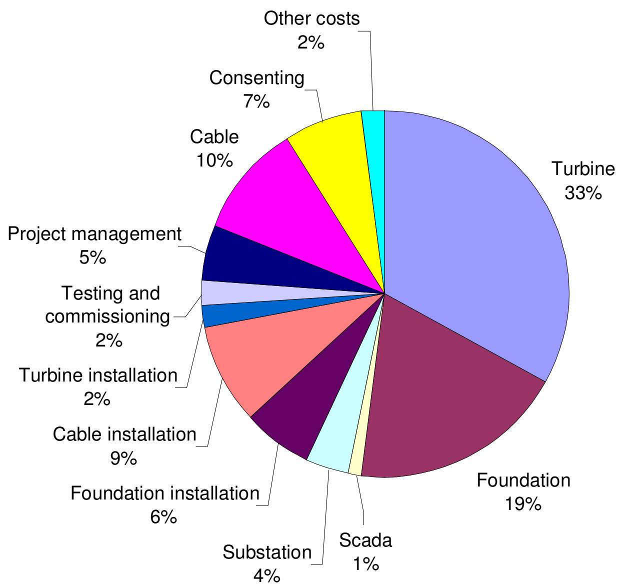


Figure 9.Estimate of capital cost breakdown for an offshore wind farm
Source: DTI, 2007a

The general increase of energy prices that has taken place since 2004 has also affected wind energy, whose generation costs have risen by about 20%. That trend can be explained by the steep rise in the price of raw materials that are found in major subcomponents of the wind turbines and by the booming demand of wind energy projects in new markets.

It is important to distinguish the generation cost of a technology and the price at which a kWh produced with it can be sold in the markets: prices are not only based on production costs, but also on the institutional and legal framework; the risk faced by the investor vis-à-vis other technologies; the demand for the product; the competition; the uncertainty of future income streams; etc. For wind energy, the elements that most affect its price –besides the wholesale price of electricity (as determined by fuel prices) are the rules that govern the electricity market, including the administrative procedures; the conditions and cost to access the grid and the payment mechanism. The latter constitutes a crucial element for the investor, since it will determine the income flow in a technology whose costs are greatly determined at the time of making the investment.

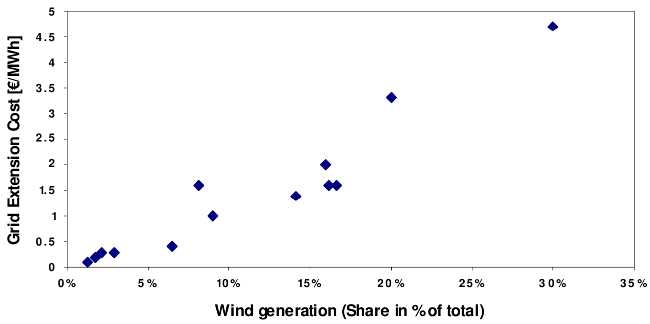


Figure 10. Range of grid extension costs based on different country specific studies.
Source: EWEA 2005

The allegedly negative impact that introducing large amounts of wind power into the electricity grid can entail to the whole power system has been debated on many occasions and its at the root of certain discriminatory practices against wind energy producers, be it in the form of restricted access; power cuts; excessive technical requirements for wind turbines or the financial burden of paying the whole cost of a new line that is needed. From recent studies it follows that at wind penetrations up to 20% of the gross electricity demand, system operation costs would increase by about 0.01 to 0.4 €cent/kWh due to wind variability and uncertainty.

What is more, the increased need for balancing, and especially for grid upgrades has to be understood in the context of the internal electricity market that is being created, which will naturally require better interconnections and flow managements for the benefit, not only of wind power, but of all other technologies. Relatively simple measures, such as the creation of larger balancing areas and the operation of the power system closer to the delivery hour; can be applied and will decrease costs, while optimising the overall functioning of the entire system.

Market Development

Over the past decade the global market for wind power has been expanding faster than any other source of renewable energy. Since the year 1997 the average annual increase in cumulative installed capacity has been 29%. From just 7,600 MW in 1997 the world total has multiplied more than twelve-fold in ten years to reach over 94,000 MW.

A substantial manufacturing industry has been created, with an estimated 200,000 people employed around the world. Such has been the success of the industry that it has attracted an increasing number of investors from the mainstream finance and traditional energy sectors.

In a number of countries the proportion of electricity generated by wind power is now challenging conventional fuels. In Denmark, 20% of the country's electricity is currently supplied by the wind. In northern Germany, wind can contribute 35% of the supply. In Spain, Europe's fifth largest country, the contribution has reached 10%, and is set to rise to 15% by the end of the decade.

The booming wind energy markets around the world exceeded expectations in 2007, with the sector experiencing yet another record year with installations of 20,073 megawatts (MW). This takes the total installed wind energy capacity to 94,112 MW, up from 74,133 MW in 2006. Despite constraints facing supply chains for wind turbines, the annual market for wind continued to increase at the staggering rate of 31% following the 32 % increase in 2006 and the 2005 record year, in which the market grew by 41 %. This development shows that the global wind energy industry is responding fast to the challenge of manufacturing at the required level, and manages to deliver sustained growth. In terms of economic value, the wind energy sector has now become firmly installed as one of the important players in the energy markets, with the total value of new generating equipment installed in 2007 reaching €25 billion, or US$36 billion.

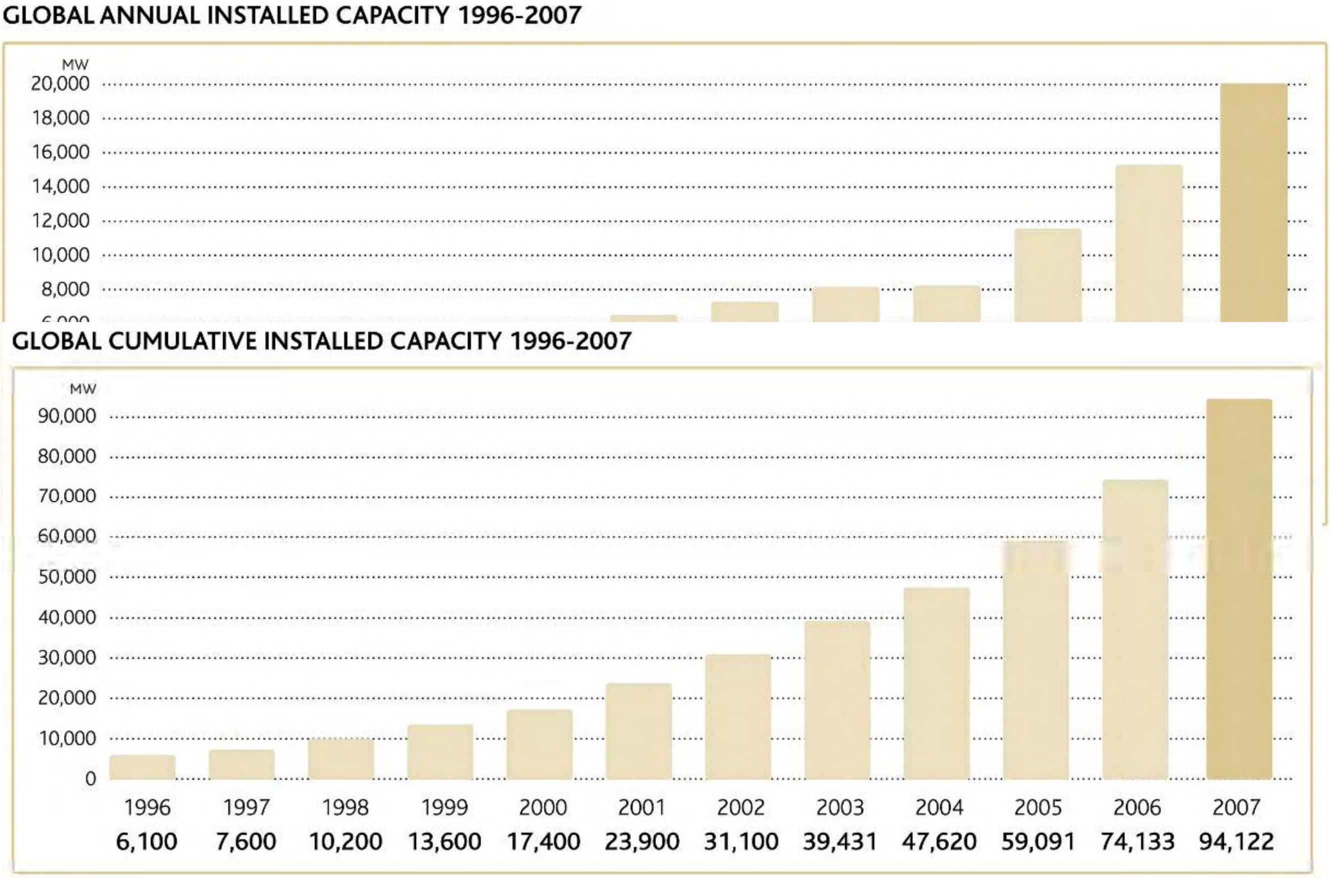


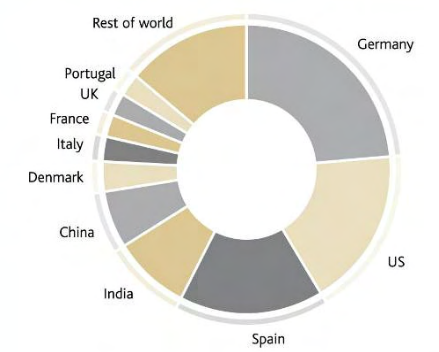
Figure 11. Global annual and cumulative installed capacity (1996-2007).
Source: GWEC

The countries with the highest total installed capacity are Germany (22,247 MW), USA (16,818 MW), Spain (15,145 MW), India (8,000 MW) and China (6,050 MW). Ten countries around the world can now be counted among those with over 2,000 MW of wind capacity, with France, U.K and Portugal reaching this threshold in 2007.

In terms of new installed capacity in 2007, the US continued to lead with the all times record of 5,244 MW, followed by Spain (3,522), China (3,449), India (1,730 MW), Germany (1,667 MW), and France (888 MW). This development shows that new players such as France and China are gaining ground.

Europe continues to lead the market with 57,136 MW of installed capacity at the end of 2007, representing 61 % of the global total. In 2007, the European wind capacity grew by 19 %, producing approximately 120 TWh of electricity, equal to 3.8 % of total EU electricity consumption in an average wind year.

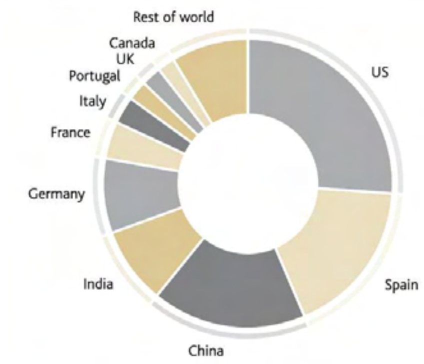
TOP 10 TOTAL INSTALLED CAPACITY



	MW	%
Germany	22,247	23.6
US	16,818	17.9
Spain	15,145	16.1
India	8,000	8.5
China	6,050	6.4
Denmark	3,125	3.3
Italy	2,726	2.9
France	2,454	2.6
UK	2,389	2.5
Portugal	2,150	2.3
Rest of world	13,008	13.8
Total top 10	**81,104**	**86.2**
Total	**94,112**	**100.0**

Figure 12. The top-10 countries in cumulative wind capacity by the end of 2007.
Source: GWEC

TOP 10 NEW CAPACITY



	MW	%
US	5,244	26.1
Spain	3,522	17.5
China	3,449	17.2
India	1,730	8.6
Germany	1,667	8.3
France	888	4.4
Italy	603	3.0
Portugal	434	2.2
UK	427	2.1
Canada	386	1.9
Rest of world	1,723	8.6
Total top 10	**18,350**	**91.4**
Total	**20,073**	**100.0**

Figure 13. The top-10 countries in annual wind installed capacity in 2007.
Source: GWEC

Despite the continuing growth in Europe, the general trend shows that the sector is gradually becoming less reliant on a few key markets, and other regions are starting to catch up with Europe. The growth in the European market in 2007 accounted for just 43% of the total new capacity, down from nearly three quarters in 2004. For the first time in decades, more than 50% of the annual wind market was outside Europe, and this trend is likely to continue into the future.

While Germany and Spain still represent 60 % of the EU market, we are seeing a healthy trend towards less reliance on these two countries. In the EU, 3,365 MW were installed outside of Germany, Spain and Denmark in 2007. In 2002, this figure still stood at only 680 MW. The figures clearly confirm that a second wave of European countries is investing in wind power.

The US reported a record 5,244 MW installed in 2007, more than double the 2006 figure, accounting for about 30% of the country's new power-producing capacity in 2007. Overall US wind power generating capacity grew 45% in 2007, with total installed capacity now standing at 16.8 GW.

Asia has experienced the strongest increase in installed capacity outside of Europe, with an addition of 5,436 MW, taking the continent over 16,000 MW. In 2007, the continent grew by 53 % and accounted for 24 % of new installations.

China, for a second consecutive year, more than doubled its total installed capacity by installing 3,449 MW of wind energy in 2007, a 256 % increase from last year's figure. It has become the strongest market in Asia, while India remains the country with the largest installed capacity in Asia with 8000 MW, while China reached 6050 MW. The Chinese market was boosted by the country's new Renewable Energy Law, which entered into force on 1 January 2006. The goal for wind power in China by the end of 2010 is 5,000 MW, which has already been reached well ahead of time.

ANNUAL INSTALLED CAPACITY BY REGION 2003-2007

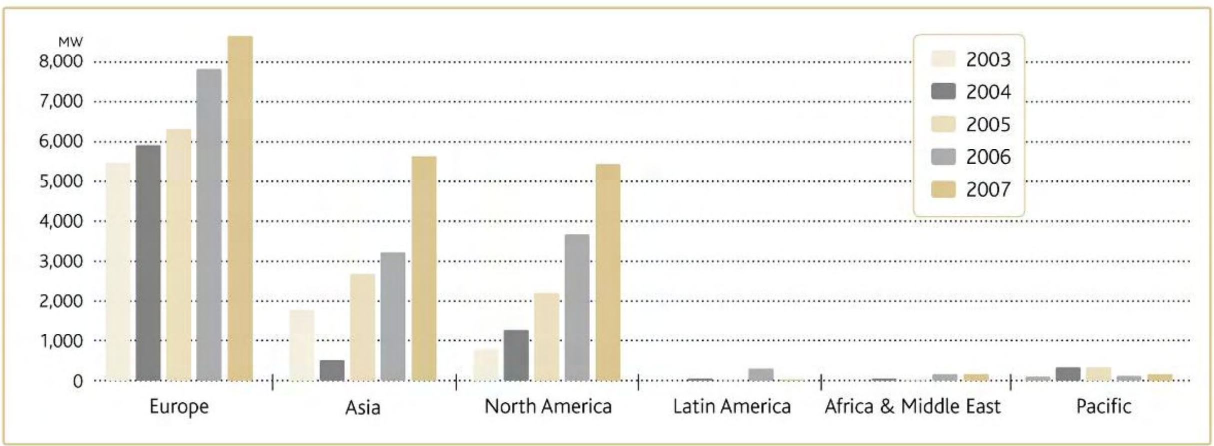


Figure 14. Annual wind installed capacity by region (2003-2007)
Source: GWEC

Growth in the relatively young African and Middle Eastern market picked up considerably in 2007, with 159 MW of new installed capacity, bringing the total up to 528 MW. This represents a 44 % growth, and should be seen as a promising sign for future developments.

III. The Environmental Impacts of Wind Power

The construction and operation of wind power installations, often in areas of open countryside, raises issues of visual impact, noise and the potential effects on local ecology and wildlife. Many of these issues are addressed during consultation with the local planning authority, from which consent must be obtained to proceed with a development, and in most cases through a detailed environmental impact assessment.

Visual impact

Wind turbines are tall structures which ideally need to operate in an exposed site where they can make best use of the prevailing wind. This means they are likely to be visible over a relatively wide area. Whether this has a detrimental effect is a highly subjective issue. Being visible is not the same as being intrusive. While some people express concern about the effect wind turbines have on the beauty of our landscape, others see them as elegant and graceful, or symbols of a better, less polluted future.

The landscape is largely human-made and has evolved over time. Changes to the visual appearance of the countryside, such as lines of electricity pylons, which were once considered intrusions, are now largely accepted as part of the view. In comparison to other energy developments, such as nuclear, coal and gas power stations, or open cast coal mining, wind farms have relatively little visual impact. Nevertheless, most countries with a wind power industry have established rules which exclude certain areas, such as national parks or nature reserves, from development. Others have identified priority areas where wind power is specifically encouraged.

Some wind turbines are located in industrial areas or close to other infrastructure developments, such as motorways, where they may be considered less intrusive. Large wind farms of 100 or more turbines can also be located in areas with low population density or in the sea. It is also worth emphasising that wind turbines are not permanent structures. Once removed, the landscape quickly returns to its previous condition.

Noise

Generally speaking, the sound output of wind turbines can be subdivided into mechanical and aerodynamic noise. The components emitting the highest sound level are the generator, the yaw drive which turns the nacelle of the turbine to face the wind, the gearbox and the blades. Some of the sound generated by these components is regular and some of it irregular, but all of it (except, that generated by the yaw mechanism) is present only while the turbine is actually operating. Even then, compared to road traffic, trains, construction activities and many other sources of industrial noise, the sound generated by wind turbines in operation is comparatively low (see table 1).

Better design and better insulation have made more recent wind turbine models much quieter than their predecessors. The approach of regulatory authorities to the issue of noise and wind farms has generally been to firstly calculate the ambient (existing) sound level at any nearby houses and then to ensure that the turbines are positioned far enough away to avoid unacceptable disturbance.

Source/activity	Indicative noise level dB(A)
Threshold of pain	140
Jet aircraft at 250m	105
Pneumatic drill at 7m	95
Truck at 48 kph at 100m	65
Busy general office	60
Car at 64 kph at 100m	55
Wind development at 350m	35-45
Quiet bedroom	35
Rural night-time background	20-40

Table 1. Comparative noise levels from different sources
Source: Sustainable Development Commission (2005)

Wildlife – birds

Birds can be affected by wind energy development through loss of habitat, disturbance to their breeding and foraging areas and by death or injury caused by the rotating turbine blades. Compared to other causes of mortality among birds, however (see table), the effect of wind power is relatively minor. One estimate from the United States is that commercial wind turbines cause the direct deaths of only 0.01 - 0.02% of all of the birds killed annually by collisions with man-made structures and activities.

Well publicised reports of bird deaths, especially birds of prey, at sites including the Altamont Pass near San Francisco and Tarifa in southern Spain, are not indicative of the day to day experience at the thousands of wind energy developments now operating around the world.

As a general rule, birds notice that new structures have arrived in their area, learn to avoid them, especially the turning blades, and are able to continue feeding and breeding in the location. Problems are most likely to occur when the site is either on a migration route, with large flocks of birds passing through the area, or is particularly attractive as a feeding or breeding ground. This can be avoided by careful siting procedures. Modern wind turbines, with their slower turning blades, have also proved less problematic than earlier models.

A 2001 study by ecological consultants WEST for the National Wind Coordinating Committee estimated that 33,000 birds were killed that year in the United States by the 15,000 turbines then in operation – just over two birds per turbine. The majority of the fatalities had occurred in California, where older, faster rotating machines were still in operation; these are steadily being replaced by more modern, slower rotating turbines.

In Europe, a 2003 study in the Spanish province of Navarra - where 692 turbines were then operating in 18 wind farms - found that the annual mortality rate of medium and large birds was just 0.13 per turbine.

In Germany, records of bird deaths from the National Environmental office Brandenburg showed a total of 278 casualties at wind farms over the period 1989 to 2004. Only ten of the birds were species protected by European Union legislation. By the end of the period Germany had over 16,500 wind turbines in operation[7].

The UK's leading bird protection body, the Royal Society for the Protection of Birds, says that the most significant long-term threat to birds comes from climate change. Changes in the climate will in turn change the pattern of indigenous plant species and their attendant insect life, making once attractive areas uninhabitable by birds. According to the RSPB, "recent scientific research indicates that, as early as the middle of this century, climate change could commit one third or more of land-based plants and animals to extinction, including some species of British birds." Compared to this threat, "the available evidence suggests that appropriately positioned wind farms do not pose a significant hazard for birds," it concludes.

[7] German Federal Government „Kleine Anfrage der Abgeordneten Dr. Christel Happach-Kasan et. all; Drucksache 15/5064 - Gefährdung heimischer Greifvogel- und Fledermausarten durch Windkraftanlagen

Collaborative work between the wind power industry and wildlife groups has also been aimed at limiting bird casualties. In the Altamont Pass, for example, operators have agreed to turn off their turbines during busy migratory periods.

In the UK, the solution adopted at the Beinn an Tuirc wind farm in Scotland was to create a completely new habitat for the Golden Eagles which hunted there, providing a fresh source of their favourite prey, the grouse.

Cause	Estimated deaths per year
Utility transmission and distribution lines	130-174 million
Collision with road vehicles	60-80 million
Collision with buildings	100-1,000 million
Telecommunications towers	40-50 million
Agricultural pesticides	67 million
Cats	39 million

Table 2. Main causes of bird deaths in the United States
Source: American Wind Energy Association

Wildlife - bats

Like birds, bats are endangered by many human activities, from pesticide poisoning to collision with structures to loss of habitat. Despite publicity given to bat deaths around wind farms, mainly in the United States, studies have shown that wind turbines do not pose a significant threat to bat populations. A review of available evidence by ecological consultants WEST (Johnson (2005)) concluded that "bat collision mortality during the breeding season is virtually non-existent, despite the fact that relatively large numbers of bat species have been documented in close proximity to wind plants. These data suggest that wind plants do not currently impact resident breeding populations where they have been studied in the US."

The overall average fatality rate for US wind projects is 3.4 bats per turbine per year, according to a 2004 report by WEST. No nationally endangered or threatened bat species have been found.

Monitoring of wind farms in the US indicates that most deaths involve bats that are migrating in late summer and autumn. One theory is that migrant bats, which are not searching for insects or feeding, turn off their "echolocation" navigation system in order to conserve energy. The American Wind Energy Association has now joined forces with Bat Conservation International, the US Fish and Wildlife Service and the National Renewable Energy Laboratory to look at why these collisions occur and how they can be prevented.

A number of national wind energy industry associations have adopted guidelines for how prospective developers should approach the issue of both birds and bats. The Australian Wind Energy Association, for example, "strongly recommends… scientifically rigorous study of the activities over all seasons of birds and bats…" This should include targeted investigations that are "necessary to obtain general data on bird and bat use of sites and their surrounding region" to enable the developer and their regulators to assess the risk of collisions.

In general, wind farming is popular with farmers, because their land can continue to be used for growing crops or grazing livestock. Sheep, cows and horses are not disturbed by wind turbines. The first wind farm built in the UK, Delabole in Cornwall, is home to a stud farm and riding school, and the farmer, Peter Edwards, often rides around the turbines on his horse.

Offshore wind farms

In most European coastal states national regulations have been established covering the procedures required to obtain building permits for offshore wind farms. The project developer has to assess in qualitative and quantitative terms the expected environmental impacts on the marine environment. These procedures ensure that projects comply with international and EU law, conventions and regulations covering habitat and wildlife conservation.

Within the structure of an environmental impact assessment, an initial baseline study is conducted before any impacts can occur. Subsequent monitoring is necessary to record any changes within the marine environment which may have been caused by anthropogenic factors. The monitoring phase may go on for several years, and evaluations and conclusions are updated annually to assess changes over time (Koller (2006)).

Potential impacts of offshore wind farms include**:**

Electromagnetic fields: Magnetic fields emanating from power transmission cables can affect marine animals. Connections for offshore wind farms are therefore based on multi-conductor cable systems to avoid this phenomenon.

Noise: Construction operations, especially the ramming of turbine foundations into the sea bed, can disturb marine wildlife. However at the Horns Rev site in the North Sea off Denmark, for example, monitoring has shown that neither seals nor harbour porpoises, both active in the area, have been forced to make any substantial changes to their behaviour. Both fish and benthic communities have in fact been attracted to the foundations of the wind turbines after their construction, the latter using them as hatchery or nursery grounds.

On the noise produced by operating offshore wind turbines, information currently available indicates that this lies in the same range of frequencies as that generated by sources such as shipping, fishing vessels, the wind and waves.

Birds: As on land, sea birds have generally learned to live with the presence of offshore wind turbines. At the Utgrunden and Yttre Stengrund wind farms off Sweden, for example, research shows that very few waterfowl, including Eider ducks, fly close enough to the turbines to risk collision. One estimate is that one waterfowl is killed per wind turbine per year.

At the much larger Nysted wind farm off the coast of Denmark, radar plotting research found that flocks of migrating sea birds mostly flew round the outside of the block of 72 turbines.

At a nine turbine development along the sea wall at Blyth in Northumbria, UK, 1-2 collisions have been recorded per turbine per year.

IV. Challenges and Perspectives

Future Technology improvements – The Research Agenda

The development of wind turbines is a remarkable success story which is not yet complete. The wind industry is now poised at a stage where it is regarded by many as mature technology and able to stand on its own commercially. While that status is a great achievement, it is important to realise the potential for yet greater growth that can best be furthered by continuing vigorous R & D effort. The design drivers are always reduction in cost and increased reliability. A wind turbine is a complicated integrated structure – all its elements interact and each will play its part in the optimisation.

In order for wind power to become fully competitive with conventional power generating technologies, even without internalisation of external costs to society, or reform of the very large subsidies they receive, it is up to the wind energy sector to make further cost reductions. Some 60% of cost reductions in the last two decades are estimated to be the result of economies of scale brought about by increased market volume, in turn a result of market volume in a handful of countries. The remaining 40% of cost reductions can be directly attributed to research and development.

Initiated by the European Wind Energy Association, the European wind energy sector has discussed the research agenda towards 2020. This agenda has constituted the base of the Technology Platform which was launched last year. Historically, the R&D focused mainly on technology development and the scientific disciplines required for this. The present R&D agenda has a wider scope, incorporating also grid integration issues, public support and environmental issues. It highlights the key R&D priorities. This agenda for research should be seen as only the first edition of an ongoing identification process, which is currently being updated through the European Technology Platform for Wind Energy.

The Priorities listed below are divided into three categories: showstoppers, barriers and bottlenecks.

Showstoppers

These are the key priorities, which is to say that they are considered to be issues of such importance that failure to address them could halt progress altogether. Thus they need special and urgent attention.

1. In terms of <u>resource estimation</u>: maximum availability of wind resource data, in the public domain where possible, to ensure that financiers, insurers and project developers can develop high quality projects efficiently, avoiding project failure through inaccurate data.

2. With regards to <u>wind turbines</u>: the availability of robust, low-maintenance offshore turbines, as well as research into the development of increased reliability and availability of offshore turbines.

3. For <u>wind farms</u>: the research and development of wind farm level storage systems.

4. In terms of <u>grid integration</u>: planning and design processes for a grid, with sufficient connection points to serve future large-scale wind power plants. This task should be undertaken by the wider energy sector.

5. With regards to <u>environment and public support</u>: a communication strategy for the demonstration of Research results on the effects of large-scale wind power plants on ecological systems, targeted at the general public and policy makers. To include specific recommendations for wind park design and planning practices.

Barriers

Barriers are defined as being principal physical limitations in current technology, which may be overcome through the opening up of new horizons through generic / basic research over the medium to long term.

1. <u>Wind Resource</u>: Resource mapping of areas with a high probability of high wind resource potential, but as yet unexplored.

2. <u>Wind Turbines</u>: i) Integrated design tools for very large wind turbines operating in extreme climates, such as offshore, cold / hot climates and complex terrain; ii) State of the art laboratories for accelerated testing of large components under realistic external (climatological) conditions.

3. <u>Wind Farms</u>: i) Understanding the flow in and around large wind farms; ii) Control systems to optimise power output and load factor at wind farm level; iii) Development of risk assessment methodologies.

4. <u>Grid Integration</u>: Control strategies and requirements for wind farms to make them fully grid compatible and able to support and maintain a stable grid.

5. <u>Environment and Public Support</u>: i) Effects on ecology adjacent to wind energy developments; ii) Development of automatic equipment to monitor in particular bird collisions, and sea mammals' reaction to underwater sound emissions.

6. <u>Standards and Certfication</u>: development of the following international standards: i) Energy yield calculation; ii) Grid connection protocols and procedures; iii) Risk assessment methodology; iv) Design Criteria for components and materials; v) Standardisation of O&M mechanisms

Bottlenecks

Bottlenecks are problems which can be relatively quickly overcome through additional short or medium term R&D, i.e. through the application of targeted funding and / other resources.

1.<u>Wind Resource</u>: Development of cost effective measuring units, including communications and processing, and which are easily transportable, for the assessment of wind resource characteristics, such as LIDAR, SODAR and satellite observation.

2. <u>Wind Turbines</u>: Development of component level design tools and multi-parameter control strategies.

3. Grid Integration: Development of electric and electronic components and technologies for grid connection.

4. Environment and Public Support: International exchange and communication of
results of R&D into ecological impacts.

5. Standards and Certification: Accelerated finalisation of ongoing standards development activities (certification processes and test procedures, design criteria for offshore wind turbines, project certification).

Issues for Integrating Wind Power

A number of issues have to be addressed if large quantities of wind power are to be successfully integrated into the grid network. These issues relate to system operation, grid connection, system stability and infrastructure improvements.

System operation

At first sight wind energy appears to present a difficult challenge for the power system, often resulting in high estimates for ancillary service costs or assumptions that wind capacity must be "backed up" with large amounts of conventional generation. However, such assessments often overlook key factors. These include:

1. Grid systems are designed to routinely cope with varying and uncertain demand, and unexpected transmission and generation outages.
2. Wind power output can be aggregated at a system level, resulting in significant smoothing effects, which increase with large scale geographic distribution of wind farms.
3. Forecasting of wind power output in both hourly and day ahead timeframes.

Wind power will still have an impact on power system reserves, the magnitude of which will depend on the power system size, generation mix, load variations, demand size management and degree of grid interconnection. Large power systems can take advantage of the natural diversity of variable sources, however. They have flexible mechanisms to follow the varying load and plant outages that cannot always be accurately predicted.

The need for additional reserve capacity with growing wind penetration is in practice very modest, and up to significant wind power penetrations, unpredicted imbalances can be countered with reserves existing in the system.

Steady improvements are being made in forecasting techniques. Using increasingly sophisticated weather forecasts, wind power generation models and statistical analysis, it is possible to predict generation from five minute to hourly intervals over timescales up to 72 hours in advance, and for seasonal and annual periods. Using current tools, the forecast error for a single wind farm is between 10 and 20% of the power output for a forecast horizon of 36 hours. For regionally aggregated wind farms the forecast error is in the order of 10% for a day ahead and 5% for 1-4 hours in advance.

The effects of geographical distribution can also be significant. Whereas a single turbine can experience power swings from hour to hour of up to 60% of its capacity, monitoring by the German ISET research institute has shown that the maximum hourly variation across 350 MW of aggregated wind farms in Germany does not exceed 20%. Across a larger area, such as the Nordel system covering four countries (Finland, Sweden, Norway and Eastern Denmark), the greatest hourly variations would be less than 10%.

Grid connection and system stability

Connecting wind farms to the transmission and distribution grids causes changes in the local grid voltage levels, and careful voltage management is essential for the proper operation of the network. All network system operators therefore lay down "grid codes" which define the ways in which generating stations connecting to the system must operate in order to maintain stability. These vary from country to country, but cover such issues as voltage quality and frequency control.

In response to increasing demands from TSOs, for example to stay connected to the system during a fault event, the most recent wind turbine designs have been substantially improved. Most of the MW-size turbines being installed today are capable of meeting the most severe grid code requirements, with advanced features including fault-ride-through capability. This enables them to assist in keeping the power system stable, when large faults occur. Modern wind farms are moving towards becoming wind energy power plants that can be actively controlled.

Infrastructure improvements

Transmission and distribution grid infrastructure will need to be upgraded in order to accommodate large amounts of wind power effectively. Expansion of wind power is not the only driver, however. Extensions and reinforcements are needed to accommodate other power sources required to meet a rapidly growing electricity demand.

On costs, a number of country-specific studies have indicated that the grid extension/reinforcement costs caused by additional wind generation are in the range of 0.1 to 4.7€/MWh, the higher value corresponding to a wind penetration of 30% in the UK system. If these costs were properly "socialised" (paid for by the whole of society), the share for each consumer would be small. Added to this, increasing the share of wind power in electricity supply is likely to have a beneficial effect on the cost of power to end users, especially when the benefits of carbon dioxide reductions, health effects and environmental degradation are taken into account.

A number of recent studies ( )have concluded that a large contribution from wind energy to power generation needs is technically and economically feasible, and in the same order of magnitude as the contributions from conventional technologies developed over the past century. The barriers to increasing wind power penetration are not inherently technical, they conclude, but mainly a matter of regulatory, institutional and market modifications.

Long Term Trends of Basic Costs

Despite the recent increase of capital costs of wind power generation (something that, on the other hand, has affected all other electricity generation options) the long-term trends for wind energy have shown a substantial reduction.

A variety of models that analyse the long-term cost trend of wind –and other renewable energies- have been developed in the past decade. The European Commission, in its 2007 Strategic Energy Review (EC, 2007a) has presented an amalgam of their main outcomes, as part of its impact assessment on renewables, and shows that the capital cost of wind energy is likely to fall to around 826 €/kW by 2020, 788 €/kW by 2030 and 762 €/kW by 2050. A similar pattern is expected for offshore (see Table):

	€/kW in 2020	€/kW in 2030	€/kW in 2040	€/kW in 2050
Onshore	826	788	770	762
Offshore	1274	1206	1175	1161

Table 3. Capital cost of energy technologies assumed for the PRIMES baseline model (as applied in the impact assessment of the European Commission). *Source: EC, 2007a.*

In the same way, the Department of Trade and Industry (DTI, 2007b) has commissioned a study to Ernst and Young, which looks in the present and future costs of the renewable technologies. For onshore and offshore wind energy, the consultancy foresees that the upward trend will continue up to 2010 and will decrease afterwards, once the supply chain bottlenecks are solved.

A common way to look at the long-term cost trend is to apply the experience curve concept, which analyses the cost development of a product or a technology as a function of cumulative production, based on recorded data. The experience curve is not a forecasting tool based on estimated relationships; it merely points out that if the existing trends continue in the future, then we may see the proposed decrease. Still, it is commonly utilized in most economic sectors, including the energy sector.

An excellent overview of the experience curves for wind and their usefulness can be found in Junginger *et at* (2005).

Unfortunately some of them use non-compatible specifications, which mean that not all of these can be directly compared. Using the specific costs of energy as a basis (costs per kWh produced) the estimated progress ratios in these publications range from 0.83 to 0.91, corresponding to learning rates of 0.17 to 0.09. i.e. when total installed capacity of wind power is doubled the costs per produced kWh for new turbines are reduced between 9% and 17%. The recent study carried out by DTI (2007) considers a 10% cost reduction every time the total installed capacity doubles.

Naturally, the level of R&D –public and private- will have a strong impact on future costs, and this is where learning curves do not capture the importance of policy support. According to the studies mentioned above, the main factors that are behind the cost reduction of wind in the last two decades have been continued R&D effort, the upscaling of the turbines and economies of scale due to mass production.

It is logical to assume that, in the long term production costs of the wind industry will continue their downward trend, once the production shortages are overcome. In the case of offshore projects, the cost decrease should be more pronounced, since that segment is still high in the learning curve and large scale industrial facilities have not been developed yet. The evolution of steel; cast iron; copper and carbon fiber prices casts some doubts, since their high demand coming from other economic sectors and geographical areas is likely to be maintained. The question is then to what extent the technological improvements and the economies of scale are able to compensate those.

The long-term production costs of wind have to be compared with those of the other electricity generating technologies. These, notably the ones using gas and oil, have experienced a sharp rise since 2004. For these reasons, and independently of the learning pace of the wind industry sector, one may expect the technology to become closer to competitiveness in the coming years.

Offshore Development

Offshore wind is an emerging industry and a new user of the sea with distinct industrial and political development requirements compared to onshore wind power.

Offshore wind power technology builds on onshore wind technology, and its future development will require participation from other sectors such as offshore oil and gas engineering and technology, the logistical skills of offshore service providers, transmission system operators and the infrastructure technology of the power industry.

Although long-term prospects for offshore wind power are promising, the technology faces a number of challenges in terms of technological performance, lack of skilled personnel, shortage of appropriate auxiliary services (e.g. crane vessels), impact on the local environment, competition for space with other marine users, compatibility with the grid infrastructure and secure integration into the energy system.

A recent EWEA(2007) report estimates that between 20 GW and 40 GW of offshore wind energy capacity will be operating in the European Union by 2020. In the period up to 2020, however, the amount of this potential that can be developed is limited by a number of factors; the extent to which the barriers are resolved will determine the capacity that will result. Industrial commitment and ambition, research and development efforts, political action at Member State and EU level and development of adequate grid infrastructure are all factors that will determine the level of offshore wind energy installations by 2020.

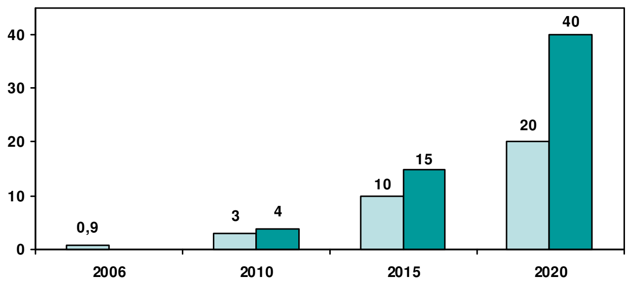


Figure 15. European offshore wind development (Cumulative, GW)
Source: EWEA, 2007

What is certain is that in order to maximise the delivery of offshore wind capacity, industry and governments must join forces. The role of national authorities is to provide a stable, predictable market framework which gives the industry the confidence to innovate and invest in the required manufacturing capacity.

On the industry side, the challenge is to create a sustainable offshore wind industry. While the onshore wind industry has become a global industry, offshore wind is still primarily based around a limited number of European Member State markets. No series production in offshore wind manufacturing and installation has yet been established, and the sector is still developing and utilising large specialised components rather than the standard components needed for reducing cost.

Scenarios of Market Development – The Mitigation Potential

Projections and scenarios of Wind Energy Market Development have been included in several Energy Scenarios produced during the last decade. The most widely referenced series of the “World Energy Outlook” of the IEA (IEA, 2004; IEA, 2007) unfortunately consistently underestimate the development of wind energy. Much closer to the real development have been the series of scenarios called “Wind Force 12” produced from 1999 to 2005 by European Wind Energy Association and Greenpeace Inernational.

In 2006 the Global Wind Enery Council, Greenpeace International and the German Aerospace Center (DLR) have produced the “Global Wind Energy Outlook” Scenario (GWEC, 2006) which examines the future potential for wind power up to the year 2050. Three different scenarios for wind power are assumed – a Reference scenario based on figures from the ‘World Energy Outlook” of the International Energy Agency (IEA, 2004), a Moderate version assuming that current targets for renewable energy are successful, and an Advanced version assuming that all policy options in favour of renewables have been adopted.

These are then set against two scenarios for global energy demand. Under the Reference scenario, growth in demand is again based on IEA projections; under the High Energy Efficiency version, a range of energy efficiency measures result in a substantial reduction in demand.

The results show that wind energy can make a major contribution towards satisfying the global need for clean, renewable electricity within the next 30 years and that its penetration in the supply system can be substantially increased if serious energy efficiency measures are implemented at the same time.

Under the Reference wind power scenario, wind energy would supply 5 % of the world's electricity by 2030 and 6.6 % by 2050. Under the Moderate scenario, wind energy's contribution would range from 15.5 % in 2030 to 17.7 % by 2050. Under the Advanced scenario, wind energy's contribution to world electricity demand would range from 29.1 % in 2030 up to 34.3 % by 2050.

All three scenarios assume that an increasing proportion of new wind power capacity is installed in growing markets such as South America, China, the Pacific and South Asia.

The costs and benefits of these scenarios include:

Investment: The annual investment value of the wind energy market in 2030 will range from €21.2 billion under the Reference scenario to €45 bn under the Moderate scenario and up to €84.8 bn under the Advanced scenario. In 2007 the annual investment has been €25 bn.

Generation costs: The cost of producing electricity from wind energy is expected to fall to 3.-3.8 €cents/kWh at a good site and to 4-6 €cents/kWh at a site with low average wind speeds by 2020.

Employment: The number of jobs created by the wind energy market will range from over 480.000 in 2030 under the Reference scenario to 1.1 million under the Moderate scenario and to 2.1 million under the Advanced scenario.

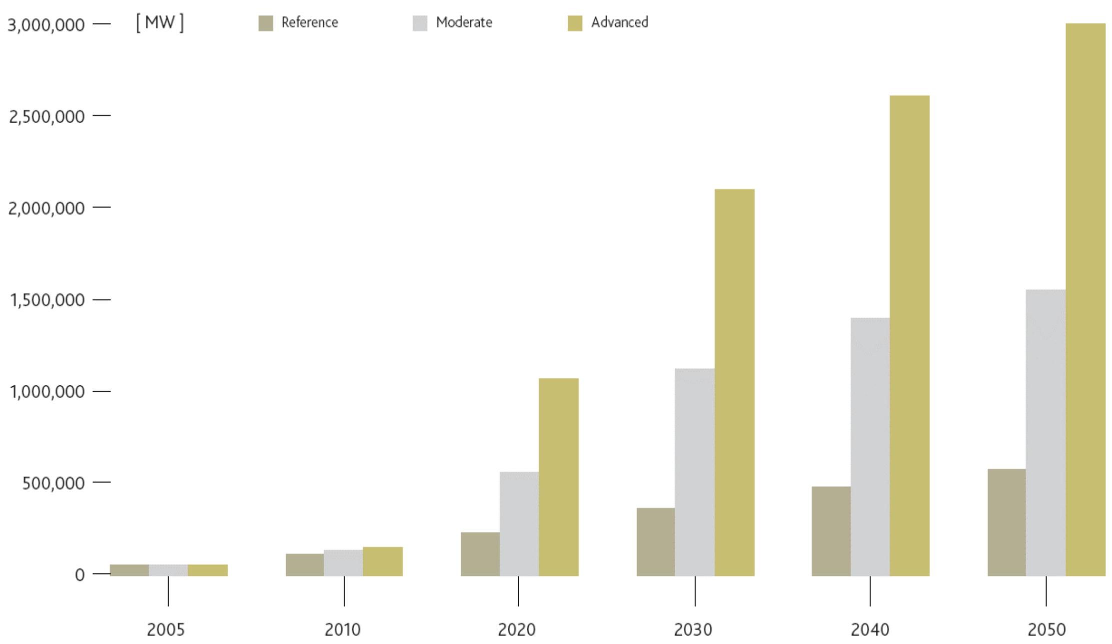
SUMMARY OF GLOBAL WIND ENERGY OUTLOOK SCENARIO FOR 2030

Global Scenario	Cumulative wind power capacity (GW)	Electricity output (TWh)	Percentage of world electricity (High Energy Efficiency)	Annual installed capacity [GW]	Annual investment (€ bn)	Jobs [million]	Annual CO_2 saving (million tonnes)
Reference	364	892	5 %	24.8	21.2	0.48	535
Moderate	1,129	2,769	15.6 %	58.3	45.0	1.14	1,661
Advanced	2,107	5,176	29.1 %	129.2	84.8	1.44	3,100

SUMMARY OF GLOBAL WIND ENERGY OUTLOOK SCENARIO FOR 2050

Global Scenario	Cumulative wind power capacity (GW)	Electricity output (TWh)	Percentage of world electricity (High Energy Efficiency)	Annual installed capacity [MW]	Annual investment (€ bn)	Jobs [million]	Annual CO_2 saving (million tonnes)
Reference	577	1,517	6.6 %	34.3	28.8	0.65	910
Moderate	1,557	4,092	17.7 %	71.0	54.2	1.39	2,455
Advanced	3,010	7,911	34.3 %	168.6	112.0	2.80	4,747

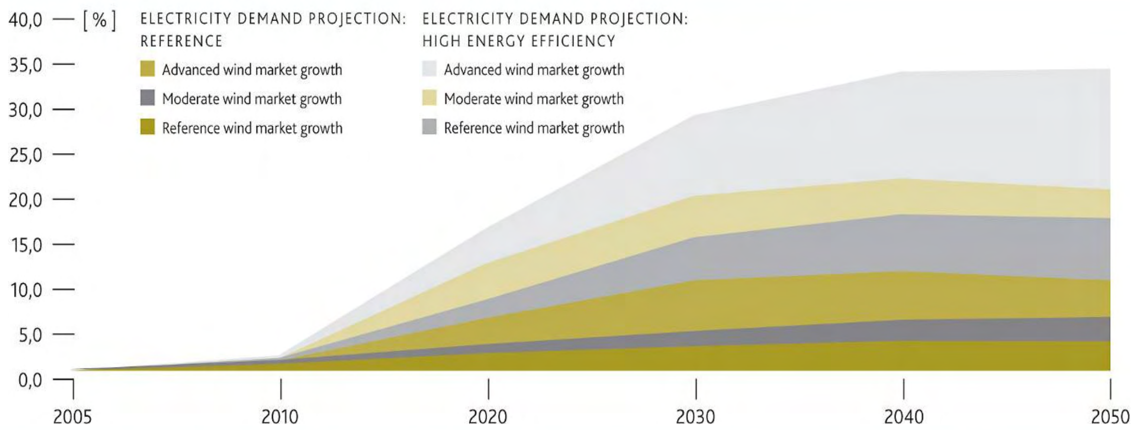
GLOBAL CUMULATIVE WIND POWER CAPACITY



GLOBAL CUMULATIVE CAPACITY [MW] AND ELECTRICITY GENERATION [TWh]

Year		2005	2010	2020	2030	2040	2050
Reference	[MW]	59,078	112,818	230,658	363,758	482,758	577,257
	[TWh]	124	247	566	892	1,269	1,517
Moderate	[MW]	59,078	136,543	560,445	1.128,707	1.399,133	1.556,901
	[TWh]	124	299	1,375	2,768	3,677	4,092
Advanced	[MW]	59,078	153,759	1.072,928	2.106,656	2.616,210	3.010,302
	[TWh]	124	337	2,632	5,167	6,875	7,911

WIND POWER PENETRATION OF WORLDS ELECTRICITY SUPPLY



3 DIFFERENT WIND MARKET DEVELOPMENT SCENARIOS - WITH DIFFERENT WORLD ELECTRICITY DEMAND DEVELOPMENTS

		2005	2010	2020	2030	2040	2050
WIND MARKET GROWTH - IEA PROJECTION ("REFERENCE")							
Wind power penetration of Worlds electricity in % - Reference (IEA Demand Projection)	%	0.8	1.5	2.7	3.5	4.1	4.0
Wind power penetration of Worlds electricity in % - High Energy Efficiency	%	0.8	1.8	3.6	5.0	6.3	6.6
MODERATE WIND MARKET GROWTH							
Wind power penetration of Worlds electricity in % - Reference	%	0.8	1.8	6.6	10.8	11.8	10.8
Wind power penetration of Worlds electricity in % - High Energy Efficiency	%	0.8	2.2	8.6	15.6	18.1	17.7
ADVANCED WIND MARKET GROWTH							
Wind power penetration of Worlds electricity in % - Reference	%	0.8	2.1	12.1	20.1	22.1	20.9
Wind power penetration of Worlds electricity in % - High Energy Efficiency	%	0.8	2.4	16.5	29.1	34.0	34.2

Source: GWEC, 2006

Carbon dioxide savings

A reduction in the levels of carbon dioxide being emitted into the global atmosphere is the most important environmental benefit from wind power generation. At the same time, modern wind technology has an extremely good energy balance. The CO_2 emissions related to the manufacture, installation and servicing over the average 20 year lifecycle of a wind turbine are "paid back" after the first three to six months of operation.

The benefit to be obtained from carbon dioxide reductions is dependent on which other fuel, or combination of fuels, any increased generation from wind power will displace. Calculations by the World Energy Council show a range of carbon dioxide emission levels for different fossil fuels.

On the assumption that coal and gas will still account for the majority of electricity generation in 20 years' time – with a continued trend for gas to take over from coal – it makes sense to use a figure of 600 tonnes per GWh as an average value for the carbon dioxide reduction to be obtained from wind generation.

This assumption is further justified by the fact that more than 50 % of the cumulative wind generation capacity expected by 2020 will be installed in the OECD regions (North America, Europe and the Pacific). The trend in these countries is for a significant shift from coal to gas. In other regions the CO_2 reduction will be higher due to the widespread use of inefficient coal burning power stations.

Taking account of these assumptions, the expected annual saving in CO_2 from the Reference scenario will be 339 million tonnes in 2020, rising to 910 million tonnes in 2050. The cumulative saving over the whole scenario period would be 22,800 million tonnes.

Under the Moderate scenario the saving would be 825 million tonnes of CO_2 annually in 2020, rising to 2,455 million tonnes in 2050. The cumulative saving over the scenario period would be just over 62,150 million tonnes.

Under the Advanced scenario, the annual saving in 2020 would increase to 1,582 million tonnes and by 2050 to 4,700 million tonnes. The cumulative saving over the whole scenario period would be 115,500 million tonnes.

The market development during the last two years (2006-2007) is larger even than the one assumed in the Advanced Scenario.

CONCLUSIONS

The most recent science shows that the climate problem is getting much worse much faster than was thought to be the case only a few years ago. The Intergovernmental Panel on Climate Change's 4th Assessment Report indicates clearly that to avoid the worst climate damages, global GHG emissions must peak and then begin to decline before the end of the next decade, and be reduced very rapidly after that to levels less than 50% below 1990 levels by 2050. This will require emissions reductions of at least 30% by 2020 from industrialized countries.

Precisely how low emissions need to go by 2050 or 2100 is a question which should be carefully watched as the science evolves, but the immediate task is to 'reverse the supertanker' and start on that downward trend before 2020. That is where wind power has a very critical role to play. The power sector is still the largest single source of greenhouse gas emissions. The options for making major emissions reductions in the power sector in the period up to 2020 are three: 1) efficiency; 2) fuel switching from coal to gas; and 3) wind power.

Wind power's contribution in the period up to 2020 could be reductions of more than 8 billion tons of CO2, 1.5 billion tons in 2020 alone. While the logical question to ask presently is if such huge numbers are practically achievable, most probably in the near future the governments will be asking the wind energy industry, 'can't you do more?'.

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Integration of renewable energy into future energy systems

Wolfram Krewitt
Systems Analysis and Technology Assessment, Institute of Technical Thermodynamics,
German Aerospace Center (DLR)
Stuttgart, Germany

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I. Background

Renewable energies are expected to play a key role in reducing global greenhouse gas emissions, and thus making the future energy supply system more sustainable. Due to a re-inforced exploitation of energy efficiency measures and renewable energy potentials, renewable energies by 2050 can achieve a share of up to 70% of the global electricity generation, and 65% of global heat supply (see Fig. 1 and 2). Because of the partly fluctuating nature of some renewable energy sources, a key challenge in such a supply system is to properly match load and supply. In our current energy supply system, we are capable of dealing with significant variability in demand, but we are used to look at the supply side as combining a given set of 'base load', 'middle load' and 'peak load' power plants. With an increasing share of renewable energies, the concept of 'base load' versus 'peak load' power plants will become less meaningful. The issue at stake will be to guarantee firm capacity from a number of various energy technologies and energy sources. Innovative concepts for pooling various decentralised renewable energy sources, using energy storage options and for long distance energy transport between supply and demand clusters are required to integrate renewable energy sources into a reliable supply system

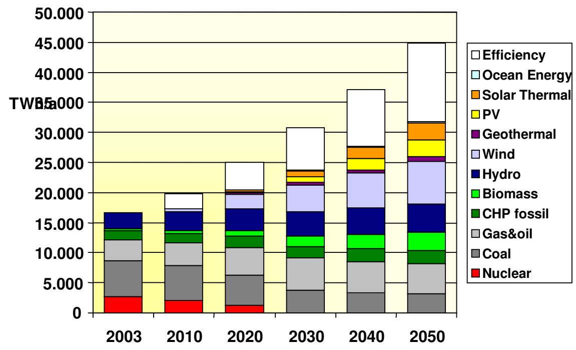

Figure 1: Development of future global electricity supply under the 2°C Scenario (Krewitt et al. 2007)

II. Understanding temporal and spatial variations in the availability of renewable energy sources

Temporal variations in the availability of renewable energy resources are often considered to be a key barrier towards a supply system with high shares of renewable energy. While basically various technical options are available to match supply and demand, including load management, energy storage and energy transport, high quality information on the availability of renewable energy sources in space and time is required to apply these options in the most adequate way. Two different time-scales are relevant for different levels of information:

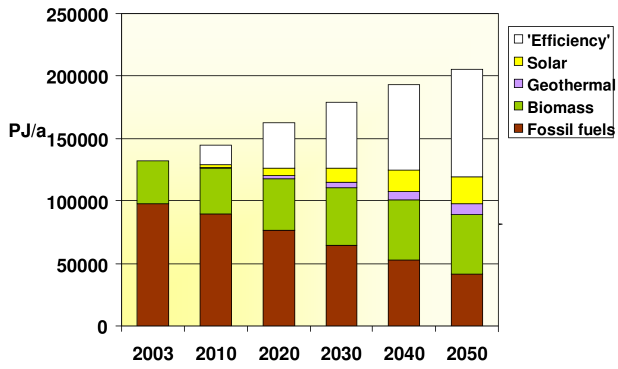

Figure2: Development of future global heat supply under the 2°C scenario (Krewitt et al., 2007)

Short term forecasting (e.g. day ahead) is required to schedule the dispatching of power plants in the supply system. For the development of future renewable energy exploitation strategies, long term historic time series are needed to provide information on the average availability of the respective resources in a given region.

While the exploration of fossil resources is a well established activity both in research and industry, the field of 'energy meteorology' is a quite new scientific discipline, which however faces rapidly growing interest. New tools and algorithms are developed, which partly make use of remote sensing data. Current short term wind energy forecast systems achieve an average accuracy of more than 95% for the day-ahead forecast, and of more than 96% for the 4-hours forecast (Rohrig, 2006).
Figure 2 exemplarily shows high temporal and spatial resolution data on solar irradiation, which is available as long term time series. Translating the solar irradiation into PV electricity generation potential (only adequate roof area within settlement areas is used for PV) shows that even on a cloudy autumn day at lunchtime the PV electricity generation potential

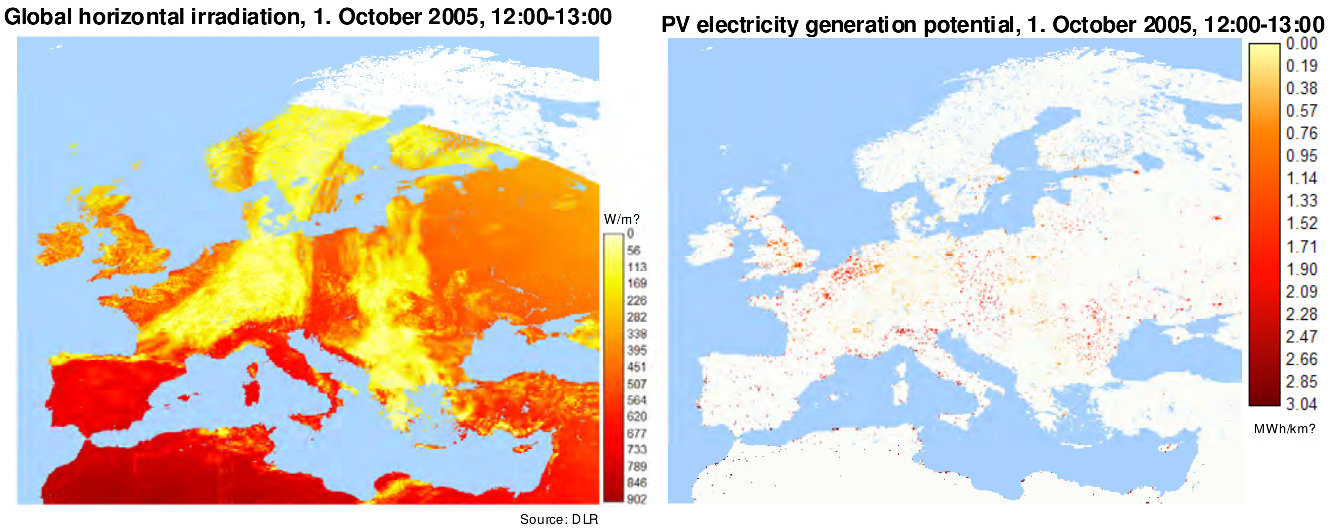

Figure 2: Solar resource assessment based on satellite data, and resulting PV electricity generation potential (PV only on roofs in settlement areas) (Scholz, 2006)

(164 GWh) can cover nearly half of the European demand (345 GWh). As it is expected that PV electricity generation will reach grid parity within the next ten years (i.e. PV electricity will be competitive against electricity from the grid), the operation of PV panels will become an economic option for millions of households, with significant implications on electricity supply structures.

Integration of renewable energies into electricity supply systems

Distributed electricity generation

Higher shares of renewables in the supply system lead to an increased level of decentralisation. In conventional grid structures, electricity is fed into the grid at high voltage levels by relatively few, large power stations, and is brought to the customer via several intermediate grid levels. As generation becomes more widely distributed, the number of electricity sources increases, and the direction of flow can be reversed. The distribution grids assume the function of transporting electricity in different directions and become service providers between generators and consumers. Central power stations will continue to exist, but in addition there will be a large number of smaller, distributed systems. This change in structure demands the coordination of the operation of a large number of systems in the electricity network, which is facilitated by adequate information and communication technologies (see Degner et al, 2006). Current grids are not designed in a way that major amounts of electricity can be fed into the distribution grid. However, technical solutions are under development, including e.g. converter technologies that even can provide ancillary services to the grid, and control schemes that enable a high penetration of distributed generation in distribution grids.

Technical issues related to quality of supply, power quality, grid control and stability, and safety and protection are considered as main barriers for a high deployment of decentralised generation. There are a number of approaches to remove these barriers and thus lead to better integration of decentralised generation (Scheepers et al., 2007):

- Active management of distribution systems increases the amounts of distributed generation that can be accommodated. Typical examples are voltage control in rural systems and fault level control in urban systems through network switching.
- The active network management philosophy is based on the concept of intelligent networks where technological innovations on power equipment and information and communication technologies are combined to allow for a more efficient use of distribution network capacities. It includes the active involvement of both consumers and distributed generators: load and generation characteristics are taken into account in network operation and planning.
- High numbers of small generators pose problems to system operators as they displace large central generation which presently is used for system control. The virtual power plant concept aims at pooling small generators either for the purpose of trading electrical energy or to provide system support services.

- The micro-grid concept is based on the assumption that large numbers of micro-generators are connected to the network and that these can be used to reduce the requirement for transmission and high voltage distribution assets. The individual micro grids are arranged to be able to operate autonomously in the case of loss of supply from the higher voltage networks.

A lack of incentives for the distribution system operators is a main barrier towards the deployment of decentralised generation. Often the distribution system operators maintain a passive operation philosophy rather than treating distributed generation as an active control element in the operation and planning of their networks. Many distributed system operators regard distributed generation as an additional complexity and thus fear additional costs. Aggravation of market access due to various entry barriers is another main obstacle. A high degree of concentration on the power markets renders it difficult for small distributed generation units to establish themselves on the market (Scheepers et al., 2007).

The regulatory context is of key importance for deployment of distributed generation. The regulatory regime should at least neutralise the negative total impact of increasing distributed generation on the system operator's allowable costs, and it needs to remove any existing biases against the introduction of active network management.

Electricity Storage

Energy storage in an electricity generation and supply system enables the decoupling of electricity generation from demand. Some of the renewable energy technologies have no inherent storage capabilities. Storage can improve the economic efficiency and utilisation of the entire system. By optimising the existing generation and transmission assets in the market, less capital could be needed to provide a higher level of services, at the same time allowing fluctuating renewables more opportunities for development.

A broad range of different electricity storage technologies is available, which differ with respect to e.g. their capacity, typical duty cycles, response time to full power, load following capability. Table 1 provides a summary of storage technologies relevant in our context, and their respective typical applications. There are some interesting new developments like

- Adiabatic compressed air energy storage (CAES, Figure 4), which in contrast to conventional CAES incorporates the compression heat into the expansion process and thus does not need additional fuel. The efficiency for an adiabatic CAES is up to 70%.
- Lithium-ion batteries, which became the most important storage technology in portable applications in recent years. The efficiency is 90-95%, and the gravimetric energy density is superior to all other commercial rechargeable batteries in the capacity range of kWh and above.
- Redox-flow batteries, a technology well suited for large-scale applications because the electrolyte can be stored in big tanks. The system efficiency today is in the range of 60-75%.

The economic performance of a storage system very much depends on the conditions under which it is operated. It is determined by the system's power plant mix, fuel prices, electricity prices, prices for grid services, regional interconnection of supply and demand, etc. There is a quite extensive literature available on the technical and economic characterisation of storage technologies, but there is a lack of modelling studies analysing trade-offs between load management, grid management, electricity transport and electricity storage in systems with high shares of renewable energies.

Table 1: Storage application (Kleimaier et al., 2008)

	X-Large Scale	Large Scale	Medium Scale
Response time	> 15 min	< 15 min	1s-30s[1)] / 15 min[2)]
Typical discharge times	days to weeks	hours to days	minutes to hours
Storage technologies	Hydrogen storage systems	Compressed air storage (CAES) Hydrogen storage systems Pumped hydro	Batteries (Li-Ion, lead-acid, NiCd) High temperature batteries Zinc-bromine batteries Redox-flow batteries
Applications	reserve power compensating for e.g. long lasting unavailability of wind energy	Secondary reserve Minute reserve Load levelling	[1)]Primary reserve [2)]Secondary & minute reserve Load levelling, peak shaving

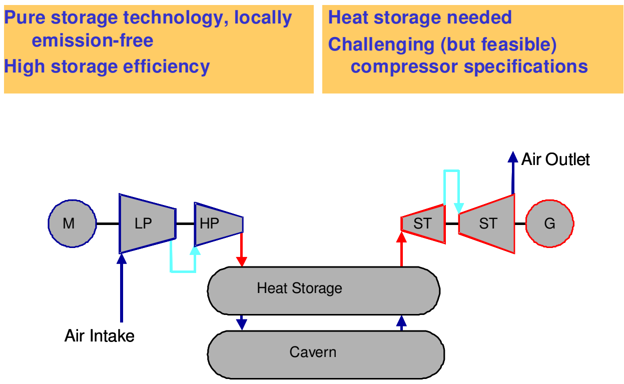

Figure 4: Adiabatic compressed air energy storage system

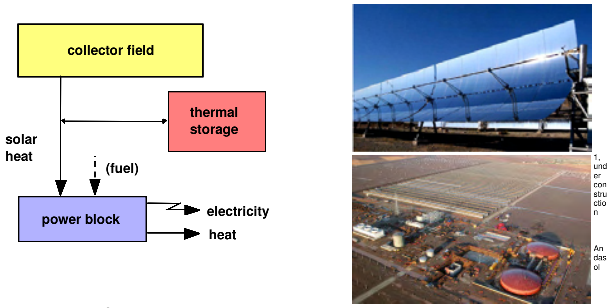

Figure 5: Concentrating solar thermal power plant with heat storage

Figure shows the concept of a concentrating solar thermal power plant with an on-site heat storage system. The 50 MW Andasol I power plant currently built in Spain is equipped with a molten salt thermal storage system, which has a capacity equivalent to 7 full load hours. Such a power plant can deliver dispatchable solar bulk electricity. The sun belt regions (e.g. Middle East/North Africa) offer huge potentials of direct solar irradiation, which can be exploited in a cost efficient way by using concentrating solar thermal power plants.

Long distance electricity transmission

While energy storage decouples supply and demand in time, the transmission of electricity can decouple supply and demand in space. Transmission of electricity allows the pooling of different renewable energy sources even on a trans-continental level, and can link areas with large renewable energy resources to regions with high electricity demand. While conventional Alternating Current transmission technology is not suited to transmit electricity across distances of more than 500 km, the High Voltage Direct Current (HVDC) technology can be used to link e.g. the vast solar resources in the world's sun belt to demand centres, thus facilitating the provision of dispatchable solar bulk electricity (see e.g. Trieb et al., 2007).

One of the advantages of HVDC is the low cost for transmission of very high power over very long distances, which are in the range of 0.5-1.5 €ct/kWh (for 700 TWh, 150 GW, 3000 km) (Asplund, 2007; Trieb 2007). The total losses to transmit power over 3000 km are in the order of five percent. Today's HVDC schemes have maximum power of 3000 MW and the transmission distances are around 1000 km. A new type of converters, called HVDC Light, was introduced in the late 1990s. Unlike the case for AC cables, there is no physical restriction limiting the distance or power level for HVDC underground or submarine cables. There is an emerging market of this new technology to transfer power in the sea, e.g. from wind parks, and to strengthen the electricity grid in areas where overhead lines cannot get permits within a reasonable time.

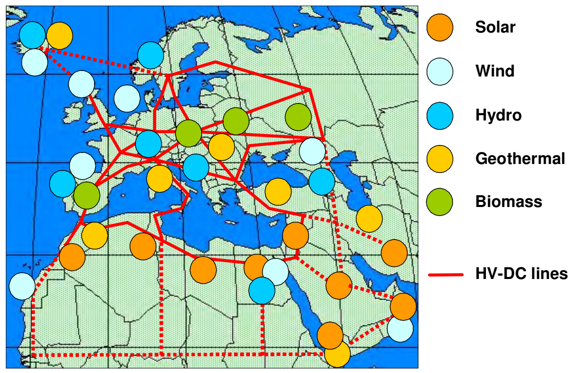

Figure 6: Concept of a HVDC based trans-continental ‚super grid' (Trieb et al., 2007)

IV. Integration of renewables into heat supply systems

District heating systems

District heating systems offer significant advantages for the integration of economical large-scale renewable heating. A large share of the renewable energy potential can be exploited only in settlement areas with a district heating supply system. The relevant renewable energy resources are biomass, solar, and geothermal heat.

In the case of biomass, the integration into a district heating system allows the operation of larger facilities, which have lower specific investment costs than small scale boilers. Large heating plants (> 2 MW) can economically be equipped with emission abatement technologies. As a consequence, requirements towards the quality of the biomass can be less stringent without failing to comply with emission standards, which again reduces costs. The very efficient combined production of heat and power requires an adequate heat demand, which in many cases is available only when pooling individual consumers in a district heating network.

In the case of deep geothermal heat, the exploitation of large heat flow volumes is required to compensate the high drilling costs. In most cases, the corresponding large heat demand is only available in district heating networks. Due to its relatively low thermal efficiency, also geothermal electricity generation goes along with producing a significant amount of waste heat. Selling the waste heat might be crucial for the economic performance of geothermal electricity production, which is possible only if large consumers are available. In most regions of the world, the potential for deep geothermal heating is very small without district heating networks. Near-surface geothermal energy can be used in heat pumps.

District heating systems are a prerequisite for the integration of economical large-scale solar heating systems with seasonal storage. Central solar heating plants with seasonal storage aim at a solar fraction of 50% or more of the total heat demand for space heating and domestic hot water. Figure shows the main components of a central solar heating plant with seasonal storage. The energy gained by the solar collectors is delivered via a collecting network to the heating central. From there, heat is either supplied directly to the consumer (in case of demand) or the surplus heat arising in summer is transferred to a seasonal heat storage to be used for space heating and domestic hot water supply in autumn and winter. A gas or biomass boiler can cover the remaining heat demand. A key component is the seasonal heat storage (see also next section). Currently four different storage types have been developed:

- The hot water heat storage has the widest range of utilisation possibilities, as it can be used independent of geological conditions, and also in small size, e.g. as a heat storage for a period of days. It consists of a water-filled containment of steel-enforced concrete, which is partly submerged into the ground.
- A gravel/water heat storage consists of a pit sealed with a water-proof synthetic foil, filled by a storage medium consisting of gravel and water. No static support structure is necessary.
- Ina duct heat storage, solar heat is conducted via U-tubes probes directly into water-saturated soil. These poly-butane tubes are inserted into bore holes with a diameter of 10-20 cm, which are 20 to 100 m deep. The operational behaviour is slower than for the other heat store types, as heat transport within the store occurs mainly by heat conduction.
- Aquifer heat storage uses naturally existing closed layers of ground water for storing heat. Via well bore holes ground water is taken out of the store, heated, and then pumped back into the store through another bore hole.

Each of the four types of seasonal heat storages has been realised in demonstration plants. Operational performances are in the expected range. The choice of a certain type of storage system depends on the local geological and hydro-geological conditions. Further R&D is required to increase storage efficiency and to reduce costs.

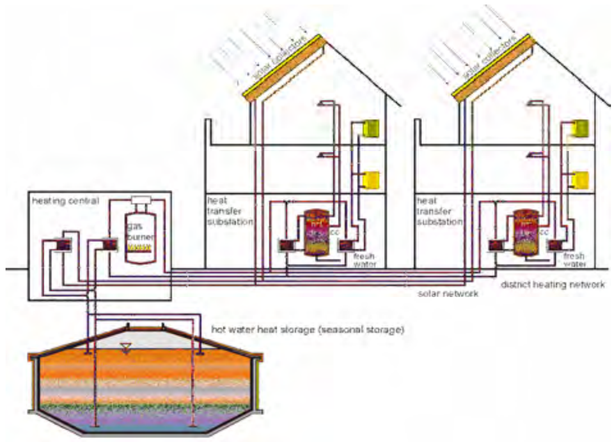

Figure 7: Scheme of a central solar heating plant with seasonal storage (Heidemann et al., 2006)

Heat storage for temperatures from 50–500 °C

Increased use of renewable energies, intensified use of waste heat and a large scale expansion of combined heat and power systems will not be possible without the availability of technically and economically attractive heat storage systems. Figure shows the range of temperatures and the wide-ranging applications of heat storage systems (Müller-Steinhagen et al., 2007). The storage capacity ranges from a few kWh up to GWh, the storage time from minutes to days and even months, and the temperature from -20°C up to 1000 °C. This is possible only by using different storage materials (solids, water, oil, salt, air) and the corresponding thermal storage mechanisms. To achieve high shares of renewables in heating and cooling, more efficient and compact systems are required. The target of the European Solar Thermal Technology Platform is to increase storage density over water by a factor of 8 by 2030, which is considered to be very challenging, but not impossible.

Due to its outstanding thermodynamic properties and its cost effectiveness, water is still the preferred storage medium if permitted by temperature and available space. In household applications, hot water heat stores are almost exclusively used. The development of very large heat storage systems for seasonal heat storage has made considerable progress, but further research on improved insulation materials and design methods is required to reduce heat losses. Heat storage systems using latent heat of fusion or evaporation (so called Phase Change Materials, PCMs) or the heat of sorption offer higher storage densities. Sorptive and thermochemical processes allow thermal storage for an almost unlimited period of time, since heat supply or removal occurs only if the two physical or chemical reaction partners are brought into contact. Both latent and sorptive heat storage technologies today are in a relative early development phase. Suitable concepts for storing process heat above 100°C include solid sensible heat stores, liquid salts, phase change materials, steam storage, and reversible chemical reactions. For most advanced high temperature storage concepts, there is still significant demand for R&D activities both at fundamental and applied level.

Solar thermal power plants concentrate solar radiation to produce heat at temperatures from 300 to above 1000 °C, which is used to run a steam turbine or combined cycle process. Storing some of the heat during the sunshine hours, the solar share of the power block is increase, and the power plant can supply dispatchable power. Power plants currently built in Spain use molten salt to store sufficient thermal energy to operate for 7 full-load hours without solar radiation. Heat storage based on sensible heating of solid concrete is expected to offer more economic solutions. On the long term, storage concepts using phase change materials to store heat at temperatures up to 1000 °C are required to run solar thermal power plants with high efficiency gas turbines.

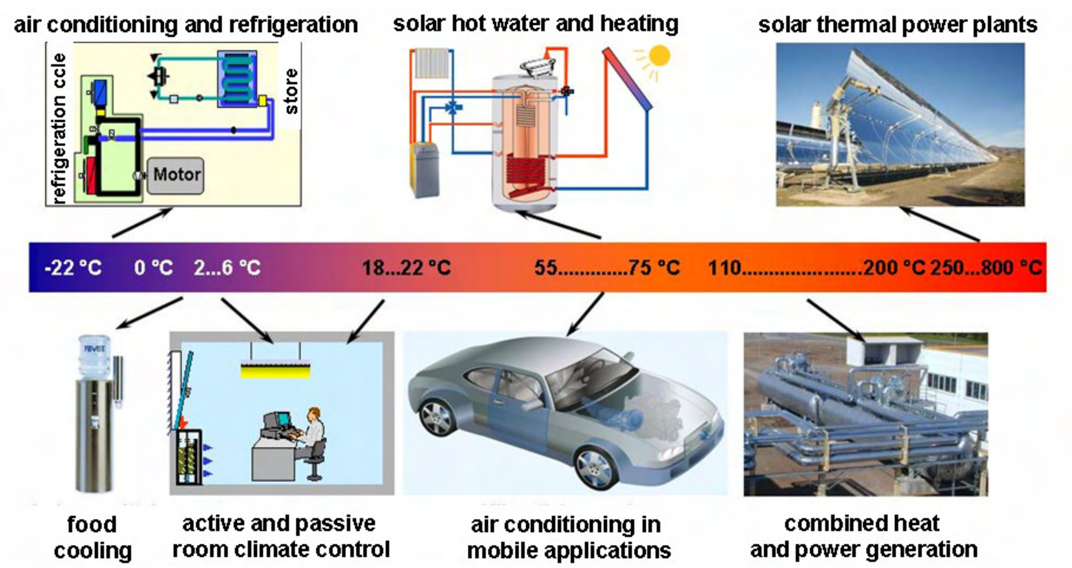

Figure 8: Examples and temperature range for thermal storage (Müller-Steinhagen et al., 2007)

V. Conclusions

A wide range of technical options is available to facilitate the integration of high shares of renewable energy sources into energy supply systems. Experience from the last decade confirms that new and increasing requirements for system integration resulted in fast and continuous innovation. Several demonstration projects around the world show that systems with a high share of fluctuating renewables can be managed in a reliable way. Future work is required to better understand the trade-offs between options for improved grid management, energy storage options, and energy transport between regions with different supply and demand patterns.

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Mitigation potential, cost of renewable energy systems and costs of transition

Manfred Fischedick, Wuppertal Institut

With contributions from: Carmen Dienst, Magdolna Pranter, Nikolaus Supersberger, Johannes Venjakob, Peter Viebahn.

I. Introduction

For the discussion of how renewable energies can contribute to climate protection it is not only necessary to get detailed knowledge about specific characteristics of the different technology options. The assessment of the overall mitigation potential of the mix of renewable energy, the corresponding costs for each element and for the transition paths in total is also of utmost importance. Aspects of system integration, covered in the previous chapter, determine the possibilities and limits of a further extension of renewable energies.

In this context this chapter

- summarizes the current knowledge about the renewable energy potentials
- discusses the role of renewable energies within already existing global energy scenarios and defines the relevant determining parameters (especially costs are a decisive aspect of how far a transition path can be realized)
- gives a literature overview about the costs of renewable energy technologies as such and assesses the costs of combined extension paths (in particular the latter figures are not independent of the behaviour of the energy system as a whole)

The task of the chapter is to create a better feeling of which contribution renewable energies can make to match the climate protection challenge. Nevertheless the role of renewable energies in distinct future paths is not only determined by the climate change topic, but also by a number of future challenges (e.g. security of energy supply). Last but not least the keynote presentation can only be seen as an impulse for discussion (first step analysis) and cannot give a comprehensive overview or analyse the total number of existing literature sources. That will be the task of the special report itself, whose preparation is suggested, as one can identify several improvement options for the description of renewable energies. Furthermore several open questions arouse during the preparation of this paper.

II. Overall potential of renewable energies

The IPCC AR4 gives an overview of the worldwide renewable energy potentials. All sources of renewable energies are analysed concerning current status and global technical potential. Figure 1 gives an overview of the numbers listed in the report. One structural problem becomes evident: Different sources and different methods have been used to determine the potentials. In that context a comparison and also a realistic classification of the potentials become difficult.

	Current use	Technical potential	
Hydro (large)	2.800 TWh (1)	6.000 TWh (2),(3)	(1) BP 2006 (2) BP 2004 (3) IEA 2006a (4) WEC 2004d (5) Martinot et al 2006 (6) IEA 2006b (7) Archer and Jacobsen 2005 (8) Johansson et al 2004 (9) Aringhoff et al 2003 (10) IEA 2003h (11) Renewables 2004
Hydro (small&micro)	4 TWh (4), 250 TWh (5)	150-200 GW	
Wind	0,5 % global (6)	126.000 TWh (7), 600 EJ (8)	
Biomass	46 EJ (6)	250 EJ (8)	
Geothermal	2 EJ (8)		
Solar thermal electric		630 GW in 2040 (9), 4.700 GW in 2030 (10)	
Solar photolvoltaic		450.000 TWh (4),(11)	
Ocean, wave energy		500 GW (4)	
Ocean, marine currents		10 TW/h (3)	

Figure 1: Overview of global renewable energy potential (IPCC 4 AR, 2007)

So far interdependencies will be discussed in terms of possible synergetic effects and conflicts, being complementing or competing climate protection options.

The chapter pays attention to the state of the art already been covered in IPCC AR4. But it goes a step beyond and concentrates on weaknesses and gaps of the current description as well as the dynamics of the development.

Additionally it should be mentioned that most of the referred sources are not primary sources. Figure 1 presents nothing more than a compilation of secondary sources. Just to give an example: one of the most important sources is the background paper being prepared for the International Renewable Energies Conference 2004 in Bonn (Johansson et al. 2004). The paper refers to the year 2000 report of the UNDP „World Energy Assessment: Energy and the Challenge of Sustainability“. Although this report was updated in 2004, no new information was given on the potentials of renewable energies. The report of 2000 relies on sources mainly dating back to the end of the 1990s. It can be assumed that this path can - at least in some parts - be backtracked for another few years and sources.

Apparently there seems to be a great need for updating. It should be investigated where the potentials data used in current publications come from, how valid they still are and with which methodology they were determined. It is also important to get more information on the preconditions the evaluations were based on.

As analyses of renewable energy potentials are the essential basis for current and future scenario designs, a detailed check of the given data regarding validity and significance is necessary and should be focused on the following aspects:

Assumptions and preconditions (e.g. cost status) of the existing estimations

Validity of these assumptions

Influence of current technical innovations on the potentials of renewable energies

Examination of current studies on potentials (new methodologies and aspects?)

Influence of future changes on the renewable energies (e.g. climate change impact on renewable energies, demographical developments, competition for limited resources)

Availability of new approaches and methodologies (e.g. GIS-modelling[8]) for the determination of potential that have not yet been taken into consideration in the surveys of the IPCC

It has to be considered that there is always a competition between the accuracy and quality of potential data on the one hand and the necessary quantity of input-data on the other hand. Methodologies employed on the regional level are mostly unappropriate approaches for estimations on global level. Data availability and complexity of data let rough estimates appear as yet the only possible approach on a global level.

III. Role of renewable energies in existing scenarios

Scenarios are analytical tools that describe our possible future energy supply under different assumptions. In the past many scenarios have been developed, but not all of them show detailed data for renewable energies. The share of renewable energies in primary energy supply remains the dominant factor for most scenarios (cf. figure 2). Another indicator is the share of renewable energies in electricity generation. Few scenarios show the share of renewable energies in final energy or in low-temperature or their relevance as transport energy.

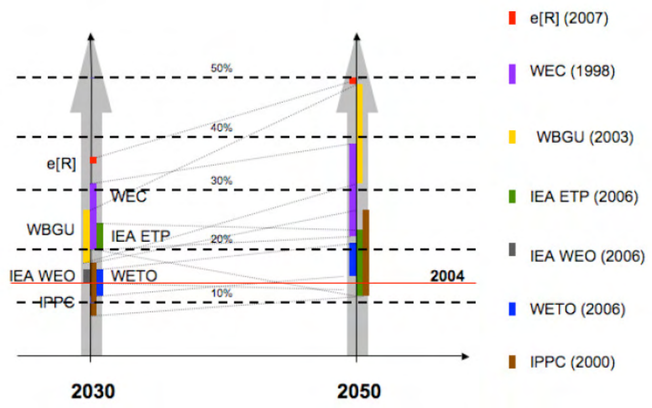

Figure 2: Share of renewable energies in the primary energy supply in different world scenarios

Figure 2 includes the renewable energy development outlined in different scenarios and scenario families (as most of the scenarios represent a set of different scenarios grounding on similar frame conditions as population growth). In figure 2 scenario families are indicated through a wider bar showing their range of results for renewable energies for the years 2030 and 2050. The share of renewable energy sources in the described energy scenarios differs significantly from something between 11% and 50% for the year 2050. It is worth to mention that in this compilation the IPCC-SRES scenarios rather mark the lower end than being comparably optimistic. By 2050 the IEA *ETP reference scenario* shows one of the lowest shares of renewable energies with 11% share in primary energy, while several other scenarios such as *Energy [r]evolution* (a study conducted on behalf of Greenpeace) and WBCSD’s scenario reach almost 50% share by 2050.

A multitude of reasons is responsible for the significant differences between the scenario results:

Storyline of the scenario (e.g. Business as Usual scenarios or intervention, target-oriented scenarios)

Assumptions directly related to renewable energies (e.g. potentials, costs, learning curves, barriers and obstacles, structural effects, feasibility of intervention policies)

Modelling philosophy and methodology (most of the models are “structure-conservative”: they keep conventional structures, but do not accept significant technological and infrastructural changes)

Status, development perspectives and implementation rates of competing strategy elements (e.g. availability and costs of CCS, energy efficiency improvements).

[8] Regarding the question of current surveys, the reports of the International Institute for Applied Systems Analysis (IIASA) may be mentioned as an example. The Global Agro-Ecological Zones-Assessment (AEZ) is a methodical approach to calculate the potential yields of agricultural areas, based on GIS-modelling – a novel approach for the analysis of biomass potential worldwide.

It must be considered that the scenario modellers use different calculation methods making the comparison difficult. In most cases either the “substitutional method” or the “efficiency or IEA method” is used. Both methods show differences in how to account for renewable energies within the primary energy mix. The “efficiency method” counts the electricity outcome directly as primary energy while the “substitution method” counts the equivalent of primary energy from fossil fuels needed to generate the same amount of electricity. The usual correlation factor is 1/0.38 or 2.6. The consequences of these effects are discussed in (Martinot et al 2007). Another comprehensive comparison of world energy scenarios can be found in (Hamrin 2007). Furthermore the categorisation of traditional biomass use causes other discrepancies. Traditional biomass use represents about 9% of primary energy consumption. Some authors exclude traditional biomass from renewable targets and some scenarios argue that traditional biomass is not sustainable. In contrast, many other modellers, e.g. the IEA, do not differentiate between traditional and modern biomass use, or do not specify whether traditional biomass is included or not.

Learning – i.e. learning curves or the potential of endogenous technology change - play a significant role. The learning curve concept links investment costs to the amount of installed technology units: the higher the number of installed units, the lower the investment costs will get (hence the lower the generation costs of useful energy will get). Learning curves are basically time independent. Combined with assumptions about corresponding market penetration rates learning curves can be linked to the dimension of time, making statements on the cost development of technologies in a certain time span possible (cf. figure 3).

Often energy scenarios are including economic assumptions to some degree. Econometric models and cost optimisation models strongly rely on cost assumptions of future technologies. Hence, they are very sensitive towards differences in learning curves. Real life dynamics show interdependences of learning curves, cost aspects and the amount of disseminated technology units: The quicker cost decreases can be realised, the more units will be disseminated, and the more units will be disseminated, the quicker costs will decrease: a circle of mutual amplification develops. However, these complex dynamics are oversimplified in many scenarios, using fixed learning curves instead. This partly leads to an underestimation of cost decreases of renewable energy technologies, underestimating chances for real technology dissemination.

It is one of the most urgent and pressing needs to establish reliable learning rates and curves to be able to include real life cost functions in energy models and scenarios. The complex interdependences using reliable databases allow valuable understanding of and insights into the dynamics of energy system change. Knowledge of this type is a prerequisite for the formulation of energy policies.

The IPCC AR4 includes some of the best databases currently available for cost developments. However, these databases are one-dimensional, not including varying learning dynamics comprised of both aggregate production and temporal aspects. Thus different degrees of dissemination over time cannot be reflected in the cost development of technologies.

Different learning dynamics on the time axis are shown in figure 3. The different curves show two results:

- different technologies have different learning dynamics
- depending on the framework (be it political or economical or both) learning curves develop in different ways: the more optimistic the underlying assumptions, the more pronounced cost decreases of technologies actually are
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Although using different sets of learning curves allows more sophisticated approaches to energy system modelling, insecurities persist. The challenge is to minimise these insecurities.

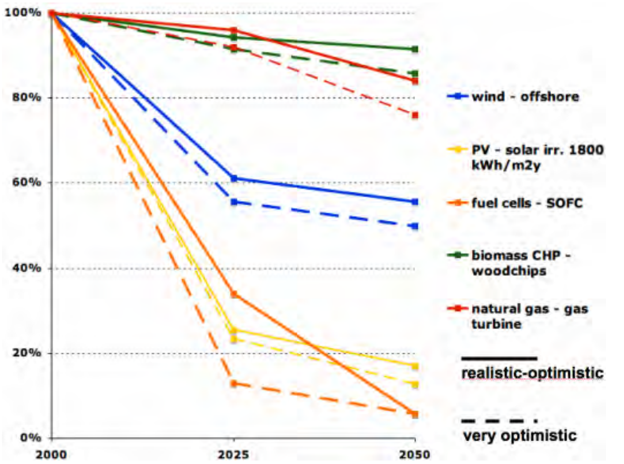

Figure 3: Development of technology costs depending on the assumptions on political and economical environment in NEEDS energy scenarios: very optimistic scenario assuming very positive surroundings, realistic-optimistic scenario assuming not so positive surroundings (data based on: Krewitt et al, NEEDS 2007)

As the share of renewable energy in the primary energy apply does not tell anything about the efforts necessary to provide the required technologies and to cover the related costs it seems to be sensible to add a scenario comparison based on the absolute primary energy demand (cf. figure 4). Once more this figure shows the large range of the possible contribution renewable energies could provide.

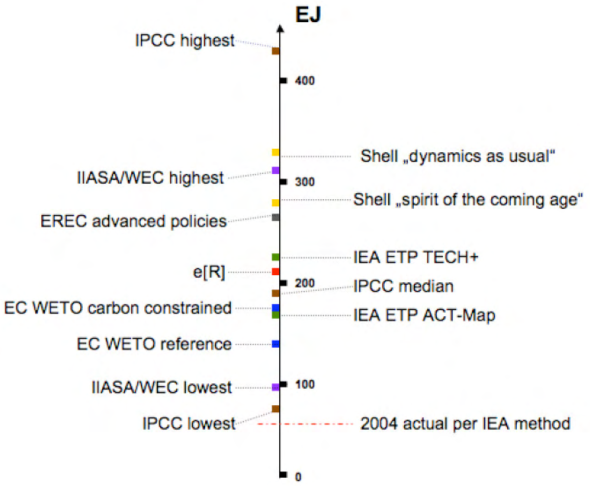

Figure 4: World Primary Energy from renewable energies in 2050 in different world scenarios

There is only little variation among the different *baseline* scenarios in figure 4 regarding the role of renewable energies in the future. Alternative scenarios show a broader range of differences. The world primary energy supply based on renewable energies in 2050 varies from 70 EJ to 450 EJ between the scenario groups. In comparison to figure 2 this compilation shows that actually those scenarios characterized by a comparably large *share* of renewable energies need not necessarily belong to the group of scenarios characterized by an extremely high total primary energy contribution of renewable energies. The best example for this is the *Energy [r]evolution* scenario which marks the upper edge of figure 2 (with a share of 50% renewable energies in 2050) and is to be found in the medium range of figure 4. It is the overall system behaviour and the development of other strategic elements (in particular the energy efficiency) that make the difference.

IV. Mitigation potential

Mitigation potentials are very important for the discussion about climate protection assumptions. Here mitigation potential is understood as the dedicated contribution of renewable energies to greenhouse gas reduction in climate protection scenarios. In that context the mitigation potential is not directly corresponding to the overall renewable energy potential discussed in chapter 9.2. It is mostly only a part of it taking constraints for the use of renewable energies into consideration as well as system interdependencies.

As mentioned before, in many existing scenario surveys one can find statements on the role of renewable energies in primary energy supply, but the corresponding contribution of renewable energies to the reduction of greenhouse gas emissions or even CO_2 emissions is often omitted. The reason is that several types of models face methodological restrictions (e.g. low disaggregation level of the energy system within economic models) or data access for the public is limited. Only a limited number of surveys directly pay attention to the GHG mitigation potential (e.g. IEA Energy Technology Perspective), most of them concentrate on one country or specific sector (e.g. electricity system).

In IPCC AR4 for a selected number of scenarios the mitigation potential for different time periods were outlined (cf. figure 5). The figure shows cumulative emissions reductions for alternative mitigation measures from 2000 to 2030 and 2000 to 2100. The numbers are based on different models and calculated for different stabilisation levels (dark bars show the

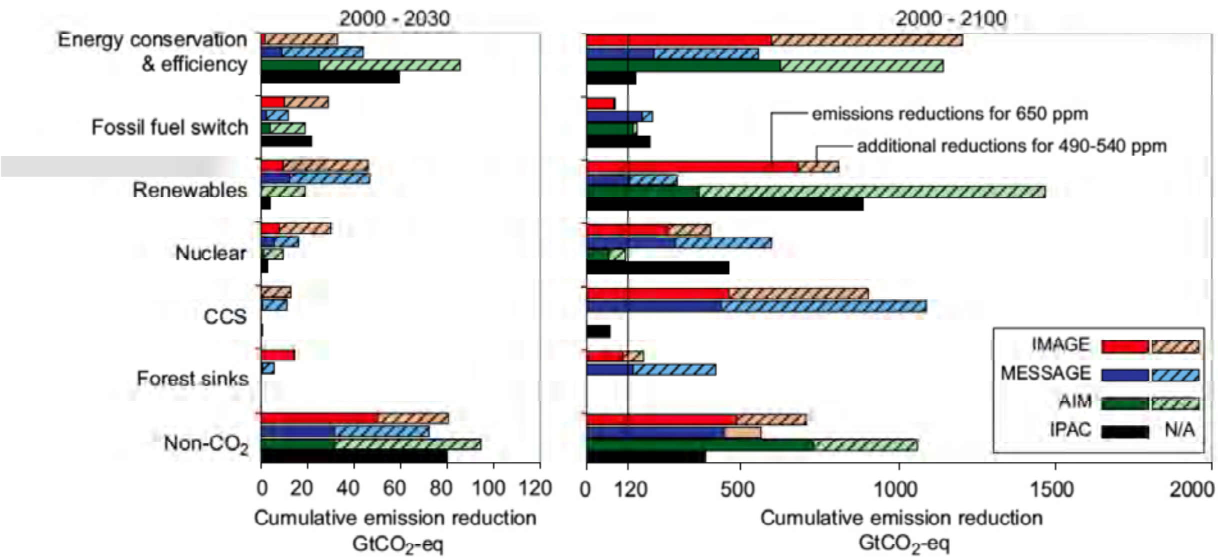

Figure 5: Mitigation potential of different measures resulting from distinguished stabilisation scenarios and based on different models (IPCC AR4 2007)

resulting mitigation requirements for a stabilisation level of 650 ppm CO_2-eq; light bars show what is additionally necessary to achieve more sophisticated stabilisation targets in the range of 490 to 540 ppm CO_2-eq.
Figure 5 clearly shows that the resulting CO2 emissions reductions of each strategy option are strongly dependent on the targeted stabilisation level and the used model. However, it can be seen that the extension of renewable energies is an essential strategic element for climate protection.

	Potential contribution to electricity mix (%)	Additional generation above baseline (TWh/yr)	Net extra emissions reductions ($GtCO_2$-eq/yr)	Cost ranges (US$/t$CO_2$-eq)	
				Lowest	Highest
OECD	10	687	0.45	-16	33
EIT	5	99	0.06	-16	30
Non-OECD	5	572	0.42	-14	27
World	7	1358	0.93		

Figure 6: Potential greenhouse gas emission reduction and costs in 2030 for wind power replacing fossil-fuel thermal power plants (IPCC AR4 2007)

In the selected scenarios the contribution to stabilise greenhouse gas emissions increases not only due to more sophisticated stabilisation targets (which are in economic models related with higher CO2-prices), but in particular increases significantly in the later time period.

Technology Perspectives (ETP) conducted by the IEA in 2005; IEA 2005) or for selected regions (e.g. from the American Solar Energy Society for the Unites States or from the German Ministry for Environment for Germany; Kutscher 2007, Nitsch 2007).

V. Mitigation Costs

From the economic perspective in particular costs are a relevant decision factor. Of course there is a strong interdependence between the mitigation potential (achievable potential) and the emission reduction costs, but the availability of reliable mitigation cost data is limited. This holds true for mitigation costs of single technologies and more so for complex transition paths.

In IPCC AR4 the mitigation potential and corresponding mitigation costs of relevant mitigation measures (incl. renewable energy technologies) are outlined at least for the electricity sector. The selected data are based on a survey of existing technology studies. Figure 6 gives the example of wind energy.

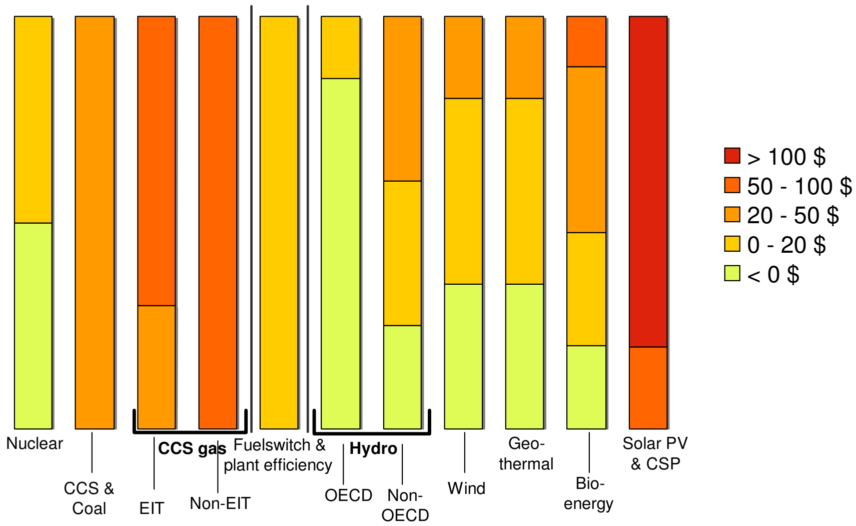

Figure 7: Cost range of relevant mitigation measures in US$ by 2030 (data based on IPCC AR4 2007)

From figure 5 the same conclusion can be drawn with regard to CCS and even to nuclear energy. But on the other hand it seems to be clear that in particular in the first decades the role of energy efficiency is much more important. Comparable results show other scenario analyses for the global level (e.g. *Energy*

As the figure shows, data on costs for single technologies are not transparent. For wind energy the cost range is dependent on the power plant size, the plant site (i.e. the country and the concrete plant site where the wind turbine will be installed), the technology status and perspectives (learning rates) and market penetration. Therefore, cost ranges rather than just one figure should be indicated. Anyway, these mitigation costs data are important information as they enable the scenario producers and policy decision makers to compare different mitigation measures with each other as is done in figure 7.

However, the practical value of these data is limited, as they normally do not consider system interdependencies (e.g. changing system behaviour: electricity mix and carbon intensity, electricity demand). Additionally, they cannot be summarized in a simple way, as the outlined data on potentials do not reflect the competition between different applications forms using the same type of primary renewable energy resources. That's directly understandable for the solar energy, as for example a roof can only be used for the installation of a photovoltaic module (to produce electricity) or a solar collector (to generate heat). Much more important is the competition in the biomass sector. Besides using the limited land for food production, biomass can be used for electricity production, for heating purposes as well as for transport and even as feed for industrial processes.
So the impact of renewable energy introduction is much more complex than isolated technology surveys show. The mitigation potential and costs depend on several aspects like system characteristics (which vary from country to country; e.g. high carbon intensity of electricity generation in Germany) and the sector of implementation (as this determines the amount of substituted conventional technology). Furthermore the employment of technologies pursuing a reduction of greenhouse gas emissions could have a negative impact on other ecological aspects. Bearing greenhouse gas mitigation as key target and limiting negative spill- over effects in mind, the optimal allocation of limited renewable energy resources is necessary. And coming from the political reality other aspects besides climate protection (e.g. security of energy supply) may speak for a different allocation system as it would be chosen when only thinking about climate protection. This kind of complexity cannot be considered sufficiently in energy models (in particular not in those with limited technological disaggregation level).

Mitigation cost data of separate technological options are often missed in world energy scenarios and this holds true all the more for the economic assessment of complete transition paths. In IPCC AR4 stabilisation scenarios have been investigated "solely" in terms of the expected overall GDP losses. Most of the underlying models do not (or actually cannot) distinguish between cost effects of different mitigation strategies. More information on the role and the cost impact of renewable energies within overall stabilisation scenarios can be found in a currently published paper on model comparison (Edenhofer et al 2006). This survey in particular shows the specific cost impacts of renewable energies highlighting the impact of endogenous technology change (e. g. consideration of learning curves) as a relevant factor within the used hybrid model MIND for the resulting CO_2-mitigation potential of renewable energies and for the resulting GWP (Gross Welfare Product) losses. MIND combines an intertemporal endogenous growth model of the macro-economy with sector-specific details taken from the field of energy system modelling. Figure 7 makes clear, that GWP losses connected with the achievement of a specific stabilisation target (in the survey a fixed concentration level at 450 ppm CO_2-eq was estimated), is a result of several variables, e.g. learning rates of renewable energies and the development perspectives of alternative options (in this case the availability of CCS and the efficiency of investments in CCS).

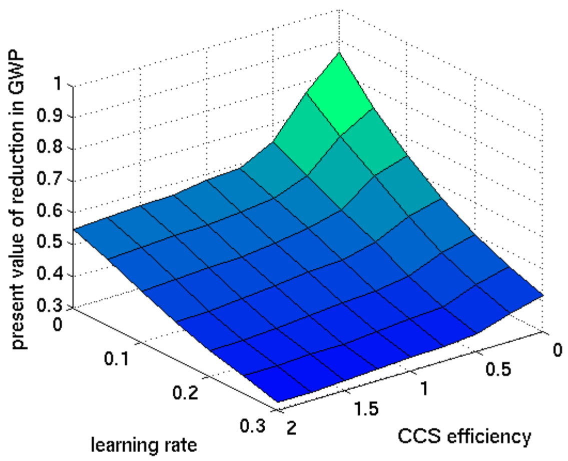

Figure 7: Role of endogenous technology change for the corresponding GWP losses of greenhouse gas stabilisation pathways (Edenhofer 2006)

Besides these investigations there are some scenarios highlighting the additional investment costs (not the total costs) of higher market penetration of renewable energies using a system analytical perspective (e.g. IEA *ETP* scenarios; IEA 2005). In these scenarios the IEA compares the additional costs (for the installation of renewable energies) with corresponding cost savings leading to what one can call differential costs of the extension of renewable energies. The other speciality within the *ETP* scenarios is that they consider different cost components including costs resulting from R&D efforts for further development of renewable energy technologies. From IEA perspective the most important cost components of accelerating the development of clean and efficient technologies are:

- investments in R&D
- investments in demonstration projects
- support for deployment programmes to reduce the cost of new technologies

- increased investment costs for the customer due to investment in technologies that are not cost-effective without CO_2 emission reduction incentives
- saved costs by avoided investments in fossil-fuel generation capacity

Most of the scenarios do not quantify the amount of investments that would be needed for R&D activities. The IEA (IEA 2006) tries to give a rough estimation: Total deployment costs (R&D&D) are estimated to USD 720 billion in the MAP scenario (less than 10% of the additional investment costs over the period 2005 - 2050).

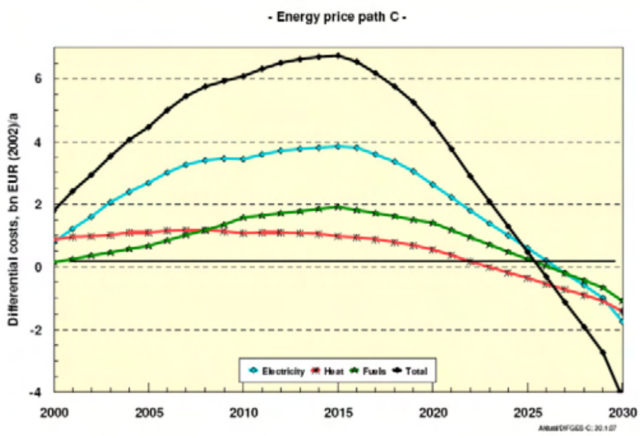

Figure 8: Total cost differential (annual numbers) within the German LeadScenario of renewable energy extension (Nitsch 2007).

More disaggregated cost calculations of climate protection scenarios are available only from some bottom-up models, e.g. Greenpeace: *Energy [r]evolution* (global perspective) and *LeadScenario* of the German Ministry for Environment (German perspective). In particular the *LeadScenario* analysis is a very concrete one as it calculates the total cost differential on the time axis caused by a further extension of renewable energies compared to a Business as Usual path (cf. figure 8). The most interesting aspect is that the cost differential changes from + to – in the second half of the third decade of this century. In the next years the extension of renewable energies is more expensive than a further use of conventional sources. But due to learning effects on one hand and increasing fossil fuel costs on the other hand the electricity, heat and fuel supply with renewable energies becomes cheaper than conventional alternatives after 2025.
As yet (for key note preparation) no full investigation of literature could be done, more in-depth analysis is necessary.

Renewable energies in the context of other climate protection options

The extension of renewable energies is not the only option to contribute to climate protection. Already *Post-SRES* scenarios mark a wide range of technologies contributing to specific stabilisation targets. The more sophisticated the target, the lower the share of fossil fuels and the higher the share of renewable energies and the nuclear option (cf. figure 9).

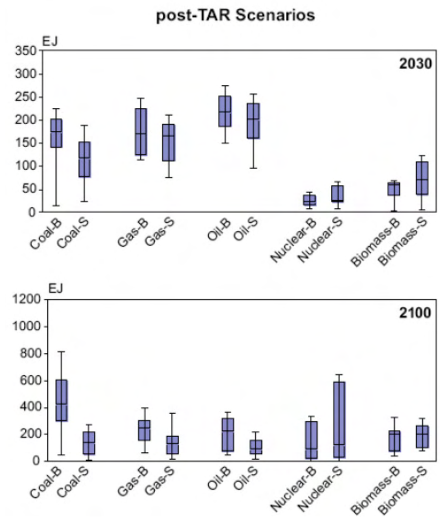

Figure 9: Impact of climate protection targets on primary energy mix for 2030 and 2100; left-side bars show baseline scenarios (B: no-intervention) while right-side bars show intervention and stabilisation scenarios (S): the figure marks the full range of different scenario results coming from different assumptions (IPCC AR4 2007)

While figure 9 focuses on the supply side options, most of the existing climate protection scenarios highlight the relevance of energy efficiency on the demand side as crucial mitigation measure. Common sense of most of the existing scenarios is that renewable energy and energy efficiency measures need to be realized simultaneously to reach ambitious climate mitigation targets. Both in combination are often designated as "twin pillars of sustainable energy". But while a parallel deployment of renewable energy and energy efficiency is required, even greater synergies could be exploited once *policies* combine the two. A combined strategy could help to reduce overall energy costs, provide electric grid benefits, increase price stability and generate other economic benefits. In some cases, such as in Zero Energy Homes, efficiency measures create leverage for renewable energies, also allowing overall attractive packages of both. In other cases, there are not only synergies, but also competition between both strategic measures. This competitive situation arises e.g. on a technical level. For instance in extremely efficient "passive houses", the use of renewable energy or district heating becomes in many cases technologically and economically difficult. From the current point of view these interdependencies (synergies and conflicts) have not been investigated sufficiently, from the overall system perspective as well as from the specific supply side perspective.

It is worthwhile to compare the options, if possible on the basis of a systematically comprehensive approach taking a sufficient set of aspects into consideration (for this context see also chapter 12). Suitable categories are (selection):

The figure above shows a comparison of levelized electricity generation costs (LEC) of fossil fuelled power stations and plant based on renewable energies for a time period until 2050. The calculation until 2020 is based on the installation of new natural gas combined cycle (NGCC) plant as well as new pulverised hard coal plant both without CCS. For the situation after 2020 new CCS based hard coal fired IGCC as well as new CCS based NGCC are assumed to be installed.

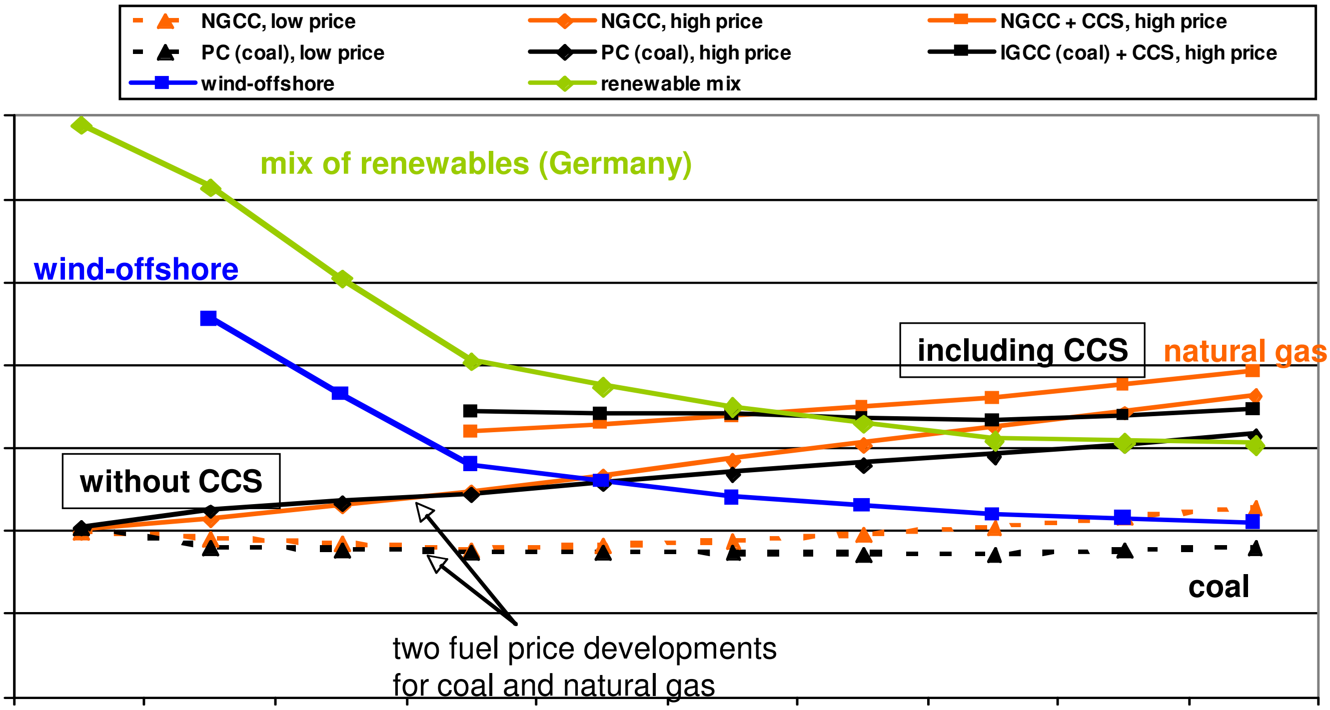

Figure 10: Cost comparison between renewable energies and carbon capture and storage on the time axis (Fischedick et al 2007)

- Current technology status and development perspectives
- Availability over time
- Security of energy supply
- Economic aspects (e.g. resulting electricity generation costs)
- Quality of supply (e.g. fluctuating supply)
- GHG emissions
- Further life cycle categories
- System compatibility
- Public perception and acceptance

To give an idea of how complex this comparison can get and how different the conclusions for the scenario makers can be, figure 10 compares the renewable energy option with carbon capture and storage (CCS) using the frame conditions for Germany and focussing on economic aspects on the one hand and ecological aspects on the other hand.

While the fossil fuelled power plant LEC develop from 4 ct_{EUR}/kWh_{el} in 2005 to 3.5 ct_{EUR}/kWh_{el} (lower price variant) and to 4.9 ct_{EUR}/kWh_{el} (upper price variant) in 2020, the implementation of CCS technologies causes an additional cost jump of about 50% in 2020. CCS based power plant finally reach LEC of 6 ct_{EUR}/kWh_{el} and 6.9 to 7.8 ct_{EUR}/kWh_{el}, respectively. Both plant types show a similar cost increase for different reasons: In the case of the NGCC the cost development is influenced mainly by the natural gas price increase whereas in the case of IGCC it is caused mainly by the constantly rising CO_2 certificate price.

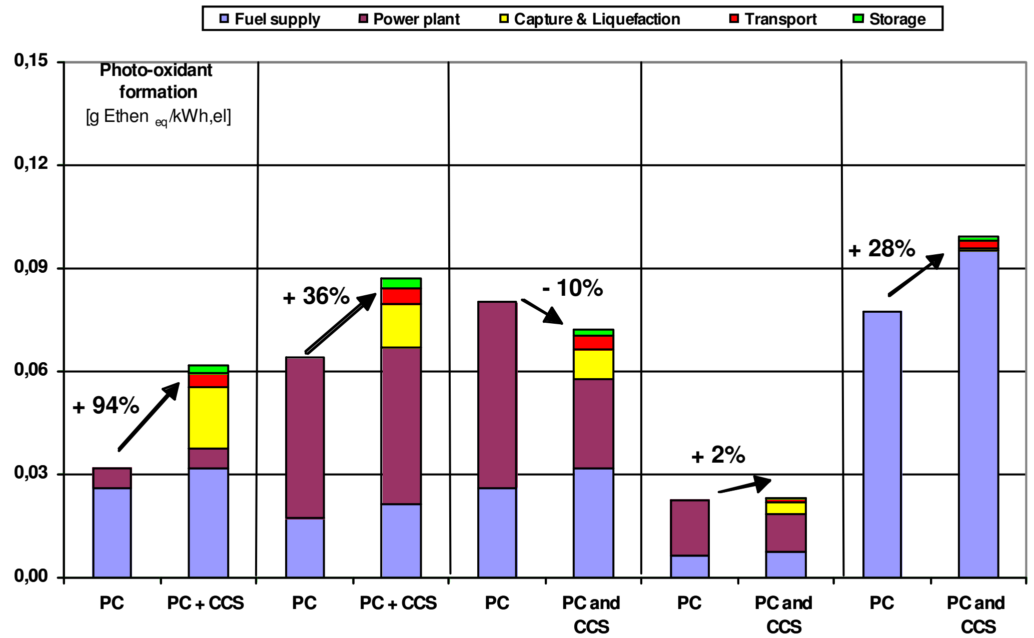

Figure 10: Results from life-cycle analysis comparing renewable energies and carbon capture and storage (Fischedick et al 2007)

In renewable electricity production a distinction is made between offshore wind power on the one hand and a mix of all renewable energy technologies on the other hand. Their cost development is based on learning curves as explained. Especially the wind power plant's cost curve is based on the latest cost development review and predictions on future offshore investment costs provided by the German government.

Assuming mass market effects and technology improvements the LEC of new installed wind offshore power plant can be decreased from 13.1 ct_{EUR}/kWh_{el} currently (2006) realised in Germany to 8.1 ct_{EUR}/kWh_{el} in 2020 (within a range of 5.6 ct_{EUR}/kWh_{el} for wind-offshore and 19.6 ct_{EUR}/kWh_{el} for photovoltaics). In 2050 a further cost reduction to 6.1 ct_{EUR}/kWh_{el} (wind-offshore: 4.2 ct_{EUR}/kWh_{el}) is expected.

According to the chosen price assumptions of fossil fuels a mix of renewable energies can become more economic than CCS based power stations around 2031. With smaller price increases the cost equality moves to 2050. Electricity from offshore wind power alone will become cost competitive around 2020. Since wind power plant cannot just replace fossil fuelled power plant, the whole mix of renewable energies is the more relevant comparison.

All in all it should be kept in mind that there are some uncertainties in both the renewable energies as well as the CCS technology scenarios. For example, if the proposed cost decreases of renewable energies (for which an ambitious worldwide extension of renewable power plant is assumed) will not occur, CCS technologies may play a more important role to reduce greenhouse gas emissions in the decades from 2020 on. On the other hand, considering a fuel price increase much stronger than the moderate increases assumed in the "upper price scenario", a contrary development would follow with uneconomical CCS power plant but much more energy efficiency and renewable energies.

However, the figure clearly shows a structural effect. While renewable energy technologies probably become cheaper, the fossil fuel electricity generation might become more expensive in the future, in particular if CCS is included. From the climate protection perspective, CCS is the fossil fuel option, nearly comparable on a par with renewable energies (as CCS provides not a CO_2-free but a CO_2-poor option, resulting at the end in specifically higher GHG-emissions compared to renewable energies, in particular when considering the whole process chain).

CCS requires additional energy consumption of 20% to 44%, depending on the power plant's efficiency and the CO2 content of the fuel. This is not only influencing the greenhouse gas emissions balance but several other baseline impact categories of an LCA: *photo-oxidant formation*, *eutrophication*, *acidification*, *PM10-equivalents* and *cumulated energy demand (CED)* are usually selected.

The figure above focuses on a pulverised hard coal power plant (PC) and shows how these categories change through introducing CCS. First of all, the additional energy consumption of 28% leads to an increase in all impact categories. Furthermore, the formation of photo-oxidant increases disproportion-ately caused by the production of the scrubbing chemical. Acidification decreases slightly because the SO_x components omitted from the operation react with the amines and are scrubbed, too. The amount of PM10 equivalents (particulate matters smaller than 10 micrometers) increases only slightly, because the emissions from the operation decrease by 50% during the scrubbing process, too.

VI. Conclusions: demand for a special report on renewable energies

Previous chapters outlined the current state of knowledge concerning aspects like mitigation potential of renewable energies, costs of renewable energy systems and costs of transition paths to an extended use of renewable energies. For that reason it was necessary to give an overview about global energy scenarios (in particular those dealing with sophisticated climate protection targets) and to pick up what they specifically state with regard to renewable energies.

IPCC AR4 already covered very important aspects in that context as well, but shows some missing points. Coming from the more general topic *Mitigation of Climate Change* the weaknesses of IPCC AR4 related to the specific discussion of the relevance of renewable energies are understandable. In this context the following points are worth to be further elaborated:

Current studies on potentials of renewable energies and new methodologies should be integrated as well as aspects on how the given potentials could be influenced by changing frame conditions (e.g. new technologies, climate and demographical change)
IPCC AR4 refers to the IPCC SRES and post-SRES literature and shows for some selected cases (emission reduction scenarios) the CO_2-reduction contribution of all relevant climate protection options (incl. renewable energies). But it does not analyse and discuss systematically the factors that determine the role of renewable energies in the given global energy scenarios. To gain a better understanding of the possible role of renewable energies as a strategic element, it is reasonable to further elaborate the relevant variables. So far an assessment of best available scenarios and top-down as well as bottom-up studies seems to be needed.

IPCC AR4 specified the mitigation potential and corresponding costs of renewable energies for the electricity sector based on a survey of existing technology studies, but these results do no consider system interdependencies (e.g. changing system behaviour: electricity mix and carbon intensity, electricity demand). They do not reflect competition between several application forms (e.g. biomass can not only be used for electricity production) and do not discuss efficient ways for the allocation of limited resources. To get an overall, integrated picture about what renewable energies can deliver and how far they can contribute to ambitious climate protection targets further work should be done. This holds true particularly if a regional, sectoral or temporal breakdown of mitigation potentials is required.

Many of the existing global energy scenarios don't calculate mitigation costs and other consequences. Therefore there is a strong lack of economic assessments of mitigation paths. IPCC AR4 highlights the overall GDP losses of different mitigation paths (referring to given scenarios), but does not specify the resulting transition costs (e.g. contribution of renewable energies). For the deployment phase of renewable energies it would be good to have more estimations about the expenditures needed to realize ambitious renewable energy pathways. Moreover cost discussions in the literature mostly focus on investment needs, but include neither total cost balances (including estimation about operational costs and cost savings) nor externalities like social, political and environmental costs.

IPCC AR4 shows the possible role of different climate protection strategies referring to the results of post-SRES scenarios. But it does not provide a systematic comparison of renewable energies and other options (e.g. energy efficiency), does not reflect synergies (incl. cost reduction effects) and conflicts on system and specific application level (e.g. energy provision for settlements) and does not discuss the compatibility of renewable energies with other options

It is worthwhile to further elaborate and complement the aspects already covered by IPCC AR4 in a "Special Report on Renewable Energies".

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Global Investment in the Renewable Energy Sector

Eric Usher

Head, Renewable Energy and Finance Unit, Division of Technology, Industry and Economics,
United Nations Environment Programme, 15, rue de Milan 75441 Paris CEDEX France
T: +468212901 M:+46733121528 F: +468222233 E: eric.usher@unep.fr

Abstract

The renewable energy sector is today a multi-billion dollar industry, the fastest growing segment of the global energy market, both now in relative and absolute terms. Besides delivering new forms of energy supply, renewable energy technologies might play a significant role in mitigating global climate change and today's high rate of investment seems to indicate this is already occuring. This paper assesses how the renewable energy sub-sectors are developing today in terms of investment trends and future outlook, and considers how such information could usefully feed into the proposed IPCC Special Report on Renewable Energy.
New investment in the renewable energy sector has recently surpassed $100 billion[9] per year. Whether this figure is significant in terms of the overall financing requirements to mitigate global climate change would be the fundamental contribution of an investment section within the proposed Special Report on Renewable Energy. A secondary contribution would be a better understanding of what the current investment trends tell us about the finance community's growth projections for the renewable energy sector. Preliminary analysis indicates that the finance community is projecting continued high growth for the sector for the foreseeable future, and has begun to include climate change as a key driver for sector growth alongside energy security concerns, high oil prices and today's increasingly supportive policy frameworks.
This paper is based on the work of the UNEP Sustainable Energy Finance Initiative and largely references the report "Global Trends in Sustainable Energy Investment 2007" prepared with New Energy Finance Ltd[10], and the background paper for the Tenth Special Session of the UNEP Governing Council/Global Ministerial Environment Forum[11].

[9] Unless otherwise stated all figures quoted are in USD.
[10] UNEP SEFI, New Energy Finance, Global Trends in Sustainable Energy Investment 2007, June 2007.
[11] Background Paper for the Ministerial Consultations of the Tenth special session of the Governing Council/Global Ministerial Environment Forum Monaco, 20–22 February 2008

How Much Climate Investment is Needed ?

Studies have begun to estimate both the economic effects that climate change will have on global society as well as the costs of possible mitigation and adaptation measures. Although the capacity to enact either a mitigation or adaptation strategy is based on country-specific conditions, technology, and information availability, models have been used to calculate the approximate cost to stabilize atmospheric emissions at different levels.

The IPCC Fourth Assessment Report estimated that the impact on global GDP of reducing greenhouse gas emissions would range from a cost of 0.2–2.5 percent in 2030 and 4 percent in 2050 to a slight benefit in both periods.[12] The Stern Report[13] concluded that the cost of stabilizing emissions at 550 ppm CO2-eq would average 1 percent of global GDP, approximately $134 billion in 2015 and $930 billion in 2050.14 The UNFCCC secretariat estimates a GDP cost of 0.3–0.5 percent in 2030 to return emissions to 2004 levels, equivalent to 1.1-1.7 percent of global investment, or $200–210 billion in additional capital mobilization across the economy.[15] Although these costs are large by some standards[16], the overall effect on world income has been calculated to result in a delay in GDP of only a few years,[17] partly since some capital requirements could be diverted from business as usual investment activities or paid for by lower fuel costs and other savings. In general, stabilization costs are lower if measures are implemented sooner via a well-planned response.[18]

Although investment in new renewables is not directly comparable to climate mitigation investment it is clear that the $100 billion renewables milestone is a large contribution towards the $134 billion and $200 – 210 billion mitigation requirements projected respectively by Stern and the UNFCCC Secretariat. It appears that renewables investment and specifically wind investment makes up the largest share of climate mitigation investment, followed by large hydro, although further research review will be required during the special reports preparation to clarify this issue.[19]

Renewable Energy Investment

In 2007 a UNEP investment trends analysis of the sustainable energy sectors – defined as new renewables and energy efficiency[20] - was prepared by New Energy Finance and the Sustainable Energy Finance Initiative[21]. As shown in Figure 1, new investment in the global sustainable energy sector more than quadrupled in the last four years, from $28.6 billion in 2004 to $117.2 billion in 2007. Ninety four per cent of this investment was in renewables, with the remainder in energy efficiency[22] and other low carbon technologies. Figure 2 shows for 2007 the distribution by type of financial transaction and includes both a breakdown of the $117.2 billion total investment figure and the additional refinancing activity carried out in the form of mergers and acquisitions and management buy-outs[23].

The $117.2 billion total investment figure breaks down as four types of investment in technologies and companies and two types of investment in energy generation projects on the ground. Although not shown Figures 1 or 2, the types of investment that have grown quickest in recent years have come from four sectors of the financial community that had previously shown little interest: venture capitalists and private equity investors, who provide the risk capital needed for technological innovation and

[12] IPCC, "IPCC Fourth Assessment Report – Synthesis Report. Topic 5." Table 5.2, p. 8.

[13] Sir Nicholas Stern et al, "Stern Review on the Economics of Climate Change" (Stern Review).

[14] Ibid, section 9.8, p. 233.

[15] Investment and Financial Flows to Address Climate Change, UNFCCC, 2007.

[16] Specifically, the UNFCCC secretariat projects mitigation investment requirements of $148 billion in new power generation, $36 billion in industrial efficiency, $51 billion in building efficiency, $88 billion in greener transport, $56 billion in agriculture and forestry and $35–$45 billion in technology research and development.

[17] Chritian Azar Christian and Stephen H. Schneider, "Are the economic costs of stabilising the atmosphere prohibitive?", *Climatic Change* 42.

[18] This conclusion is mostly based on the fact that infrastructure investments have very long operating lives and cannot be easily retrofitted to reduce greenhouse gas emissions. For example, if much of the estimated $22 trillion to be invested on energy infrastructure between today and 2030 (WEO2007) is not climate neutral then the chance of meeting a safe stabilization target is limited.

[19] Comparable data for the large hydro and nuclear sectors must be collected since the current comparison is based on aggregate IEA data (WEO2005) which does not dissociate the two sectors. Also, energy efficiency investment might be the largest depending on the treatment of the historical rate of efficiency improvement (i.e., is the current 1.2% to 1.5% rate of improvement considered additional from the climate mitigation perspective or business as usual ?)

[20] Many of the figures presented in this paper that are drawn from that analysis are aggregate figures for both renewables and efficiency. Wherever possible the share of investment that was explicitly for renewables will be stated. This analysis would be disaggregated to show only the renewables figures in the proposed IPCC Special Report on Renewable Energy.

[21] Global Trends in Sustainable Energy Investment 2007, UNEP SEFI and New Energy Finance.

[22] Due to the bottom-up analysis approach used, the energy efficiency investment figures only include investments in new energy efficiency technologies or businesses and therefore largely understate the overall investment in efficiency. The largest financial flows to energy efficiency are not the types of externally financed transactions that this reporting process covers, but rather internal investments made by industry actors, governments and consumers.

[23] Mergers & Acquisitions and Management Buy Outs do not increase overall investment into the sector, but rather consist of new financiers buying out existing investors.

commercialization (up 69 percent in 2006 and 27 percent in 2007); public capital markets, which mobilize the resources needed to take companies and projects to scale (up 124 percent in 2006 and 80 percent in 2007); and investment banks, who help refinance and sell off companies through mergers & acquisitions and management buy-outs, allowing the all important exit liquidity needed for markets to grow and for first mover investors to realize returns (up 34 per cent in 2006 and 43 per cent in 2007).[24] The engagement of these four new sectors signals an increasing mainstreaming of sustainable energy financing and, owing to the big names involved such as Goldman Sachs and some of California's most prolific venture capitalists, these actors have had a strong knock-on effect that has further strengthened investor resolve to scale up this climate mitigation sector.

Further indication of the change of sentiment towards renewables can be seen by comparing the performance of publicly traded renewable energy stocks with other sectors. Figure 3 compares the performance of four stock market indices, including the WilderHill New Energy Global Innovation Index (NEX), the Standard and Poor's 500, the Nasdaq and AMEX Oil. Prior to 2004 the NEX renewable energy index closely tracked the technology focused NASDAQ, indicating that investors saw renewables stocks as technology investments, i.e., investments for the future. This changed in 2004, when wind and solar companies in Europe and Japan began to generate significant revenues and their perception within the financial markets began to shift from long-term future technology prospects to near-term industrial grade revenue producers[25].

Investment in new renewables now represent about 10 – 12 % of total energy sector investment and somewhat more in the power sector. Established low-carbon energy sectors such as large hydro also continue to attract investment, although with more modest levels of growth.[26] It is estimated that new renewables now provide 5.5% of global power capacity and large hydro 18%[27]. Wind alone accounted for 12 per cent of newly installed capacity in 2006. In that year new renewables received $22 billion of new power generation investment and an additional $34 billion in new technology and manufacturing investment, the second figure suggesting that a quickened pace of new capacity additions can be expected in the coming years. For countries at the forefront, the economic development benefits are also becoming clearer. In 2006 there were over 2.3 million jobs in the renewable energy sector alone, more than the 2 million in oil and gas and over half the 4 million jobs globally in the air transport industry28.

The ability of the capital markets to mobilise investment quickly behind new technologies is changing the dynamic of the energy industry, which traditionally has relied upon the large incumbents to lead the technology innovation process. New focused renewable energy companies, many of which didn't exist 5 years ago, can now raise money more easily than the much larger and more established energy companies. This allows them to develop new technologies, scale up manufacturing capabilities and react quickly to global market opportunities. For instance, the solar photovoltaic market has seen the emergence of a new breed of pure-renewable technology leaders such as REC in Norway, Q-Cells in Germany and SunPower in China. For the wind and hydro sectors some electric utilities are now choosing to spin off their renewables subsidiaries as independently listed companies in order to mobilize capital more easily.29 The Spanish Utility Iberdrola, for instance in December 2007 spun off its renewables subsidiary through an initial public offering, following on the success of France's EDF in listing EDF Energies Nouvelles. The Iberdrola offering raised $6.6 billion, an amount six times greater than the world's previous largest renewable energy IPO. With a capitalization of $33 billion, this new Spanish renewables operator has a higher market value on its own than all but the largest integrated European power utilities.

In line with solar, the biofuels markets have also received a great deal of investment in both technology focused and diversified industry actors, although 2007 has seen decreasing investor confidence in some regions based on difficult market conditions and the realisation that not all biofuels are equivalent in terms of energy and CO2 balance and sustainability issues. In the biofuels sector as with the other technology areas the investor landscape is becoming more crowded, but more professional.

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[24] New Energy Finance Analyst Reaction (28/12/07) and Global Trends in Sustainable Energy Investment 2007, SEFI and New Energy Finance.

[25] This is indicated in Figure 3 by the separation in 2004 of the NEX from Nasdaq. Technology stocks have not increased much in value since 2004, while renewable stocks have increased significantly.

[26] International Energy Agency (IEA) 2005 estimated combined investment in large hydro and nuclear generation of $44.1 billion, although did not disaggregate the two.

[27] Martinot et al, (Draft) Renewables 2007 Global Status Report, REN21, January 2008.

[28] ICAO-2006

[29] Investors typically accord low valuations (i.e., stock price to earnings ratios) to regulated utilities meaning that the same business may be worth 3 to 5 times more if seen as a renewables stock rather than an electric utility stock.

One impact of competition is that investor interest is internationalizing rapidly to places like China and India. Figure 4 shows a breakdown of investment by region and by the three major types of investment of VC/Private Equity, Public Markets and Asset Finance. With $15 billion of sustainable energy financing in 2006, developing countries accounted for 21 percent of global investment in the sustainable energy sector, up from 15 percent in 2004 and far surpassing the growth rates of developed countries. Large emerging countries account for the majority of those investments, with China, India and Brazil representing 9 percent, 5 percent and 4 percent, respectively, of global investment; all three countries are now major producers of and markets for sustainable energy, with China leading in solar, India in wind and Brazil in biofuels. China has seen the quickest growth in recent years and Indian companies have been the largest net buyer of companies abroad, spending more than $800 million in 2006 to acquire principally European manufacturers. The results in the rest of the developing world, however, have been less promising and require increased engagement from Governments and the development finance community.

Changes in Finance Sector Engagement

In the area of asset finance increasing competition in the on-shore wind debt markets has driven innovation in the banks with loans now going out 20 years on conventional project financings and new financial structures such as portfolio financing and turbine financing becoming more common. Risks are growing with the size of projects, leading in some cases to blockages and in others to new roles for different financial actors. Capital market solutions are becoming increasingly important and the rating agencies are now getting familiar with the sector through their first portfolio securitisations financed through the bond markets. Off-shore wind growth is slower, however the first limited recourse financings have now been arranged.

Debt providers are also moving into other technologies such as small hydro and biofuels, a sector where off-take agreements are no longer essential for project financing. In PV and solar thermal the first non-recourse transactions have taken place in Spain. Landfill gas and small-scale biogas is experiencing dynamic growth. The lack of financing solutions for exploration is still limiting growth of geothermal. A number of leading lenders are now also moving into private equity. These banks and others are also beginning to look beyond the confines of Europe and North America, although more slowly than the capital markets.

SEFI Advisory Board Report, Zug 2006

Investment in renewables today is widely spread between the main sectors of wind, biofuels, biomass and waste, solar. According to New Energy Finance estimates, in 2006 over 50% of asset financing went into the wind sector. By contrast, when it came to venture capital and private equity investment, the largest recipient among the sectors was not wind but biofuels, which attracted $2.8 billion. In the public markets, solar was the largest recipient of investment, receiving $4.4 billion, with biofuels second at $2.5 billion.

Overall, adding together the venture capital and private equity, public markets and asset financing figures, wind came out as the most heavily invested sector in 2006, with $17.2 billion, followed by biofuels with $11.7 billion, solar with $7.2 billion and biomass and waste with $4.2 billion.

Venture Capital and Private Equity

Venture Capital is generally invested in companies with very high growth potential, therefore those that are usually trying to develop some new technology innovation. Private Equity is generally used to finance a company with a proven technology or business that needs capital to develop a new activity or scale up its operations.30 In terms of the proposed IPCC Special Report on Renewable Energy, analysis of venture capital and private equity investment can provide insight into the mid-term future that the investment community sees for the renewable energy sector (ie 5 to 10 years out).

Venture Capital and Private Equity flows into new renewables totaled $8.5 billion in 2007, according to estimates by New Energy Finance, up 215% on the 2005 tally of $2.7 billion31. Figure 5 shows the breakdown of VC/PE by sector. The lion's share of venture capital and private equity money, particularly in wind, was used to increase manufacturing capacity. In solar however, a significant portion – around 40% - went into developing new technologies, and in biofuels this share was about 20%.

The United States dominated venture capital and private equity transactions in clean energy in 2006. European economies, with large financial sectors, such as in the UK, Germany and France, made up a surprisingly low proportion of the VC/PE flows. One

[30] Venture capital seeks high risk / very high investment return opportunities; private equity seeks medium risk / medium return opportunities; public equities (ie stock markets) seek low risk / low return opportunities; and the public (ie bonds) and private (ie banks) debt markets seek very low risk and very low return opportunities.

[31] New Energy Finance, Analyst Reaction – Review of 2007: New Investment in Clean Energy Surges Past $100bn, December 2007.

reason for this could be that some of the early-stage money requirement for firms in those countries was provided by public stock markets such as the London Stock Exchange's Alternative Investment Market rather than by venture capitalists. Another is that many European firms had already reached a more mature stage than their US equivalents.

According to the Cleantech Venture Network, the overall clean tech sector[32] accounted for 9.1% of overall VC investment in North America in 2005[33]. Figures are not available for 2006 and 2007, however it is clear that this share has increased considerably, particularly for the renewables part of the clean tech sector. Cleantech Venture Network has also studied the returns of clean tech venture investing, collecting publicly available data on exits through Initial Public Offerings, Mergers and Acquisitions and on the performance of publically traded companies[34]. For instance 67 clean tech IPOs were identified in the US in the period 1987 – 2004. For 56 of these, exit returns to pre-IPO investors could be estimated. Median estimated returns were 433%, or about 5.3x invested capital.

Public Investment Markets

Companies with a track record or a proven business model will often look to the public equity markets to raise financing needed to scale up manufacturing or other commercial operations. In terms of the proposed IPCC Special Report, analysis of the public investment markets can provide insight into the near-term future that the investment community sees for the renewable energy sector (ie 2 to 5 years out).

In 2006 and 2007 there was a surge in investment in renewable energy companies via public capital markets. As shown in Figure 6, the amount of money raised through the stock markets for the sustainable energy sector is estimated to have reached $19 billion in 2007, more than 90% for renewables, and up from less than $1 billion in 2004. As shown in Figure 7, the aggregate market capitalization of renewable energy stocks increased from $20 billion in 2000 to $58 billion in 2006, although the growth wasn't uniform. Solar, for instance, grew from less than $1 billion to $26 million in this period, while fuel cells dropped by almost two thirds.

With so much enthusiasm in the public markets, one of the key questions being asked is whether the clean energy sector is now overvalued and ready for the sort of crash that befell the technology boom early in the decade. Industry observers are mixed in their views on this question, however a number of indicators point to a reasonably healthy sector outlook even if some near-term stock market corrections seem likely. As compared to the previous boom, where clean technology focus was mostly on future technologies such as fuel-cells, the current focus is on more mature sectors such as wind and solar, 50% of which are already profitable. As well the price-earnings (P/E) multiple is more reasonable. In January 2002, at the peak of the last boom, average P/E was 75x. This dropped to 18x in March 2003, and in September 2006 was up to 32x, which is not considered unreasonable for a high technology sector.[35]

Even with some stock market corrections[36], the 2006 and 2007 story as a whole has been one of rising investor interest in renewable energy. This was reflected in sharp increases in the amount of money held in funds specialising in holding quoted clean energy stocks in their portfolios. According to New Energy Finance estimates, funds under management by private funds specialising in quoted clean energy investments reached $8.5 billion in 2006, up 43% from the 2005 figure of $5.9 billion. Funds under management by publicly quoted investment companies specialising in the sector reached an estimated $7 billion in 2006, up 59% from the 2005 level of $4.4 billion.

Asset Financing

Asset finance is a term used to describe the combined debt and equity financing of renewable energy generation projects on the ground. New Energy Finance analysis breaks out financing of renewable energy generation projects into asset financing for large scale projects and financing for small scale projects. Most of the analysis to date has been on the larger project asset finance, however during preparation of the IPCC Special Report it is expected that more information will become available on the small-scale project financing as well. In terms of the proposed Special Report, analysis of asset financing trends provides insight into technology installation costs, potentially including the impact of manufacturing bottlenecks such as those that have occurred recently in the wind and solar photovoltaic sectors.

[32] Defined as products that increase productive use of natural resources, while eliminating or reducing waste, and adding economic value.

[33] Cleantech Venture Capital Report – 2006.

[34] Cleantech Venture Investment – Patterns & Performance (March 2005).

[35] I. Simm, CEO, Impax Asset Management, Presentation to Renewable Energy Finance Forum, London, September 2006.

[36] A first correction occurred in May 2006 (see in Figure 3) brought on by news of ETS over-allocations, and a second occurred in January 2008, during the overall stock market fall (which occurred during, but hopefully was not caused by the IPCC Scoping Meeting in Lubeck !)

In 2007 Asset Financing in the new renewables sector reached $56 billion, up from $39 billion in 2006. See Figure 8 for the breakdown by technology. This year also saw the a more marked shift in focus from the mature wind and biofuels markets of western Europe and the US to the developing world with a jump in transactions in the South American biofuels industry and a surge of Chinese wind, biomass and waste-to-energy projects. Wind investment amounted for roughly half of the total, with biofuels ($14.5bn), biomass & waste ($7.1bn) and solar ($5.9bn) accounting for most of the rest. The year's advances

Mergers & Acquisitions

Mergers & Acquisitions (M&A) and Management Buy Outs (MBO) are used to buy and sell or refinance companies. These figures represent no net financial gain to the sector, but rather indicate the level of turnover, whereby early investors are able to 'exit' successful investments and pass them onto second generation investors. M&A/MBO activity is an indicator of the liquidity and therefore the maturity of a sector, with low levels of activity indicating that even successful investments in the sector might not be easy to sell on. Institutional investors such as pension funds are particularly reluctant and bound by their fiduciary responsibility to not enter a sector until it is sufficient liquid. For the IPCC special report, M&A/MBO data and analysis could provide a sounder basis on which to compare the liquidity of the renewables sector with other energy technology sectors.

In 2007, mergers and acquisitions (M&A) in clean energy reached $42 billion, up nearly 43% on 2006. The targets financed through M&A are generally one of three types: Capacity - the acquisition of renewable power projects; Technology – the acquisition of companies that develop or manufacture products and services; and Other targets – including deals involving carbon management firms. The large majority of financing represented acquisition of capacity projects, rather than companies developing technology or managing carbon. Wind is the dominant sector in terms of merger and acquisition activity.

Besides reviewing the best available literature on investment trends in the renewable sector, the IPCC Special Report investment section might also review some possible options for governments to stimulate the finance needed to increase renewable energy penetration across the energy sector[37], particularly in the developing countries that have not to date benefited from the current investment boom. Figures 9 and 10 assess the finance value chain for renewable energy companies and projects by taking a closer look at the finance continuum - the sources of capital needed to take a project or enterprise forward to implementation. Recommendations for public interventions that close the gaps in the continuum are proposed within each. This initial analysis was prepared for the Bonn *renewables2004* conference and has subsequently been updated in various forms but would need to be consolidated within the IPCC Special Report section on finance.

Conclusion

The years 2006 and 2007 witnessed record investment in the renewable energy sector. General consensus was that increasing technological maturity, growing staff expertise, and better understanding of technology risk were key drivers behind this growth.[38]

A look at renewable energy finance and investment reveals some key trends, including:

(1) investment in the clean energy sector has more than doubled in the last two years;

(2) current investment trends would seem to indicate that IEA projections underestimate clean energy sector growth;

(3) The ability of the markets to mobilize capital quickly behind new innovators is providing a counter-balance, or at least a fore-warning, to the obstinacy of energy sector incumbents;

(4) the investor and lender landscape is becoming more crowded but more professional. One impact of competition is that investor interest is internationalizing rapidly to emerging markets, and lenders are becoming more innovative with their financial structures and moving beyond wind to the other clean energy sectors;

(5) in venture capital and private equity, most investors are gravitating towards larger more mature deals. There is a lack of seed and angel capital in the market;

(6) on the stock markets the valuations of clean energy stocks are high, but are considered reasonable for such a high growth sector;

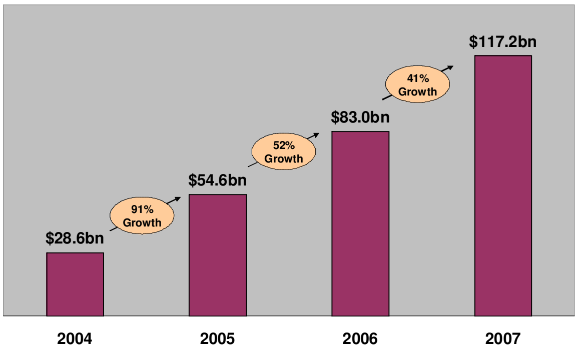
(7) the US is leading the world in financing new technology development through VC and private equity; Europe, with its somewhat more mature industry, is leading in financing through public stock exchanges;

[37] For further reading see V. Sonntag-O'Brien, E. Usher, Bonn Theme Paper 5 Mobilising finance for Renewable Energies.

[38] V. Sonntag-O'Brien, E. Usher, Special Supplement on Private Finance and Investment Trends, REN21 Global Status Report, 2006 Update.

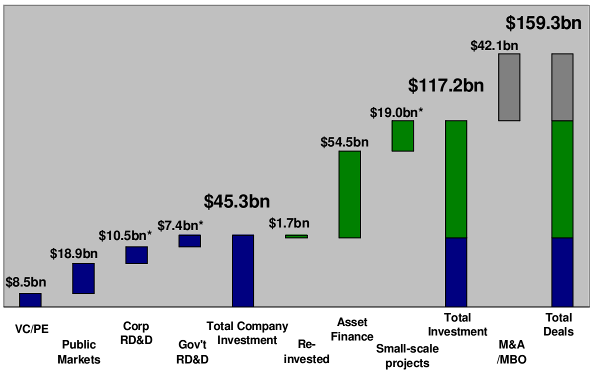
(8) Investor focus is starting to shift to emerging markets, although mostly China and India. The opposite is also happening, with China and India being substantial net buyers of clean energy companies during 2006.

This paper has tried to compress a large amount of information into a few short pages. The availability of research and industry analysis is now increasing in the investment area, particularly in the last two years, although still lags far behind other aspects of renewable energy technologies and markets. Although the various investment figures are impressive in some ways, making sense of them can be difficult at the macro level particularly as they relate to climate mitigation, the investment needs and the current response. This would be the challenge to address within the investment section of an IPCC Special Report on Renewable Energy.



Source: New Energy Finance

Figure 1: Global New Investment in Sustainable Energy



Source: New Energy Finance

Figure 2: Global 2007 Financing by Type of Transaction

Source: New Energy Finance, AMEX

Figure 3: Comparing Stock Market Indices

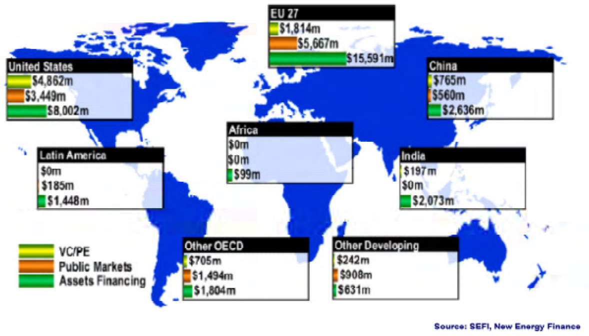


Figure 4: Global Investment in Sustainable Energy By Type and Region 2006

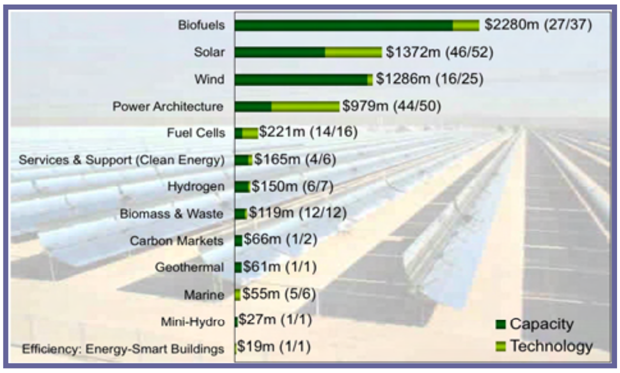


Figure 5: Venture Capital and Private Equity

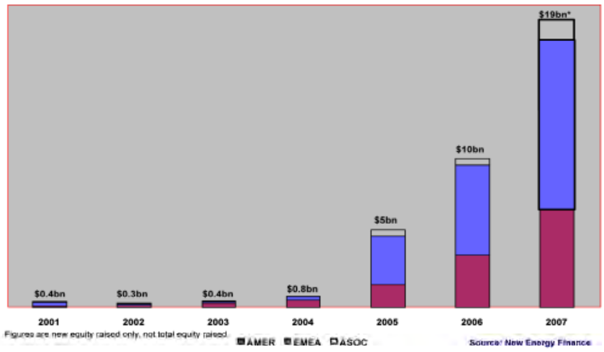


Figure 6: Global Public Market Transactions by Region

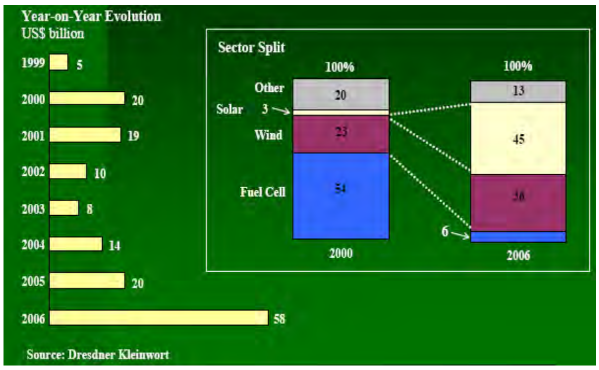


Figure 7: Aggregate Stock Market Capitalisation of the

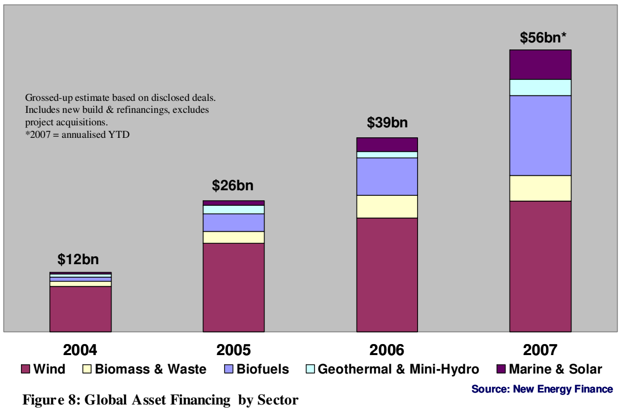


Figure 8: Global Asset Financing by Sector

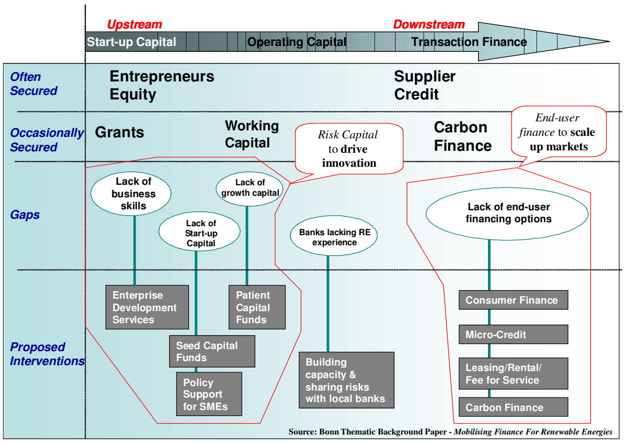


Figure 9: Finance Continuum Public Intervention Analysis Framework for Renewable Energy SMEs

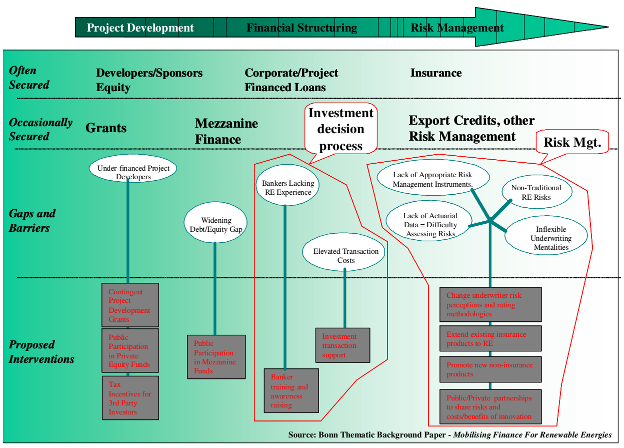


Figure 10: Finance Continuum Public Intervention Analysis Framework for Grid Connected Projects

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Policies to Promote Investment in and Deployment of Renewable Energy

Dennis Tirpak

Abstract

There are a wide variety of national policies and measures that can promote the development and deployment of renewable energy technologies which can limit or reduce GHG emissions and achieve other development goals. These include: regulations and standards, taxes and charges, tradable permits, financial incentives, research and development programs, and information instruments. Other policies, such as those affecting trade, foreign direct investment, consumption, and social development goals can also affect the deployment of renewable technologies. There are advantages and disadvantages associated with different instruments. Policy makers can evaluate policy options using criteria such as environmental effectiveness, cost effectiveness, distributional effects (including equity) and institutional feasibility. To be effective, all instruments should be carefully designed, monitored, modified over time and enforced.

Overview

Chapter 13 of IPCC 2007 provides a broad overview of national policies and possible elements of international agreements and evaluation criteria. Instruments and approaches available to national governments include: regulations and standards, taxes and charges, tradable permits, voluntary agreements, informational instruments, financial incentives, research and development and information instruments. Box 1 provides a brief definition of each instrument. Depending on the legal frameworks available to countries, these may be implemented nationally, at the sub-national level or through bi-lateral or multilateral arrangements. They may be legally binding or voluntary and they may be fixed or changeable (dynamic).

The IPCC 2007 further states that there are four principal criteria by which environmental policy instruments can be evaluated:

- Environmental effectiveness – the extent to which a policy meets its intended environmental objective or realizes positive environmental outcomes.
- Cost-effectiveness – the extent to which the policy can achieve its objectives at minimum cost to society.
- Distributional considerations – the incidence or distributional consequences of a policy. Fairness and equity are dimensions of this though there are other dimensions to distribution.
- Institutional feasibility – the extent to which a policy instrument is likely to be viewed as legitimate, gain acceptance, adopted and implemented.

There are a number of drivers that are responsible for the heightened interest in renewable technologies, including the desire for access to energy, climate change mitigation (including carbon trading), environmental concerns, energy security and diversification, and economic development (including industrial strategies, competitiveness, trade and jobs). As is the case with any new technology, renewables face a number of barriers which often prevent their deployment at a large scale. These include human resource capacity, information, technical and infrastructure, economic, institutional, and cultural. Consequently, governments in many countries at the local, sub-national and national levels have been attempting to overcome barriers through a variety of policies. Examples of some specific instruments for renewables are listed below[39].

Box 1. Definitions of Selected Greenhouse Gas Abatement Policy Instruments

<u>Regulations and Standards</u> – Specify abatement technologies (technology standard) or minimum requirements for pollution output (performance standard) to reduce emissions.

<u>Taxes and Charges</u> – A levy imposed on each unit of undesirable activity by a source.

<u>Tradable Permits</u> – Also know as marketable permits or cap-and-trade systems, this instrument establishes a limit on aggregate emissions by specified sources, requires each source to hold permits equal to its actual emissions, and allows permits to be traded among sources.

<u>Voluntary Agreements</u> – An agreement between a government authority and one or more private parties to achieve environmental objectives or to improve environmental performance beyond compliance to regulated obligations. Not all voluntary agreements are truly voluntary; some include rewards and/or penalties associated with joining or achieving commitments.

<u>Subsidies and Incentives</u> – Direct payments, tax reductions, price supports, or the equivalent from a government to an entity for implementing a practice or performing a specified action.

<u>Information Instruments</u> – Required public disclosure of environmentally related information, generally by industry to consumers. Includes labelling programs and rating and certification.

<u>Research and Development (R&D)</u> – Direct government spending and investment to generate innovation on mitigation, or physical and social infrastructure to reduce emissions. Includes prizes and incentives for technological advances.

<u>Non-Climate Policies</u> – Other policies not specifically directed at emissions reduction but that may have significant climate-related effects.

[39] For further examples of state, federal, local and utility policies and programs in the United States. see: http://dsireusa.org/Index.cfm?EE=0&RE=1

Regulations

- Renewable Performance Standards (See Box 2 for a listing and projection of expected renewable energy resulting from RPS in the US.)
- Performance standards for new facilities, e.g. GHG emissions no greater than combined cycle gas
- Green power purchasing requirements
- Interconnection standards
- Net metering rules
- Generation disclosure rules
- Contractor licensing
- Equipment certification
- Renewable access laws/guidelines/zoning codes/building permit requirements

Taxes and Charges

- Corporate tax credits/depreciation rules
- Personal income tax credits
- Sales taxes exemptions
- Property tax credits/charges

Fiscal Incentives

- Feed in tariffs
- Rebates
- Grant programmes
- Loan programmes
- Bonds
- Production incentives
- Government purchasing programmes
- Equity investments, including venture capital
- Insurance programmes
-
- Carbon taxes

Other economic instruments

- Renewable energy certificates (tradable)
- Emission trading programmes
- Off set programmes

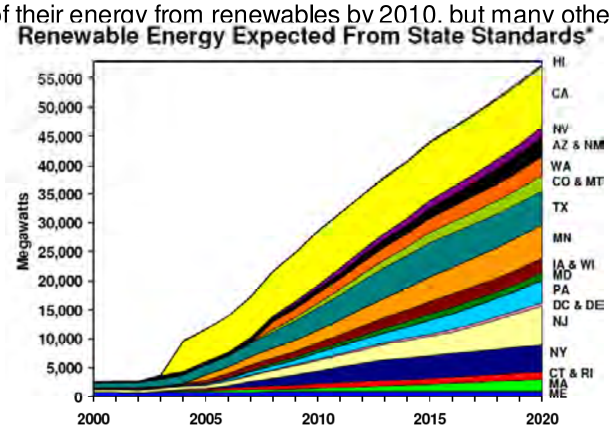
Research and Development

- Tax credits
- Grants
- Public/Private Partnerships

Policies to promote renewables are seldom applied in complete isolation, as they often overlap with other national polices relating to the environment, land use (agriculture and forestry), waste management, water, education, poverty reduction, and sustainable development. The development of policies in such cases requires coordination among ministries to promote an optimum design. Also, in most cases, promoting deployment requires more than one instrument, for example it may do little good to offer generous feed-in-tariffs at the national level, if local zoning laws prevent the installation of a facility. Applying an environmentally effective and cost effective instrument mix therefore requires a good understanding of the links with other policy areas and the interactions between the different instruments.

There is increasing evidence of which policies work and don't work. Some countries have gained significant experience and achieved rapid growth in investments and deployment. Data are available from New Energy Finance and UNEP for sustainable energy investments, particularly renewables. These data indicate that investment in sustainable energy is rapidly increasing, with $117 billion of new

Box 2. Example of RPS programs in the United States. The California RPS is most aggressive. It requires all retail energy sellers to procure 20% of their energy from renewables by 2010, but many other US



* Projected development assuming states achieve annual renewable energy targets.

Source: Union of Concerned Scientists, Renewable Electricity Standards Fact Sheet
http://www.ucsusa.org/assets/documents/clean_energy/RES_in_the_States_-_01-05_Update.pdf

investment in 2007, which was 41 % more than 2006[40]. This beat a forecast of $85 billion for 2007 by a wide margin. Over 70 countries now have wind power, including Brazil, China, Egypt, Mexico, Morocco and South Africa. Annual biofuel production is forecast to exceed 50 billion litres in 2008, about 3 percent of global gasoline consumption. Solar hot water systems have now been installed in over 50 million homes, with China accounting for 80 percent of the global market. While there are only limited studies which have evaluated the cost effectiveness of policies, it is clear that for the most part, that without a favourable policy framework renewable energy deployment is limited.

Renewable energy can fulfil many development goals. In the first instance, renewable energy can provide some of the basic needs of life and, later, it may be a means to achieve a higher standard of living. Scaling up to a global level is however a significant challenge. It would require many more governments to institute significant, stable, long-term policies. For example:

- targets for future shares or amounts of renewables exist in only 58 countries of which 13 are developing countries,
- thirty six countries have developed feed-in tariff polices,
- forty four countries, states and provinces have enacted renewable performance standards, and
- mandates for blending biofuels have been enacted in 11 developing countries in Latin America and Asia[41].

In many developing countries, there is a huge untapped or inefficiently utilised renewable energy resource which need specific national policy initiatives and international support, including finance, capacity building and technology transfer to be exploited. Financing for climate change has generally flowed from four sources: bilateral and multilateral development assistance, including the Global Environment Facility, the carbon market, including the CDM, foreign direct investment and internally generated sources of funds, including government and private sector financing. There is evidence that development assistance has been stagnant for nearly a decade and may only be an answer for least developing countries. Most new financing for renewables has come from equity markets, venture capital and other forms of private capital. New finance mechanisms and creative policies on all levels will be needed to scale up deployment in developing countries.

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Annex I

Regional Utilization Options, Capacity Building, Technology Transfer and Adaption

John Christensen

UNEP Risø Centre

Remark by the editor:
By the time of going to press the manuscript for this report was not available, therefore the information is provided in form of presentation slides.

UNEP RISØ CENTRE

Regional Utilization Options, Capacity Building, Technology Transfer and Adaptation

John Christensen
UNEP Risø Centre

UNEP DTU RISØ 1

Outlining the key issues

UNEP RISØ CENTRE

- What is in AR 4
- Current regional RE utilization
- Barriers for expansion:
  - resource data
  - systems & intermittency
  - access to technology
  - cost/capital
  - policy & institutions
  - capacity in all areas
- Capacity building
  - changing paradigms
  - context and country specific
- Technology transfer
  - what did the IPCC special report say
  - political context after Bali
  - what about IPOs
  - need for differentiated approaches

UNEP DTU RISØ 2

What is in AR 4

UNEP RISØ CENTRE

What is there

- Comprehensive coverage of status of RE technologies, costs and mitigation potential
- Extensive assessment of RE status in G8 + 3 countries
- Broad assessment of PAMs with elements of RE specificity

What is not

- Limited or no assessment of regional RE utilization options
- Cross cutting discussion of TT resulting in limited new knowledge since SRTT
- Capacity building discussion generic and de-linked from RE

UNEP DTU RISØ 3

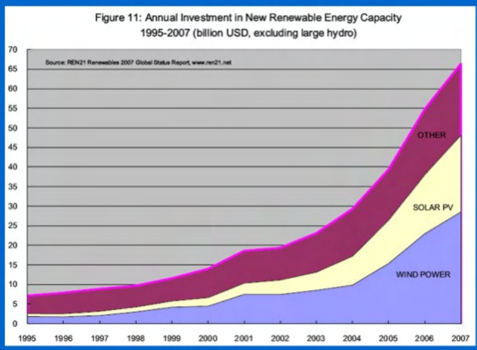
Regional Utilization

UNEP RISØ CENTRE

- Status
  - Significant expansions for wind, biomass and solar, but in small number of major GHG emitting countries
  - Policies and targets strengthened in EU, US states and number of large developing countries
- Development options
  - Increasing number of countries with policies
  - Cost coming down
  - Finance institutions – private & MDBs showing stronger interest
  - Number of RE projects in CDM increasing
  - Tech Transfer receiving more attention in COP

UNEP DTU RISØ 4

UNEP RISØ CENTRE



REN21 Renewable Energy Policy Network for the 21st Century www.ren21.net

Global status report 2007, draft – Eric Martinot

UNEP DTU RISØ 5

REN21 Renewable Energy Policy Network for the 21st Century www.ren21.net

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TOP FIVE COUNTRIES	#1	#2	#3	#4	#5
Existing capacity as of 2006					
Renewables power capacity	China	Germany	United States	Spain	India
Large hydro	United States	China	Brazil	Canada	Japan/Russia
Small hydro	China	Japan	United States	Italy	Brazil
Wind power	Germany	Spain/United States		India	Denmark
Biomass power	United States	Brazil	Philippines	Germany/Sweden/Finland	
Geothermal power	United States	Philippines	Mexico	Indonesia/Italy	
Solar PV (grid-connected)	Germany	Japan	United States	Spain	Netherlands/Italy
Solar hot water	China	Turkey	Germany	Japan	Israel

Global status report 2007, draft – Eric Martinot

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Barriers for expansion

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- Resource data
- Systems & intermittent supply
- Access to technology
- Cost and capital availability
- Policy, institutions and enforcement
- Capacity expansion for : policy, R&D, implementation, industry expansion

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Resource data

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- Solar – generic data collection, but linked with land availability, infrastructure and grid.
- Wind – generic identification but site specific data required, new methods link satellite and ground data
- Bioenergy – land availability, competing uses, water, processing and transport
- Geothermal & hydro – generic identification but specific data necessary, including land impacts etc.
- Resource assessments for most of OECD and increasing for DCs but still limited on site data.

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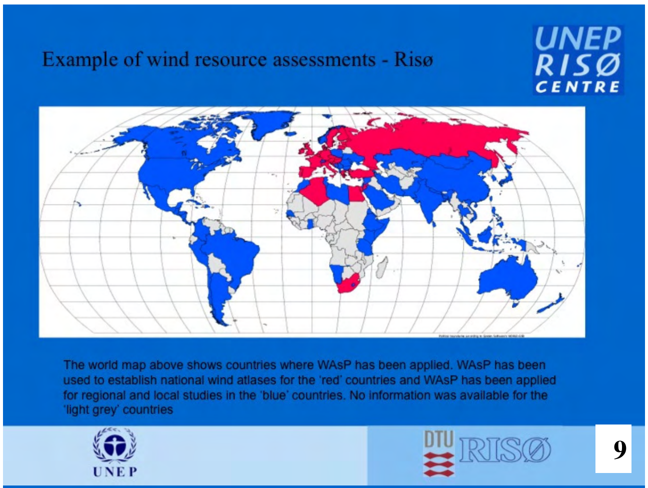
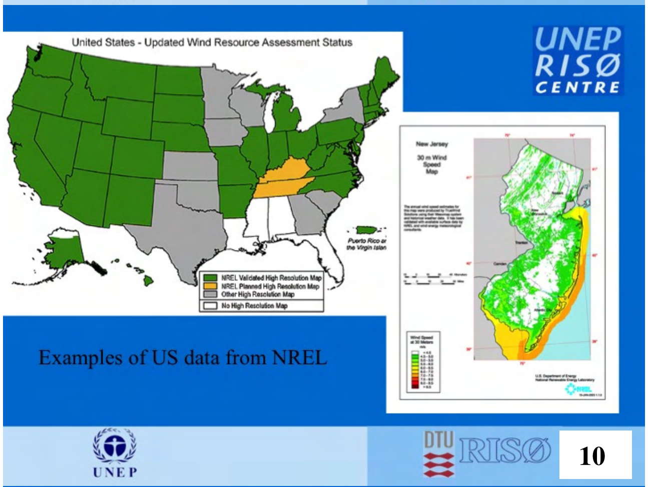
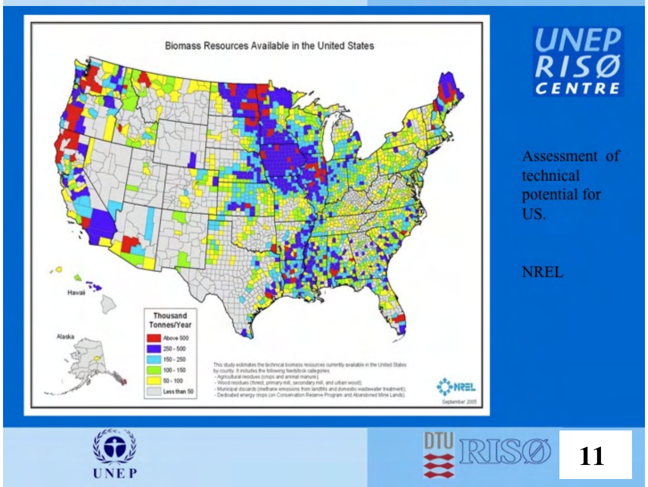
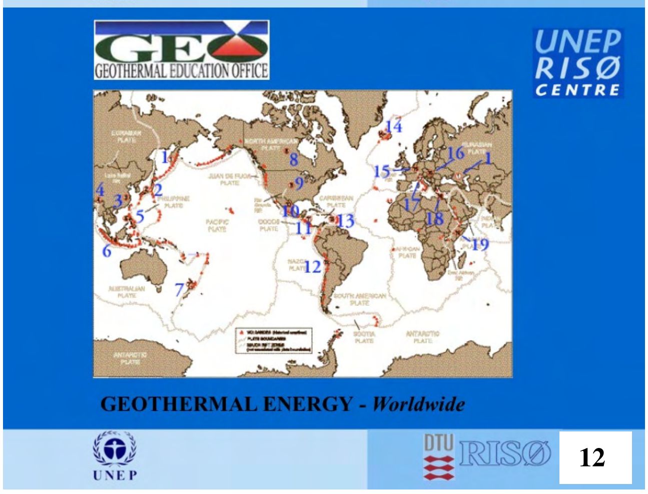
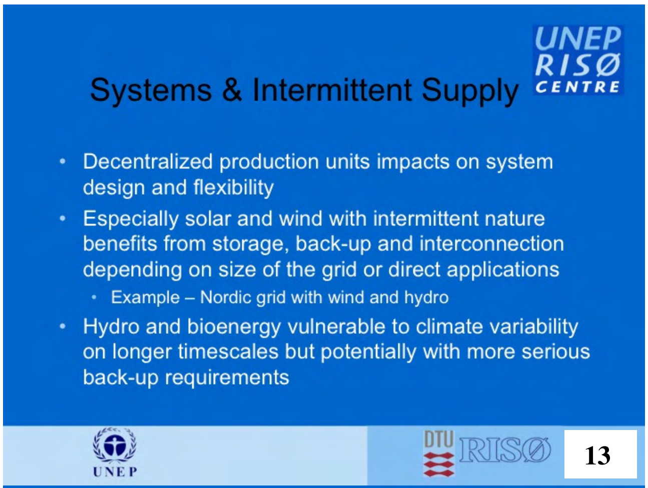
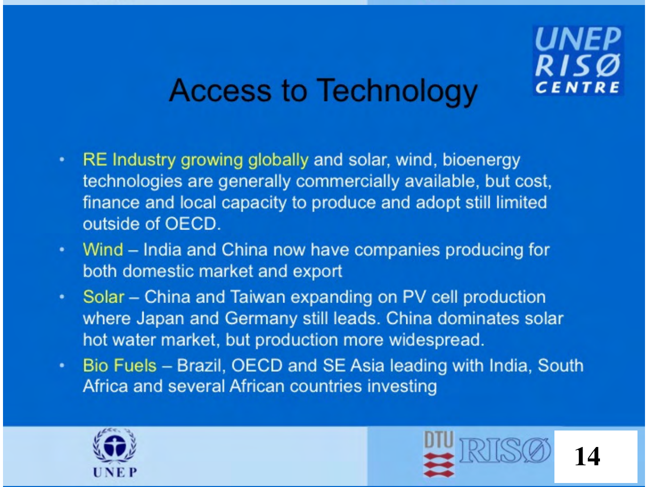






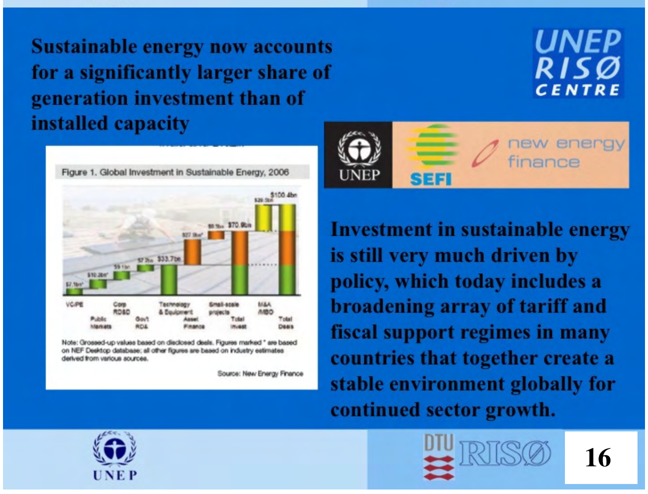






Sidebar 1. Status of Renewables Technologies—Characteristics and Costs

Technology	Typical Characteristics	Typical Energy Costs (cents/kWh)
Power Generation		
Large hydro	*Plant size:* 10 MW–18,000 MW	3–4
Small hydro	*Plant size:* 1–10 MW	4–7
On-shore wind	*Turbine size:* 1–3 MW *Blade diameter:* 60–100 meters	5–8
Off-shore wind	*Turbine size:* 1.5–5 MW (future) *Blade diameter:* 70–125 meters	8–12
Biomass power	*Plant size:* 1–20 MW	5–12
Geothermal power	*Plant size:* 1–100 MW; *Types:* binary, single- and double-flash, natural steam	4–7
Solar PV (module)	*Cell type and efficiency:* single-crystal 17%; polycrystalline 15%; thin film 10–12%	—
Rooftop solar PV	*Peak capacity:* 2–5 kWp	20–40
Concentrating solar thermal power (CSP)	*Plant size:* 1–100 MW; *Types:* tower, dish, trough	12–18 (trough)
Hot Water/Heating/Cooling		
Biomass heat	*Plant size:* 1–20 MW	1–6
Solar hot water/heating	*Size:* 2–5 m2; *Types:* evacuated tube/flat-plate	2–25
Geothermal heating/cooling	*Plant capacity:* 1–10 MW; *Types:* heat pumps, direct use, chillers	0.5–2
Biofuels		
Ethanol	*Feedstocks:* sugar cane, sugar beets, corn, cassava, sorghum, wheat (and cellulose in the future)	25–30 cents/liter (sugar) 40–50 cents/liter (corn) (gasoline equivalent)
Biodiesel	*Feedstocks:* soy, rapeseed, mustard seed, palm, jatropha, or waste vegetable oils	40–80 cents/liter (diesel equivalent)



Country	Feed-in tariff	Renewable portfolio standard	Capital subsidies, grants, or rebates	Investment or other tax credits	Sales tax, energy tax, excise tax, or VAT reduction	Tradable renewable energy certificates	Energy production payments or tax credits	Net metering	Public investment, loans, or financing	Public competitive bidding
Developing countries										
Algeria	X			X	X	X				
Argentina	X		X	(*)			X			
Brazil	X								X	X
Cambodia			X							
Chile			X							
China	X		X	X	X				X	X
Costa Rica	X									
Ecuador	X			X						
Guatemala				X	X					
Honduras				X	X					
India	(*)	(*)	X	X	X				X	X
Indonesia	X									
Mexico				X				X		
Morocco				X						
Nicaragua	X			X	X					
Panama							X			
Philippines				X	X				X	
Sri Lanka	X									
Thailand	X		X					X	X	
Tunisia			X	X						
Turkey	X		X							

RE Policies are being developed and implemented in an increasing number of developing countries. Many countries still not engaged or lacking policy and industry capacity and finance

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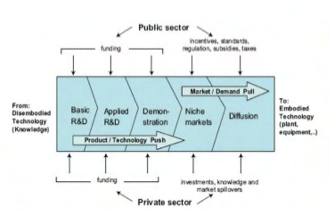
Capacity Requirements

- Capacity required for :
  - Policy development and implementation,
  - Research & Development & Deployment,
  - Industry engagement and expansion



From AR 4, WG III Technical Summary

18

Capacity Development

Capacity Barrier

To secure sustainable commercial success, renewables must overcome a number of key barriers, including:

1. Insufficient human and institutional infrastructure
2. Limited capacity to support projects and markets, owing to a lack of experience and investment

G8 RE Task Force Report

19

New approaches to capacity strengthening and market development

Old Paradigm		New paradigm
Technology assessment	→	Market assessment
Equipment supply focus	→	Application, value-added, and user focus
Economic viability	→	Policy, financing, institutional, and social needs and solutions
Technical demonstrations	→	Demonstrations of business, financing, institutional and social models
Donor gifts of equipment	→	Donors sharing the risks and costs of building sustainable
Programs and intentions	→	Experience, results, and lessons

Source: Eric Martinot, Et al (2002)

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Priority Areas for Capacity Enhancement

- Broad awareness raising and strengthened educational efforts at all levels
- Getting the policy framework right including new analytical capabilities, understanding of market oriented policy tools and an ability to implement such tools in practice
- New target groups like the upcoming regulatory institutions and regulators
- Private sector involvement both in terms of large scale industries for the commercial markets and small and medium sized enterprises for the rural and peri-urban markets

21

Priority Areas for Capacity Enhancement (II)

- Financing and lending institutions will play a crucial role - Changing the way financial institutions consider new RE investments requires both better information and new mandates to combine social and environmental factors – both risks and returns – as integral measures of economic performance.
- R & D institutions in many DCs are resource constrained and CB efforts to be focused on supporting activities, which have high local policy relevance. Policy institutions should be encouraged to involve local expertise where possible instead of often relying on international expertise.

22

Conclusions and recommendations from CB&CD literature

"Integrated and sustained action is the key" to successful expansion of RETs utilisation. Activities on capacity development needs to be designed to the specific national circumstances and involve all relevant stakeholders focusing on

- Planning and legislation
- Establishment of standards and certification
- Strengthening resource data and collection
- Project development and entrepreneur training
- Business development and finance

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Technology Transfer

- Achieving the ultimate objective of the UNFCCC, as formulated in Article 21, will require technological innovation and the rapid and widespread transfer and implementation of technologies, including know-how for mitigation of greenhouse gas (GHG) emissions. Transfer of technology for adaptation to climate change is also an important element of reducing vulnerability to climate change.
- Methodological and Technological Issues in Technology Transfer – IPCC special report, 2000

24

SRTT - conclusions

- Successful, sustainable technology transfer requires a multi-facetted enabling environment, including
  - macroeconomic conditions,
  - the involvement of social organizations,
  - national institutions for technology innovation,
  - human and institutional capacities for selecting and managing technologies
  - national legal institutions that reduce risk and protect intellectual property rights,
  - codes and standards,
  - research and technology development,
  - the means for addressing equity issues and respecting existing property rights.

UNEP DTU RISØ 25

SRTT - conclusions

- Role of industrialized countries
  - Stimulate fair competition in EST markets by discouraging restrictive business practices; overly restrictive conditions on the use of patents and refusal of licensing;
  - Reform export credit, political risk insurance and other subsidies to encourage direct foreign investment in ESTs and discourage export that lower environmental quality in developing countries;
  - Reduce the use of export controls, export cartels, licensing restrictions;
  - Reduce or eliminate tied aid as trade policy measure;
  - Ensure requirements of host countries are adequately reflected in project design.

UNEP DTU RISØ 26

SRTT - conclusions

- Role of developing countries includes assessment of local technology needs and engaging in participatory development focusing on:
  - Better choices and identification of possibilities and opportunities in local systems
  - Better commitment to projects which improves implementation and sustainability
  - Opportunities to negotiate conflicts and finance transfers
  - Empowerment- which raises awareness about the need for stakeholders to achieve solutions themselves.
  - Access to additional resources for the project

UNEP DTU RISØ 27

SRTT - Recommendations

- National Systems of Innovation:
- Targeted capacity building and strengthening scientific and technical educational institutions
- Collection and assessment of specific technical, commercial, financial and legal information;
- Identification and development of solutions to technical, financial, legal, policy and other barriers to wide deployment of ESTs;
- Technology assessment, promotion of prototypes, demonstration projects and extension services.
- Innovative financial mechanisms such as public/private sector partnerships and specialized credit facilities;
- Local and regional partnerships
- Market intermediary organizations, such as Energy Service Companies.

UNEP DTU RISØ 28

TT Support Mechanisms

- Multilateral and bilateral transfer support and dedicated partnerships
  - Bilateral ODA
  - International Finance Institutions (MDBs, GEF, etc.)
  - Technology Partnerships / bilateral or multi-country like the Asia-Pacific Partnership on Clean Development and Climate
  - New dedicated TT funds ?
- FDI and expanding public-private partnerships
- New initiatives by UK, US, Japan - ? on so-called environmental or technological transformation funds with approaches to be developed

UNEP DTU RISØ 29

Technology Transfer politics after COP 13 on Bali

- SBSTA decision to revitalize the Expert Group on TT
  - Countries to complete needs assessment
  - Need for new guidance for assessments
  - Capacity building and national focal points
- Tendency to treat TT as a stand alone activity not reflecting the barriers and incentives discussed in the SRTT
- SBI involvement makes TT building block for new treaty, but decision is not very specific apart from calling for a new funding mechanism

UNEP DTU RISØ 30

What about intellectual property rights

- IP protection generally plays a quite different role in the renewable energy industries than it does in the pharmaceutical sector, the source of many developing nation perspectives on IPR.
- Study of three renewable sectors show that the basic approaches to solving the technological problems have long been off-patent. What are usually patented are specific improvements or features.
- Thus, there is competition between a number of patented products – and the normal result of competition is to bring prices down to a point at which royalties and the price increases available with a monopoly are reduced.

ICTSD International Centre for Trade and Sustainable Development

UNEP DTU RISØ 31

TECHNOLOGY	PV	BIOFUEL	WIND
IP access limitations on current market for energy (For reducing emissions or participating in CDM).	Few concerns over IP.	Essentially no concerns over IP.	Possible concerns over IP, but likely to involve at most a small royalty.
Major developing country concerns in future market for energy.	Possible difficulties in obtaining advanced IP-protected technologies.	Possible barriers or delays in obtaining cellulosic technologies.	Possible risk of anti-competitive behaviour given concentration of industry.
IP access limitations on entering the industry as a producer of key components or products.	Possible barriers or delays in obtaining or creating the highest quality production systems.	Possible concerns over access to new enzymes and conversion organisms - but at most a royalty issue.	Possible difficulty in obtaining most advanced technologies.
Most important overall concerns in area.	Access to government-funded technologies, Standards.	Global trade barriers in the sugar/ethanol/fuel context. Access to government-funded technologies, standards.	Access to government-funded technologies, Plausible anti-competitive behaviour, standards.

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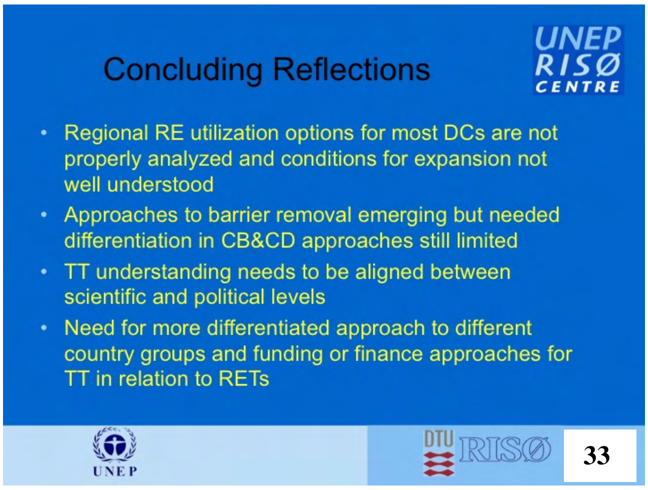
Concluding Reflections
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Regional RE utilization options for most DCs are not properly analyzed and conditions for expansion not well understood
Approaches to barrier removal emerging but needed differentiation in CB&CD approaches still limited
TT understanding needs to be aligned between scientific and political levels
Need for more differentiated approach to different country groups and funding or finance approaches for TT in relation to RETs
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Annex II
Programme of the IPCC Scoping Meeting on Renewable Energy Sources
Lübeck, Germany, January 20-25, 2008

Monday, January 21st

Time	Title lecture	Speaker
10.00 - 11:00	Registration	
Opening session and introduction		
11.00 - 11:20	Host Federal State Welcome Address	P.-H. Carstensen (Prime minister of the State of Schleswig-Holstein)
11:20 - 11:40	Host State Welcome Address	M. Müller (State Secretary at Federal Ministry for the Environment)
11:40 - 12:00	Opening Address	Ogunlade Davidson. Co-Chair WG III IPCC
12.00 - 12:20	Introductory notes to the Scoping process	Olav Hohmeyer, Vice Chair WG III IPCC
12:30 - 13:30	*Lunch break (press conference in parallel)*	
13.30 - 14:00	Introduction, use of energy, historic role of renewables and climate change	William Moomaw
14.00 - 14:30	Climate change benefits and environmental impacts of renewables in the context of sustainable development	Mohan Munasinghe, Vice Chair IPCC
14.30 - 15:00	The possible role and contribution of biomass to the mitigation of climate change	Roberto Moreira
15.00 - 15:30	*Coffee break*	
15.30 - 16:00	The possible role and contribution of direct solar energy to the mitigation of climate change	Dan Arvizu
16.00 - 16:30	The possible role and contribution of geothermal energy to the mitigation of climate change	Ingvar Birgir Fridleifsson
16.30 - 17:00	The possible role and contribution of hydro power to the mitigation of climate change	Richard Taylor
17.00 - 17:30	The possible role and contribution of marine and ocean energy to the mitigation of climate change	Hans C. Sørensen
17.30 - 18:00	The possible role and contribution of wind energy to the mitigation of climate change	Arthuros Zervos
19.00 - 20:30	*Formal Reception Lübeck town hall*	

Tuesday, January 22nd

Time	Title lecture	Speaker
09:30 - 10:00	Integration of renewable energy into future energy systems	Wolfram Krewitt
10:00 - 10:30	Mitigation potential, costs of renewable energy systems and costs of transition	Manfred Fischedick
10:30 - 11:00	*Coffee break*	
11:00 -11:30	Financing and insurance of renewable energy systems	Eric Usher
11:30 -12:00	Regional utilisation options, capacity building, technology transfer and adaptation	John Christensen
12:00 - 12:30	Policies, barriers and opportunities for the introduction and diffusion of renewables	Dennis Tirpak
12:30 - 13:30	*Lunch break*	
13:30 - 19:00	*Field trip*	Discussion of report structure
20:00	*Informal Dinner at Radisson SAS Senatorhotel*	
21:00	Presentation of discussion results to field trip participants	

Wednesday, January 23rd

Time	Title lecture	Speaker
08:00	Briefing of group chairs	
09:00	Briefing on group tasks (plenary)	
10:00	Visit of group rooms	
10:30 - 11:00	*Coffee break*	
11:00 - 12:30	Parallel Expert Groups	
12:30 - 13:30	*Lunch break*	
13:30 - 15:00	Parallel Expert Groups	
15:00 - 15:30	*Coffee break*	
15:30 - 18:00	First results of expert groups + discussion (plenary session)	Results to be posted as bullet points: - first structure of chapter - crosscutting issues to be solved - open questions
19:00 - 22:00	*Conference Dinner at "Haus der Schiffergesellschaft", Lübeck*	

Thursday, January 24th

Time	Title lecture	Speaker
8:00 - 9:00	Coordination group meeting	
9.00 - 10:30	Parallel Expert Groups	
10:30 - 11:00	*Coffee break*	
11.00 - 12:30	Summary Expert groups (plenary session)	
12:30 - 13:30	*Lunch break*	
13:30 - 14:00	IPCC Welcome Address	R. K. Pachauri, Chairman IPCC
14:00 - 15:00	Coordination of working groups, discussion, conclusion on final structure (plenary session)	
End of meeting for participants other than core writing team		
15:30 - 16:00	Final briefing of core writing team	
16:30 - 18:00	Parallel meetings core writing teams	
18:30 - 20:00	*Informal dinner of core writing team*	
20:00 - 22:00	Parallel meetings core writing teams	

Friday, January 25th

Time	Title lecture	Speaker
9.00 - 9:30	Last questions of core writing team (plenary)	
9:30 - 11:00	Final parallel meetings of core writing team	
11:00 - 11:30	*Coffee break*	
11.30 - 12:30	Final plenary of core writing team - Final scoping paper	
12:30 -13:30	*Lunch*	
End of scoping meeting		

Annex III

List of participants

Agyropolous, Daniel
Federal Ministry for the Environment, Nature Conservation and Nuclear Safety
Germany
daniel.agyropoulos@bmu.bund.de

Akai, Makoto
National Institute of Advanced Industrial Science and Technology (AIST)
Japan
m.akai@aist.go.jp

Allali, Abdelkader
Ministry of Agriculture, Rural Development and Fishing
Morocco
allali05@yahoo.fr

Arvizu, Dan
National Renewable Energy Laboratory
USA
Dan_Arvizu@nrel.gov

Babu, Suresh
TERI
India
sureshp@teri.res.in

Baidya, Saraju Kumar
Department of Hydrology and Meteorology
Nepal
sarajubaidya@yahoo.com,

Baria, Roy
MIL-TECH UK Ltd
UK
roybaria@onetel.com

Berndes, Göran
Department of Energy and Environment
Division of Physical Resource Theory
Chalmers University of Technology
Sweden
goran.berndes@chalmers.se

Blanco, Gabriel
Secretary of Environment and Sustainable Development
Argentina
gblanco@ambiente.gov.ar

Braun, Artur
EMPA - Swiss Federal Laboratories for Materials Testing & Research
Switzerland
artur.braun@empa.ch

Bruggink, Jos J.C.
Energy Research Centre of the Netherlands (ECN) and Vrije Universiteit Amsterdam (VU)
The Netherlands
bruggink@ecn.nl

Calvo, Eduardo
IPCC WG III Bureau
Peru
ecalvo@terra.com.pe

Christ, Renate
IPCC Secretariat
Switzerland
Rchrist@wmo.int

Christensen, John
UNEP Risoe Centre on Energy, Climate and Sustainable Development (URC)
Risoe National Laboratory
Denmark
john.christensen@risoe.dk

Christophersen, Øyvind
Norwegian Pollution Control Authority
Section for Climate and Energy
Norway
chr@sft.no

Cravid, Isaque Bragança Gomes
Ministerio dos recursos Naturais e Ambiente
Sao Tome and Principe
isaquecravid@hotmail.com

Davidson, Ogunlade
Faculty of Engineering, Fourah Bay College
University of Sierra Leone
Sierra Leone
ogunladedavidson@hotmail.com

De Martino Jannuzzi, Gilberto
Universidade Estadual de Campinas
Brazil
jannuzzi@fem.unicamp.br

Driesen, Johan
Katholieke Universiteit Leuven, ESAT/ELECTA
Belgium
johan.driesen@esat.kuleuven.be

Driouech, Fatima
Direction de la Météorologie Nationale
Morocco
driouech@gmail.com

Edenhofer, Ottmar
Potsdam Institute for Climate Impact Research
Germany
ottmar.edenhofer@pik-potsdam.de

Eickhout, Bas B.
Netherlands Environental Assessment Agency (MNP)
The Netherlands
bas.eickhout@mnp.nl

Elsayed Mansour
Egyptian Environmental Affairs Agency (EEAA),Ministry of State for Environmental affairs
Egypt
e_s_nasr@hotmail.com

Faaij, André A.P.C.
Faculty of Science, Utrecht University
The Netherlands
a.p.c.faaij@uu.nl

Fenhann, Joergen
UNEP Risoe Centre
Denmark
j.fenhann@risoe.dk

Fischedick, Manfred
Wuppertal Institute for Climate, Environment, Energy
Germany
Manfred.Fischedick@wupperinst.org

Fouquet, Dörthe
Kuhbier RAe
Germany
fouquet@kuhbier.com

Frankl, Paolo
IEA/ETO
France
Paolo.FRANKL@iea.org

Freitas, Marcos Aurelio Vasconcelos
Centro de Tecnologia – Cidade Universitária
Brazil
mfreitas@ppe.ufrj.br

Fridleifsson, Ingvar Birgir
United Nations University
Geothermal Training Programme
Iceland
ibf@os.is

Fujino, Junichi
Center for Global Environmental Research
National Institute for Environmental Studies (NIES)
Japan
fuji@nies.go.jp

Gabrielle, Benoit X
National institute for agronomic research (INRA)
France
Benoit.Gabrielle@grignon.inra.fr

Gagnon, Luc C.
Hydro Quebec
Canada
Gagnon.Luc@hydro.qc.ca

Greene, David
National Transportation Research Center
USA
dlgreene@ornl.gov

Habtetsion, Semereab
Ministry of Energy and Mines
Eritrea
semereabhh@gmail.com

Hamilton, Kirsty
Chatham House
UK
khamilton@chathamhouse.org.uk

Harby, Atle
SINTEF Energyresearch
Norway
Atle.Harby@sintef.no

Haroon S. Kheshgi
ExxonMobil Research & Engineering Company
USA
Haroon.S.Kheshgi@ExxonMobil.com

Helynen, Satu A
VTT
Finland
satu.helynen@vtt.fi

Hiraishi, Taka
IPCC GHG Inventory Task Force, IGES
Japan
hiraishi@iges.or.jp

Hohmeyer, Olav
Flensburg University
Germany
olav.hohmeyer@deutschland.ms

Hollands, K. G. Terry
University of Waterloo
Canada
khollands@sympatico.ca

Hongo, Takashi
Japan Bank for international Cooperation
Japan
t-hongo@jbic.go.jp

Huenges, Ernst
GeoForschungsZentrum Potsdam
Germany
huenges@gfz-potsdam.de

Infield, David
Institute of Energy and Environment,
University of Strathclyde
UK
david.infield@eee.strath.ac.uk

Johansson, Thomas
International Institute for Industrial Environmental Economics, Lund Universit
Sweden
thomas.b.johansson@iiiee.lu.se

Kainou, Kazunari
RIETI, Government of Japan
Japan
Kainou-kazunari@rieti.go.jp

Kamberi, Mirela
Climate Change Program, Ministry of Environment, Forestry and Water Administration
Albania
mkamberi@icc-al.org

Kamimoto, Masayuki
National Institute of Advanced Industrial Science and Technology
Japan
m-kamimoto@aist.go.jp

Kaneko, Masahiko
West Japan Engineering Consultants, Inc.
Japan
m-kaneko@wjec.co.jp

Killingtveit, Ånund
NTNU, Department of Hydraulic and Environmental Engineering,
Norway
aanund.killingtveit@ntnu.no

Kjaer, Christian
European Wind Energy Association
Belgium
ck@ewea.org,

Kogaki, Tetsuya
National Institute of Advanced Industrial Science and Technology
Japan
kogaki.t@aist.go.jp

Kondo, Michio
National Institute of Advanced Industrial Science and Technology
Japan
michio.kondo@aist.go.jp

Kounouhewa, Basile Bruno
Université d'Abomey-Calavi
Republic of BENIN
kbbasile@yahoo.fr

Krewitt, Wolfram
German Aerospace Center (DLR)
Germany
wolfram.krewitt@dlr.de

Krug, Thelma
Brazilian Ministry of Environment, Secretariat of Climate Change and Environmental Quality
Brazil
thelma.krug@mma.gov.br

Langniss, Ole
Zentrum für Sonnenenergie- und Wasserstoff-Forschung (ZSW)
Germany
ole.langniss@zsw-bw.de

Larsen, Hans
Risoe National Laboratory/DTU
Denmark
hans.larsen@risoe.dk

Lee, Arthur
Chevron Corporation
USA
rlas@chevron.com

Lewis, Tony
University College Cork
Ireland
t.lewis@ucc.ie

Lottmann, Jürgen
Germany
jhl@umwelt-lottmann.de

Lucas, Hugo
International Relations Department of the Institute for the diversification and saving of Energy
Spain
hlucas@idae.es

Magaña, Rebeca
Ministry of Environment
El Salvador
rmagana@marn.gob.sv

Mann, Margaret K.
National Renewable Energy Laboratory
USA
margaret_mann@nrel.gov

Markovska, Natasa
Research Center for Energy, Informatics and Materials, of the Macedonian Academy of Sciences and Arts (ICEIM-MANU)
Republic of Macedonia
natasa@manu.edu.mk

Marlay, Robert
U.S. Department of Energy
USA
Robert.Marlay@hq.doe.gov

Midgley, Pauline
German IPCC Coordination Office
Germany
pm@ier.uni-stuttgart.de

Minowa, Tomoaki
National Institute of Advanced Industrial Science and Technology
Japan
minowa.tom@aist.go.jp

Mirza, Monirul
Adaptation & Impacts Research Division, Environment Canada
Canada
monirul.mirza@ec.gc.ca

Mitchell, Catherine H C
Department of Geography
University of Exeter
UK
catherine.mitchell@exeter.ac.uk

Montalvo, Andrés Flores
Instituto Nacional de Ecología
Mexico
aflores@ine.gob.mx

Moomaw, William
The Fletcher School, Tufts University
USA
William.moomaw@tufts.edu

Moreira, Jose Roberto
CENBIO - IEE- University of Sao Paulo
Brazil
bun2@tsp.com.br

Mortimer, Nigel
North Energy Associates Ltd
UK
nigel.mortimer@northenergy.co.uk

Munasinghe, Mohan
MIND
Sri Lanka
mohan-MIND@Eureka.Lk

Nadai, Alain
Centre International de Recherche sur l'Environnement et le Développement (CIRED)
France
nadai@centre-cired.fr

Nielsen, Steffen
Ministry of Climate and Energy
Danish Energy Authority
Denmark
srn@ens.dk

Nillson, Lars
Environmental and Energy Systems Studies, Lund University
Sweden
lars.nilsson@miljo.lth.se

Niranjan, Kishore Vallentyne Vinod
The Energy and Resources Institute (TERI)
India
vvnk@teri.res.in

Nishio, Masahiro
National Institute of Advanced Industrial Science and Technology
Japan
masahiro@m-nishio.com

Nyboer, John G.
Energy and Materials Research Group, Applied Sciences, Simon Fraser University
Canada
jnyboer@sfu.ca

Osman-Elasha, Balgis M.E.
Climate Change Unit/Higher Council for Environment& Natural Resources (HCENR)
Sudan
balgis@yahoo.com

Owandano, Yoshiro
ETRI (Energy Technology Research Institute), AIST (National Institute of Advanced Industrial Science and Technology)
Japan
yoshiro-owadano@aist.go.jp

Pachauri, Rajendra
TERI
India
pachauri@teri.res.in

Pichs-Madruga, Ramón
Centro de Investigaciones de la Economia Mundial (CIEM)
Cuba
rpichs@ciem.cu

Pontes, Teresa
Instituto Nacional de Engenharia, Tecnologia e Inovação, I.P. – INETI,
Departamento de Energias Renováveis - DER
Portugal
teresa.pontes@ineti.pt

Rehfeldt, Knud
Deutsche WindGuard GmbH
Germany
k.rehfeldt@windguard.de

Ribeiro, Suzana Kahn
Federal University of Rio de Janeiro
Brazil
skr@pet.coppe.ufrj.br

Robinett III, Rush D.
Sandia National Laboratories
USA
rdrobin@sandia.gov

Robles-Gil, Sandra
Comisión Nacional del Agua (Mexico),
Commission for Climatology (CCl),
Expert Team on Climate and Energy
Mexico
sandra.robles@cna.gob.mx

Rüsch, Julia
Federal Ministry for the Environment, Nature Conservation and Nuclear Safety
Germany
julia.ruesch@bmu.bund.de

Sælthun, Nils Roar
Department of Geosciences, University of Oslo
Norway
n.r.salthun@geo.uio.no

Savolainen, Ilkka
VTT Technical Research Centre of Finland
Finland
ilkka.savolainen@vtt.fi

Scartezzini, Jean-Louis
Solar Energy and Building Physics Laboratory, Swiss Federal Institute of Technology In Lausanne (EPFL)
Switzerland
jean-louis.scartezzini@epfl.ch

Schaeffer, Roberto
Federal University of Rio de Janeiro
Brazil
roberto@ppe.ufrj.br

Schei, Tormod
Statkraft
Norway
tormod.schei@statkraft.com

Schöpe, Martin
Federal Ministry for the Environment, Nature Conservation and Nuclear Safety
Germany
martin.schoepe@bmu.bund.de

Seppälä, Jyri
Finish Environment Institut
Finland
jyri.seppala@ymparisto.fi

Sims, Ralph
Massey University
New Zealand
R.E.Sims@massey.ac.nz

Situmeang, Hardiv
PT PLN (PERSERO)
Indonesia
hardiv@indo.net.id

Smedley, Denis
Australian Greenhouse Office, Department of the Environment and Water Resources
Australia
denis.smedley@environment.gov.au

Soliano Pereira, Osvaldo L.
Universidade Salvador - UNIFACS
Brazil
osoliano@unifacs.br

Sonntag-O'Brien, Virgina
REN21 Secretariat
France
virginia.sonntagob@ren21.net

Sørensen, Hans C.
SPOK ApS
Denmark
hcs@wavedaragon.net

Takeuchi, Hiromi H.T.
AIST, Energy Technology Research Institute (ETRI)
Japan
h-takeuchi@aist.go.jp

Taylor, Richard
IHA
UK
rmt@hydropower.org

Tirpak, Dennis
USA
dennis@tirpak.com,

Torres-Martínez, Julio
Cuban Ministry for Science, Technology and Environment
Cuba
julio.torres@occyt.cu

Trittin, Tom
Flensburg University
Germany
tom.trittin@uni-flensburg.de

Tukunga, Tevita
EPU, Ministry of Lands, Survey & Natural Resources
Kingdom of Tonga
ttukunga@lands.gov.to

Turkenburg, Wim
Utrecht University
The Netherlands
w.c.turkenburg@uu.nl

Urge-Vorsatz, Diana
Central European University
Hungary
vorsatzd@ceu.hu

Usher, Eric
United Nations Environment Programme Division of Technology, Industry, and Economics Energy Branch
Canada
Eric.Usher@unep.fr

Wang, Michael
Argonne National Laboratory
USA
mqwang@anl.gov

Wiser, Ryan
Lawrence Berkeley National Laboratory
USA
rhwiser@lbl.gov

Wüstenhagen, Rolf
University of St. Gallen, Institute for Economy and the Environment (IWÖ-HSG)
Switzerland
rolf.wuestenhagen@unisg.ch

Yamba, Francis
Centre for Energy, Environment and Engineering
Zambia
fdyamba@yahoo.co.uk

van Ypersele, Jean-Pascal
Institut d'astronomie et de géophysique G. Lemaître (ASTR)
Université catholique de Louvain (UCL)
Belgium
vanyp@climate.be

Zervos, Arthouros
European Energy Council, EWEA
Belgium
zervos@fluid.mech.ntua.gr