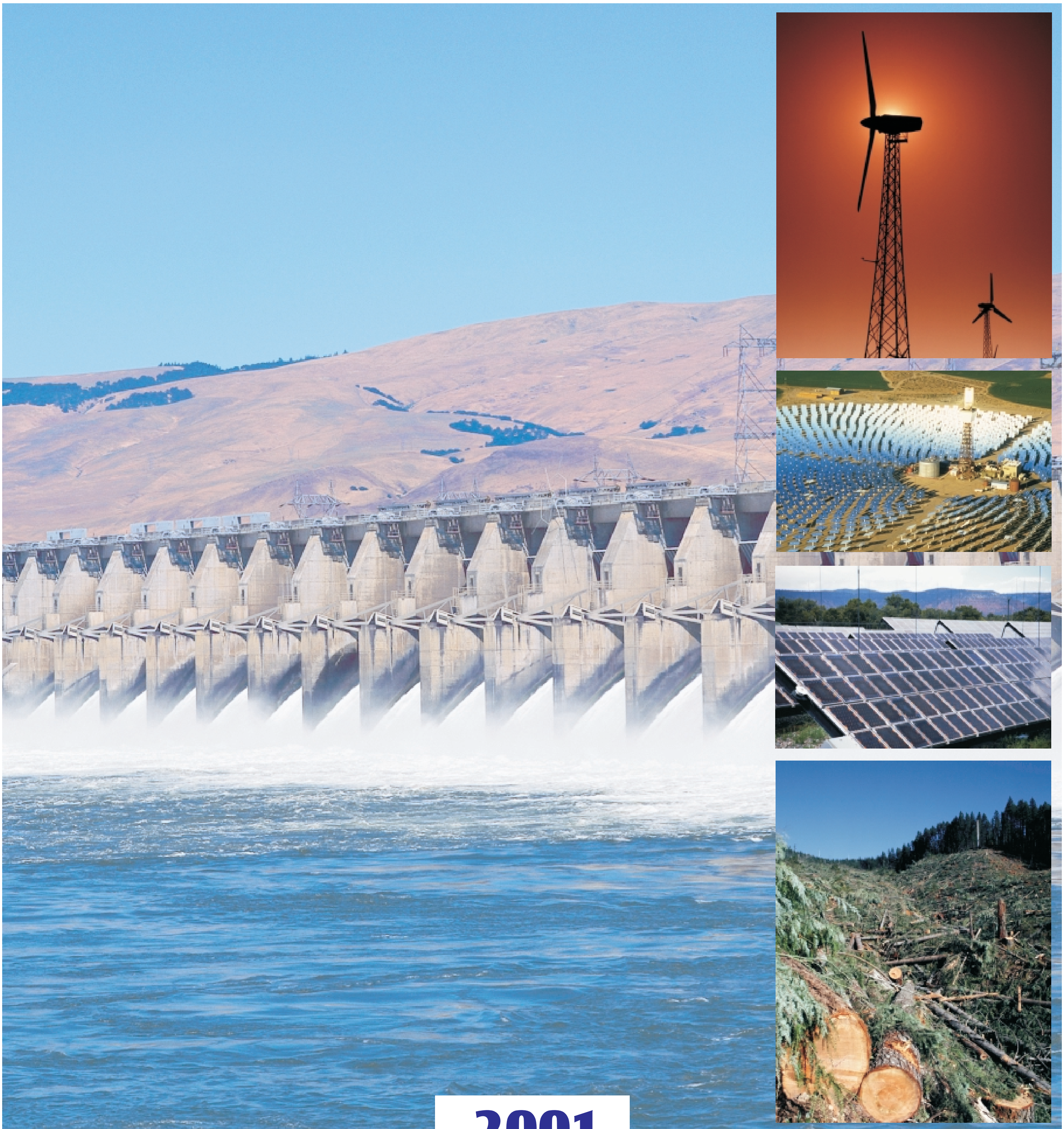
INTERNATIONAL ENERGY AGENCY

Needs for Renewables



2001

Developing a New Generation of Sustainable Energy Technologies

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Long-term R&D Needs

A Report on a Workshop of the Renewable Energy Working Party (REWP) of the International Energy Agency (IEA)

October 11, 2000
Paris, France

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Executive Summary

The International Energy Agency (IEA) Renewable Energy Working Party (REWP) organised a workshop in Paris on October 11, 2000 with the purpose of clarifying renewable energy R&D issues and fostering increased co-operation between members and non-member countries. The ultimate objective was to facilitate market deployment of renewable energy technologies to address concerns about the impact of fossil fuel combustion on climate change – global warming, while promoting the economic benefits associated with these energy options. Workshop participants included the chairpersons of ongoing IEA Implementing Agreements on renewable energy and prominent experts in the field.

The main findings of the day's deliberations were that:

- Due to recent technical and market deployment breakthroughs, confidence is building up that the world is beginning the transition to a sustainable energy system that will be largely dependent on renewable resources;
- Renewable energy technologies have made significant progress during the last few decades and contribute significantly to the energy mix of many countries around the world;
- The contribution of hydroelectricity, bioenergy and geothermal energy is significant and accounts for several percentage points of the world primary energy use;
- Renewable energy technologies such as wind turbines and solar photovoltaics (PV) are fast improving their cost effectiveness and they are being deployed in the market place at impressive rates. Annual sales of wind turbines account for several billion dollars (US) per year and are increasing at a rate of about 30%/y;
- Solar thermal low-temperature applications in buildings (passive and active) can contribute significantly towards a lower fuel demand for space and water heating. Prospects are good for broad market introduction in many areas with moderate climate;
- New sustainable energy options based on fuel cells, energy storage and hybrid systems are becoming reality and their market commercialisation may be closer than it was thought just a few years ago;
- Synergy between almost all renewable energy sources and energy efficiency options is considered an absolute requirement to quick market deployment; and
- Additional R&D, along with determined policy support for market deployment, are viewed as the way to expedite the evolution of renewable energy to the point where it can double or triple its contribution to our energy needs.

The conclusions of the workshop were that renewable energy development offers benefits for energy security and in addressing the Kyoto protocol. Other advantages associated with the commercialisation of renewable energy include social, industrial and economic benefits through the various phases of development, manufacture and market deployment. R&D needs have been identified to further advance renewable energy technologies to the stage where they can truly become the next-generation option in the transition from fossil fuels to a sustainable energy mix.

To select the best set of opportunities for international collaboration, it may be appropriate to consider convening a follow-up brainstorming meeting of technology leaders. It would be possible in such a gathering to assess the gaps in existing IEA Implementing Agreements and identify specific priorities that can be recommended to the Governing Board (GB) as new initiatives for co-operation.

Generic subjects that appear of interest for additional international co-operation include improved resource assessment mechanisms, establishment of international standards in the context of renewable energy technologies as climate change options, and synergy of renewable energy technologies with energy efficiency activities. Finally, there is perhaps scope for a more intensive information transfer, education and training initiative on the merits and opportunities for deployment of renewable energy systems.

Summary

In response to a number of strategic considerations raised in the International Energy Agency-Renewable Energy Working Party (IEA REWP) Strategic Plan, a one-day workshop was held in Paris on October 11, 2000, with the purpose of establishing long-term R&D needs. Presenters included chairs of the existing IEA implementing agreements in Renewable Energy (RE), other technology experts and key regional representatives who described programs and priorities for renewable energy in the US, Europe and Japan.

The workshop started with an address by Hans-Joergen Koch, IEA Director for Energy Efficiency, Technology and R&D and Roberto Vigotti, Chairman of the REWP. They re-emphasised the purpose of the meeting to identify effective means to complement the ongoing IEA renewables technology collaboration. The ongoing discussion about environmental degradation resulting from the growing use of fossil fuels, and the lack of stable supply of such fuels have strengthened the resolve of policy makers to accelerate the development and market deployment of clean and sustainable energy options. It was felt that the workshop could help define a roadmap of R&D initiatives within the IEA member countries to complement the current Implementing Agreements in bioenergy, geothermal energy, hydrogen, hydropower, photovoltaic power systems, solar heating and cooling; solar power and chemical energy systems, and wind power.

The technical presentations covered the main renewable energy technology areas of bioenergy, wind energy, hydropower, geothermal and the various forms of solar energy. In addition, there were extensive references to cross-cutting issues related to renewable energy such as energy storage, hydrogen, and energy efficiency.

It was shown during the workshop that progress in technology improvements and market deployment of renewable energy during the last few decades has been impressive. For example, it is estimated that bioenergy currently contributes 12-14% or about 50 EJ to global energy supply. Hydropower accounts for over 20% of the world's electrical generation while installed capacity for geothermal is over 7,000 MWe and generates over 42 TWh/y of energy. Progress in renewable energy technologies such as wind and solar has resulted in significant cost reductions and these options are fast being adopted in grid or remote site applications. Installed wind energy capacity, for example, is now (end of 2000) over 16,500 MW and the value of annual installations exceeds US$2 b. Similarly, the market for photovoltaic (PV) energy systems is rapidly growing and accounts for over US$1 b/y in sales.

The outlook for continued expansion of renewable energy, based on resource availability and expected technology improvements, is considered bright. According to the workshop presenters, bioenergy can increase its share of energy supply to

200-300 EJ, while wind energy capacity is expected to be 150 GW by 2010. Similarly, geothermal can grow substantially, with the US estimating that by 2010 it could satisfy 10% of its non-transportation energy needs from this source. Solar energy technologies such as PV, solar heating and cooling, and heat and power from solar concentrating collectors hold promise for the medium to longer term as the principle new energy sources for sustainable energy needs in the built environment. Energy storage, hydrogen, fuel cells and many energy efficiency technologies related to renewable energy should advance their stage of maturity in the next 10-20 years and contribute significantly to the transition to a clean and sustainable energy mix.

The current status of many renewable energy options confirms the optimism about the future. Based on current economics, renewable energy supplies 6 % of total primary energy in OECD countries, and over 10% worldwide. It is derived from biomass, hydroelectric and geothermal sources as mentioned above. The contribution of non-hydro renewable energy in IEA countries is expected to grow by 2.8%/y between now and 2020.

Estimates on the potential global impact of RE systems confirm that the world can make the transition to a diversified energy mix based on increasing the supply of renewable energy while gradually reducing fossil fuels within just a few decades. Economic development would continue with GDP growth rates consistent with current planning scenarios. Such a move must be accompanied by an equally strong and effective effort towards a leaner energy demand achieved through energy efficiency and recycling of many materials.

The potential benefits of such a strategic transition will be a superior environment, reduced disruptions associated with the unhealthy reliance on fossil fuels, and broadly distributed social benefits associated with the implementation of local resources to meet the demand for energy services. It has been estimated, for example, that for every MWh of renewable energy generated there may be as much as 1MT of CO_2 eliminated. Wide market deployment of renewable energy can also contribute to increased local employment and reduced needs for export of scarce foreign exchange.

The main R&D Priorities identified during the workshop were of a cross-cutting nature such as:

- resource assessment and siting (wind, geothermal, solar technologies);
- environmental attributes (bioenergy, wind, hydropower, solar);
- standards, testing and evaluation (wind energy, solar technologies, hybrid systems, hydrogen);
- marketing and financing mechanisms to expedite deployment (wind, solar technologies);
- integration of renewable energy with energy efficiency (especially in buildings);

- energy storage (improved batteries, flywheels, compressed gas, pumped hydro, etc.) especially in synergy with wind and solar technologies.

Technology-specific priorities were:

biomass

- improved conversion technologies in combustion systems, gasification, liquid fuels, co-firing of biomass wastes in coal-fired generating plants, process modelling, biotechnology.

wind turbines

- to drive the cost down there is a need for:
  better aerodynamic models, new intelligent structures and materials, improved understanding of mechanical loads, more efficient generators and converters, reliable small machines for remote locations and large sea-based machines.
- to minimise environmental impacts there is a need for:
  combined land use, visual integration, reduced noise from machines and increased knowledge of effects on flora and fauna.
- to enable large-scale use there is a need for:
  improved forecasting of power output, better power quality and hybrid systems, including hybrids with natural gas.

geothermal

- improved conversion efficiency cycles, enhanced geothermal systems, development of deep geothermal resources, shallow geothermal resources for small-scale individual users, direct use of geothermal heat for space/district heating and multi-purpose cascading.

hydropower

- improved generators, transmissions and control systems, synergy between hydro and other renewables, quantification of negative externalities.

solar heating and cooling

- product development, heat storage, integration with energy efficiency and building technologies.

solar concentrating collectors

- build confidence in technologies through:
  demonstrations showing reliability, automated operation.
- improve efficiency through:
  higher design temperatures, hybrid systems with fossil.
- reduce costs through:
  improved designs, materials and components, extend applications.

solar PV

- for the short term there is a need to:
  improve technologies related to current applications such as autonomous systems, building-integrated PV, in-line process controls, balance of systems and crystalline silicon cell and wafer production technologies.
- for the medium term there is a need for:
  improved hybrid systems, distributed generation, thin film and polycrystalline solar cells.
- for the longer term the main priorities are:
  technology improvements for large-scale systems, storage in and interaction with grids, higher efficiency contacting mechanisms and cells, cells made of plastic and other materials, monolithic compounds in PV, and organic cells.

hydrogen

- modelling tools for design, storage, safety, integrated systems for: production/storage/transport and use, production from sunlight and renewables, fuel cells, hybrid systems.

The main conclusions of the workshop were that the cost targets required for a broad commercialisation of renewable energy could be achieved. Addressing the R&D priorities identified will help advance the science and go a long way towards triggering the experience curve for the new sustainable energy options to be deployed. To quote one of the presenters at the workshop, "... the future can be oversold, but it is equally under-imagined". The experience with progress in technology evolution so far suggests that most of the estimated improvements can be exceeded. Targets of just a few years ago about the unit costs of both wind and PV power have been surpassed. Based on the collective experience of experts it was emphasised that opportunities for significant reductions in the cost of energy derived from RE sources exist for all options.

In order to arrive at a potential roadmap of future IEA activities in this area it may be appropriate as a next step in the planning process to try to construct a potential payoff matrix to select the most promising candidate technologies for additional R&D investments. It will be necessary to assess not only the potential future cost levels but also the potential supplies at a given stage of technical maturity. Under the prevailing conventional energy costs, for example, it appears that several RE options can be more competitive on the assumption that they are widely available. It may be appropriate for the IEA to assist member and non-member countries to carry out a better resource assessment and ranking of renewable energy technology potential for deployment, in a given region and application, in light of the expected cost reductions.

The global discussions about climate change and the commitments toward actions to remedy the situation (Kyoto protocol) are now pointing to the need to cost out the "right to pollute". If such measures are widely implemented in the form of a carbon or greenhouse gas tax, the corollary will be that clean and sustainable energy options will be “credited” for the equivalent CO_2 savings. In such a case, there will again be a need to establish international standards on the net benefits of each renewable energy technology and, hence, there may be a role for complementary IEA co-operation.

Another possible area for intensified international co-operation may be in training, education and information transfer. Such an initiative would expose potential users/adopters of renewable energy to the merits and opportunities of the advancing technologies and guide them towards selecting the most appropriate option(s) for their needs. Existing efforts such as the IEA CADDET should be assessed and either strengthened or complemented.

Finally, the synergy of renewable energy options with energy efficiency was a very clear conclusion of the Paris workshop. Even though there are IEA Implementing Agreements in both renewable energy and energy efficiency, there may not be sufficient communication and co-ordination between the two efforts. It may again be of benefit to all if the IEA followed up with this barrier. For example, there may be a need to organise a similar workshop to the one on October 11 with participants from both sides. In addition to the presentations, there is a need for a brainstorming session to identify future action items, such as areas for potential co-operation that would advance the overall objectives of moving towards sustainability.

Background

In response to a number of strategic considerations raised in the International Energy Agency Renewable Energy Working Party (IEA REWP) Strategic Plan, it was decided to hold a workshop in Paris to address the issue of establishing long-term R&D needs.

The objectives of the workshop were to:

- clarify renewable energy R&D issues for the CERT and the anticipated 2001 Ministerial;
- increase collaboration on R&D between IEA bodies, and between the member governments; and
- illuminate the issues concerning technology innovation infrastructure as specific for market deployment of renewable energy technologies (RETs) in member and non-member countries.

More specifically, presenters at the workshop were asked to:

- identify critical R&D topics to develop mid- to long-term options for renewable energy technologies for the time frame 2000-2020;
- characterise the potential benefits or rewards of developing the innovations required;
- relate these needs and benefits to relevant sectors of the economy (e.g., electricity, transport, buildings, etc.) to provide guidance on market pathways indicated by the potential R&D innovation; and
- identify needs not presently covered in IEA Annexes.

The workshop was held in Paris on October 11, 2000 and this report summarises the views expressed. It synthesises the main points of the workshop, including discussion that followed the presentations, and outlines a set of suggestions on R&D priorities. The workshop agenda, list of participants, and summaries of presentations as submitted by participants are included in the appendices.

The workshop started with an address by Hans-Joergen Koch, IEA Director for Energy Efficiency, Technology and R&D and Roberto Vigotti, Chairman of the REWP. They re-emphasised the purpose of the workshop to identify effective means to complement the ongoing IEA renewables technology collaboration. Current Implementing Agreements include work on: bioenergy; geothermal energy; hydrogen; hydropower; photovoltaic power systems; solar heating and cooling; solar power and chemical energy systems; and wind power.

It was felt that the workshop could help define a roadmap of major R&D collaborative initiatives within the IEA member countries, non-member countries and the private sector in order to advance the technical and economic maturity of renewable energy. In the longer term, the vision is for the new generation of RETs to penetrate the market and help the world achieve a transition to a more sustainable mix of fuels and energy services. R&D is viewed as an important component in the global effort to widely commercialise renewable energy, along with demonstrations, information dissemination and other market deployment incentives.

Public concerns about environmental degradation, including global warming, and the follow-up Kyoto commitments have strengthened the resolve by the international community to promote renewable energy as the undisputed sustainable option. The more recent oil-market disruptions have pushed renewables further up on the international energy policy agenda. In its communiqué following a special meeting in October, the IEA Governing Board

> "...affirmed its intention to give new impetus to longer-term policies to reduce oil demand, improve energy efficiency, diversify supplies and accelerate the deployment of new energy technologies".

These sentiments were reinforced by messages from the G8 group of nations and from the European Union (EU) countries encouraging the IEA to develop concrete proposals to promote energy savings and to adopt policies for energy diversification. At the same time, the IEA has been urged to focus on strengthening relationships with non-IEA countries and on working with the private sector to achieve the desired objectives of renewable energy technology development and commercialisation.

The potential contribution of renewables towards the diversification of the energy portfolio is of key importance towards the goal of energy security. At the same time, such diversification can have additional social benefits especially in energy importing countries – both developed and developing. Funds that are normally used for the purchase of imported fuels can be used for local development projects. Local employment can be increased. Through the use of new technologies, there is the potential for improved technology transfer and advancement of the use of technical skills in other sectors of the economy.

Because renewable energy resources are widely available throughout the world, they hold the promise for providing the basic power needs of over two billion people in developing countries who currently live without electricity. Renewables are also a promising option for the transportation sector in many countries because of their potential to alleviate the crisis in the supply of oil derived liquid fuels while improving the urban air quality through lower emissions.

While the above holds true, it was also recognised during the workshop that under the current cost structures, many renewable energy options are limited in market deployment to mostly niche applications. Large hydro and bioenergy projects in specific locations are exceptions to this rule. In order to broaden the market applications for RETs, they must have improved efficiency and reliability to the point where they are comparable with conventional energy. This can be achieved by a strong and sustained investment in long-term R,D&D and transitional commercialisation incentives, which recognise the environmental and social benefits of RETs. Under a level playing field policy which recognises the many hurdles faced currently by the conventional energy system, societies may agree to debit conventional energy producers/generators for the impact on our environment and use the proceeds to credit new sustainable energy options.

Efforts by the REWP to draft a new strategy towards accelerating market growth for renewable energy technologies must be closely integrated with strategic R&D directions. Policies to meet long-term R&D needs are essential to advance the science that will trigger the experience curve and technology learning processes within the business of addressing the cost of deploying new technologies. It was repeated that strategic long-term R&D turns imagination into feasible vision and new market opportunities. It promotes confidence in today's markets by focusing on aggressive cost reductions through a systems approach that addresses cross-cutting issues for most renewable energy technologies.

The exercise of priority setting for R&D in renewable energy is of interest beyond the IEA. Through increased co-operation with non-member countries, and with the private sector, the IEA can enhance both the scope and impact of major science and technology projects. The recent formation of the G8 Renewable Energy Task Force, with the IEA Executive Director participating, was recognised as a major indicator of renewed strong interest in this field. The participation of the Head of the Renewable Energy Unit in developing options and recommendations for the Task Force was also viewed as a strong positive sign.

In terms of resources required for R&D, it was observed that although the share of funds devoted to renewable energy technologies has increased within the IEA member, the total R&D budgets have declined dramatically over the last ten years. This situation came about because of the perception that conventional energy prices had stabilised. The net effect has been a lower overall funding level for all energy options. Having a bigger slice of a much smaller pie does not advance the desired objectives.

In addition to IEA specialists from member countries and the chairs of the Implementing Agreements on renewable energy, several subject matter experts and stakeholders attended the workshop. The presence of private sector representatives from major energy corporations involved in the commercialisation of renewable energy was greeted with optimism. It was clear evidence that renewable energy has made great advances over the recent past and it is approaching the stage where private entrepreneurs are willing to invest their resources in anticipation of attractive financial returns. Finally, it was recognised that the contribution of regional presentations from the three major regions of the IEA, North America, Europe and Asia/Pacific, was a good omen for the success of the effort.

Cross-cutting Visions

Recognising that technology can only be advanced through imaginative concepts based on rapidly evolving scientific principles, the session featuring keynote presentations provided participants with some excellent food for thought and discussion.

The presentation on first principles by Chris Luebkeman, Director of Research and Developments at Ove Arup & Partners International outlined the concepts of what technology is available (Now), what is coming up (New) and what technology products and services may follow (Next or Future). Over a number of examples, it was noted that advances in several technology fronts point to the direction that societies are moving towards solving many problems and inconveniences in ways that was not even imagined just a short few years before.

To take for example the concept of "when things talk..."

- The Now stage includes mobile phones that help us communicate without the awkward line, tags that contain much information that can be retrieved by the person who has the control mechanism, remote sensing devices that transmit information on a variety of observed parameters;
- The New stage includes "things that talk and think" as in networked houses where the mechanism is programmed to make a pattern recognition for predictive behaviour and reaction. New houses may have the ability to monitor your health and alert you to any problems using a computer software option linked to the outside world. Relevant information could be transmitted via software to a primary care-giver and, if necessary, emergency assistance could be summoned;
- The Next or the Future is not easy to predict. It is always oversold and under-imagined. It is quite likely that everything inconvenient will change. In this uncertain, but fast-changing world driven by breakthroughs in many fields of science and technology, the audience was challenged to imagine in the energy context:
- when personal transportation devices do not pollute (but how?);
- when buildings produce as much (or more) energy as they consume on a yearly basis (but how?);
- when facades are upgradeable to contribute to energy efficiency and generation (how?);
- that the children born today will not know what a PC is (how?) The above points were picked up as a framework for discussions in later presentations.

The presentation by Peter Hennicke of the Wuppertal Institute (Germany) described a 'bottom up' approach of analysis to the energy efficiency/demand-side management issues and associated environmental constraints of our times. The key questions investigated were:

- Is it possible to achieve the Intergovernmental Panel on Climate Change (IPCC) goal for reductions of world-wide CO_2 emissions in 2050 (e.g. 50% of the 1990 emissions)?

- Is it possible to realise a world-wide strategy of 'Doubling Wealth – Halving Resource Use'?

- Can necessary short-and mid-term steps to fulfil the climate protection goal be combined with risk minimisation (e.g. phase-out of nuclear power) and an economically reasonable path towards sustainability?

The analysis was based on a complete global model of the energy system representing 11 regions and detailed database for 160 countries. The analytical approach was similar to the one used by the International Institute for Applied Systems Analysis (IIASA) and the World Energy Council (WEC) with GDP growth rates for different countries and regions as accepted in other analyses.

By looking at the various 'energy services' sectors of shelter, mobility and production, the question was raised whether it was possible to reduce CO_2 by 50% while phasing out nuclear as soon as possible. Such an approach would be labelled a risk minimising one, and it was carefully looked at under the 'Factor Four' strategy of Doubling Wealth while Halving Resource Use[1]. This strategy was presented in a new report to the Club of Rome and it features numerous examples based on this premise.

Quadrupling resource productivity can be reached by about a 3% annual increase over some 45 years. Examples of technologies that would help achieve this goal include the Hypercar, zero external energy homes, highly efficient commercial buildings, household appliances, air conditioners, office equipment, and industrial engines. In parallel to such efficiencies, there would be a drastic decrease of transport intensities and wide and systematic recycling of products to dramatically reduce primary resource use. The Hypercar concept is built of carbon fibre, fortified epoxy resins and weighs only some 450kg. It is equipped with a hybrid engine: a small internal combustion engine supported by an equally small electric motor with a tiny battery backup.

Many countries with emerging economies, are definitely short of energy supplies and often lack an adequate conventional resource base. They could become extremely vulnerable to commodity price fluctuations. Factor Four seems to offer an attractive option for avoiding such upheavals. In their effort for rapid industrialisation and improvement of their standards of living, they could 'leapfrog' the wasteful and polluting phase that has characterised the early phases of

1 Ernst Ulrich von Weizsäcker, Amory B. Lovins and L. Hunter Lovins. Factor Four. Doubling Wealth, Halving Resource Use. London: Earthscan, early 1997. Already available in German as Faktor Vier, at Droemer Knaur, Munich.

industrialisation in the now economically advanced countries. The key to such leapfrogging could be to adopt the most energy efficient principles and technologies being developed now, while at the same time introducing advanced renewable energy options using local resources.

Some of the central results of the Wuppertal Factor Four scenario are shown in the following Table 1.

Table 1
Primary Energy Under a Factor Four Scenario

In Gtoe	1995	2020	2050
Coal	2.5	2.3	0.3
Oil	3.0	3.0	2.5
Gas	1.7	1.8	1.2
Renewables	1.8	2.6	6.3
Nuclear	0.5	0.2	0.0
World	**9.5**	**9.9**	**10.3**

Note: In parallel to the reductions in fossil fuel use and increased transition to enewable options, the total CO_2 generation would be cut by 50% within the planning horizon from 5.9 Gt C in 1995 to 5.6 in 2020 and 3.0 Gt C in 2050.

It is shown that climate protection and risk minimisation are possible and economically feasible. While CO_2 can be reduced by half, GDP can keep increasing in both the developed and developing countries while fossil fuel use will be reduced from 7.2 Gtoe in 1995 to 4.0 in 2050, and nuclear can be eliminated completely. The contribution of renewable energy can more than triple from 2.8 Gtoe to 6.3 through increased use of biomass, solar, wind and geothermal energy for electricity.

A key finding of the analysis was that total energy consumption would stay at about 10 Gtoe through energy efficiency. The amount of energy used for the basic requirements of mobility, heating, lighting, refrigeration and washing can be reduced by 50-80 %. Super efficient cars, approaching the Hypercar concept, are now being introduced by a number of manufacturers, and can travel 100 km with 2.5 l of fuel. Improved passive solar housing and buildings, recycling and energy-efficient production processes can also contribute to a much lower energy demand. Hydrogen is expected to play a key role as energy carrier.

Joachim Luther, spoke of activities at the EUREC agency and his own parent organisation, ISE of the Fraunhofer Institute in Germany. The EUREC agency represents 42 institutes in 12 EU countries with a staff of more than 1000 working in R, D&D. A key mission of EUREC is to produce position papers on the state of the art and consensus roadmaps on the future of renewable energy R&D. The Fraunhofer Institute is one of the institutes within EUREC.

It was pointed out that sales of PV products, solar collectors for heating and other energy efficient technologies such as smart windows have grown dramatically over the last few years. However, their share of the total energy market for such services is still minimal. It is important to continue with the price experience curve benefits of additional market expansion through cost reductions. Such cost reductions can certainly be achieved by improving existing technologies but, at some point, we must come up with new products and technologies, which will give us a quantum leap in cost breakthroughs. This can only be achieved through R&D on:

- today's technology;
- technology in pilot stage;
- next-generation technologies;
- beyond-the-horizon technologies, or the 'imagination' step mentioned by an earlier speaker where almost anything is possible.

For example, in the case of PV, we have:

- silicon wafer PV now;
- thin film technologies as the new;
- monolithic compounds in PV as the next-generation technologies and finally;
- organic cells and semiconductor cells based on tailored materials as the future or beyond-the -horizon technologies.

From an R&D point of view, for the first two steps we need, process technology to drive down the learning curve and bring costs down. For the next-generation technologies, we need materials research to improve such things as the efficiency of the GaInP or GaInAs cells and concentrating solar collector to 30 or 40%. For the future, of beyond-the-horizon technologies, we perhaps need to look at organic cells or tailored material that can have 10+% efficiencies.

Another example is the potential for buildings. Energy requirements for heating existing houses in Germany and other European countries is of the order of 200 kWh or 20l of oil per square metre of living area. It is interesting to mention, however, that there are low-energy houses being offered now. Using a new building code, they will consume less than half the amount of energy and generate 80% less CO_2 than the existing housing stock. Taking into account the fact that in Europe 30% of final energy goes into the building sector, it becomes obvious that there is a lot of potential in this sector if one looks at the problem from a longer term point of view. Solar energy is also playing a big role in the energy balances of new houses, contributing as much as 40% of the total energy savings. Passive solar houses being designed now would consume less that 20% of the energy needed in existing stock.

New technologies that look promising in the buildings sector include:

- improved solar envelope using intelligence systems;
- optimised windows acting as insulation or serving as active surfaces in buildings;
- electrochromics and gas chromics in advanced windows that allow switchable options and could give us 'smart' windows;
- optically selective paints with switches incorporated that can behave differently in summer and winter;
- fuel cells and advanced heat pumps.

Finally, the point was made that in our effort to come up with a new generation of energy technologies and services, we must adopt a systems approach as opposed to 'component' improvements. It is absolutely imperative that researchers and designers adopt a holistic approach to problems and address all the factors that contribute to and interact with energy supply and demand.

Gerrit Jan Zijlstra of EnergieNed, the Netherlands, pointed out that recent trends towards electricity and, more generally, energy market liberalisation have concentrated on mergers to create large, international and vertically integrated energy companies using traditional technologies. The focus has been more on efficiencies achieved through cost cutting and reducing competition. There has been strong demand for investments in power lines and gas pipelines in order to facilitate market transactions. The 'public service' principle, having governments investing on renewables, is being ignored. In summary, most of the organisational effort has been directed towards preserving the past by growing bigger and stronger financially.

On the other hand, technology developments lead to smaller energy conversion units that are better adaptable to local supply through renewable and other energy sources to satisfy decentralised demand. Small units that can generate both heat and electricity (co-generation) are becoming available. With technology advances in process automation, new materials, improved conversion processes and electricity storage techniques the overall operational economics of such small systems continue to improve. In parallel, environmental policies to address the global climate change issues will create favourable conditions for such decentralised energy units.

It has been conjectured that on the energy supply side the traditional large utility concept will be forced to change through new market forces. The new energy supply system will include production or generation companies, trade companies, retail companies, network, billing and others. Most of these new energy entities will be interested in solar and decentralised power because of their closer ties to the local energy customer. In other words, the new energy service organisations will be more influenced by the demand side for energy as opposed to the 'cost plus' reasoning which has dictated energy investments in the past.

By way of example, it was proposed that the inherent value of solar PV systems might be viewed by the energy client like an investment in a new car. Most people choose a car on the basis of more than just transport. They include in their criteria technology, comfort, safety, status and other features that fit their lifestyle. PV and other renewables may be viewed by homeowners as a means to energy independence, energy security, environmental sustainability and new technology. Such systems will be smaller and fit the distributed power mode. The backbone of the grid could still be based on fossil fuels but more environmentally friendly, such as synthetic gas – with high hydrogen content.

For such a leap forward, governments must understand 'market engineering' and provide the necessary support. 'PV is still very much a government-created market'. We need further innovation in products and market concepts. The private sector must play a role in commercialising new products through the energy service companies that believe in solar and renewables because the final user of the energy service demands them.

Graham Baxter of BP Solar spoke on the activities of the global leader in PV products manufacturing, BP Solar. The company had a 20% market share in 1999 with sales of US$180 m. According to the presenter, the solar PV markets can be divided into four segments: grid-connected applications (40% in 1999); remote industrial (25%); remote rural habitation (25%); and consumer products (10%). The off-grid applications are commercially viable without support where solar power offers a locally generated, minimal maintenance electricity supply solution. Grid-connected applications rely on government support to bridge the cost gap between consumer electricity prices and relatively high PV costs. In 1999, the market grew in excess of 30% for grid-connected applications with Japan contributing the fastest growth.

The biggest future growth areas are estimated to be in building products (rooftops and walls). Cost of PV systems is still a big factor.

To maintain the trend towards cost reductions it is necessary to continue both intensive R&D and transitional market stimulation. R&D funding must be sustained over a period of time targeted at improved manufacturing process and product development. It must focus on:

- continued development of cell and thin film technologies;
- improved performance and reliability of proven technology;
- improved manufacturing process;
- limited high-risk projects on new concepts at selected laboratories to avoid 'championship R&D' delivering record achievements at sub-economic scale.

In addition to R&D, there should be assistance towards demonstrations of promising technologies and systems. Market stimulation support should be targeted at 'levelling the playing field' for renewables and accelerating the rate of growth of the industry with resultant cost reductions. Valid mechanisms for such support include net metering, connectivity standards, portfolio standards, as well as financial measures such as low-interest loans, and capital and/or tax incentives.

In summary, the cross-cutting theme of presenters pointed to the progress achieved so far and stressed the fact that there is a very large potential for renewable energy to capture a significant role in the supply of energy services. The potential payoffs are numerous and inherent to the nature of renewable resources. They are abundant in most parts of the world as opposed to fossil fuels. They are the cleanest forms of energy known to mankind and they are sustainable.

Increased use of renewable energy fuels and services, in close synergy with energy efficiency, can benefit mankind in addressing environmental concerns. Diversified supplies can help achieve better security and energy services can be simplified through decentralised generation and distribution systems. Furthermore, the intensified use of local resources for energy can contribute social benefits such as employment, local investments and technological spin-offs from the use of new energy technologies.

For all these benefits to accrue, it is necessary to improve the cost effectiveness and reliability of RETs to the point where they are comparable with conventional energy. This can be achieved by a strong and sustained investment in long-term R,D&D and other incentives to help make the transition happen. In light of the many hurdles currently faced by the conventional energy system, societies may accept a level playing field. The net result could very well be a broadly accepted scheme by which conventional energy producers/generators are debited for the impact they cause and the proceeds are used to credit the new sustainable energy options.

Lessons Learned – Opportunities for the Future

Summary of presentations from ongoing IEA agreements and regional perspectives

In an effort to take stock of the current status of renewable energy technologies and identify their longer term potential, the chairs of the IEA Implementing Agreements presented progress reports and identified R&D opportunities for each technology. These were complemented by three regional presentations on RETs from the United States, Japan and the European Union. The combined presentations covered the whole range of options considered over the last two decades.

The impressions left from these deliberations were that, although some technologies have already made great strides towards commercialisation and currently account for significant contributions to energy supply (biomass, geothermal, hydro, wind and, to a lesser extent, solar), the potential is much larger. There was a consensus that there exists world-wide an almost unlimited potential of clean sustainable energy options that, in close synergy with energy efficiency, can play an important role in alleviating global concerns about pollution, energy security and economic development. The key to reaching this goal is a sustained effort by the international scientific and technical community to improve the economics of these energy options.

In addition to the energy supply benefits of renewable energy systems, it was recognised that their expanded market penetration can contribute towards many social and environmental benefits. Renewable energy resources can be found widely throughout the world and their local use can provide employment and other economic benefits while avoiding the export of scarce capital for the purchase of fossil fuels. Growing concerns about acid rain, air quality and climate change issues associated with the increasing use of fossil fuels can be addressed effectively with increased use of clean and sustainable renewable energy. It was demonstrated during the workshop, that the Kyoto protocol targets of CO_2 and other greenhouse gases can be met if the world develops RETs and, in parallel with energy efficiency, promotes their market deployment.

The following comments outline the progress achieved by technology and the R&D priorities that could advance the state of renewable energy. The technologies covered include: bioenergy; wind; geothermal; Hydro – large and small; solar – heating and cooling; concentrating collectors; photovoltaics; buildings; hydrogen; and cross-cutting issues. An attempt has been made to incorporate the highlights of the IEA, regional and generic theme presentations in each technology summary. A more complete list of the points raised during the workshop can be found in Appendix 1.

Technologies

Bioenergy

Bioenergy covers a wide spectrum of energy activities, from the direct production of heat through combustion of fuel wood and other biomass residues to the generation of electricity, and the production of gaseous and liquid fuels and chemicals. It is widely used throughout the world. In the developed world, it usually involves the combustion of biomass residues for heat and electricity.

In developing countries, biomass in the form of fuel wood, and agricultural residues are often the most common fuels for cooking and heating. Strong interest in liquid fuels has fostered R&D programs for the conversion of a variety of feedstocks (crops, wood, agricultural and municipal residues) to easily transportable fuels.

In North and South America, the production and use of ethanol in transport is an established and growing option. Although the current feedstocks for such plants are surplus agricultural commodities such as corn, other grains and sugar cane, cellulosic biomass will likely become the input of economic choice in the future.

The estimated contribution of bioenergy to global energy supply is of the order of 12-14%, or 50 EJ/y of a total primary energy of 406 EJ/y. This contribution could increase to about 200-300 EJ/y over the next few decades (IEA Bioenergy Agreement).

Biomass can play a dual role in greenhouse gas mitigation related to the objectives of the Kyoto protocol and other climate change initiatives. It can act as a source of sustainable energy to substitute fossil fuels and as a carbon store. Modern bioenergy options offer significant, cost-effective and perpetual opportunities toward meeting emission reduction targets while providing additional ancillary benefits arising from the wide occurrence of biomass materials. These include social benefits of employment in the growing, harvest and processing of biomass resources.

The sustainable use of the accumulated carbon through bioenergy has the potential for resolving some of the critical issues surrounding long-term maintenance of biotic carbon stocks, while expanded use of wood products can act as carbon sinks and substitutes for more energy-intensive products. The use of wood products as a fuel at the end of their lifetime provides additional emission reduction opportunities and allows repetition of the sustainable photosynthetic cycle.

The identified R&D priorities for bioenergy include the following:

- improved economics of market-driven applications such as combustion (IEA/EU)[2];
- solid biofuels characterisation and standardisation (IEA);
- combustion of solid biofuels including improved low power stoves and boilers (IEA);

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[2] Source(s) of the priority; IEA indicates the implementing agreement presenter, US, EU, Japan, the respective regional presenter.

- improved efficiency of energy generation from wastes (Japan);
- co-combustion of biomass and bio-wastes in coal-fired electricity plants (EU);
- conversion of biomass into heat and power, cost reductions and reduced environmental impacts such as addressing ash disposal-use, emission reductions and other (IEA/EU);
- gasification and gas clean-up capabilities including CHP plants and synthesis for liquid fuels (IEA/EU/US);
- improved liquid fuels technologies including biodiesel, ethanol from lignocellulosics and bio-oils from flash pyrolysis (IEA/US/EU);
- demonstration and dissemination of promising bioenergy technologies to convince potential adopters of the benefits (EU);
- fundamental research (plant biotechnology, kinetics for processes) (US);
- process modelling (IEA/US);
- integrated process development (US);
- sensor and control systems (US).

The outlook for bioenergy development is for 'biorefineries' that produce solid, gaseous and liquid fuels and chemicals using biological and/or thermal conversion processes. Although the main feedstocks in the developed world are currently residues from forest, agricultural and municipal activities, biomass feedstocks could also come from energy crops that are genetically modified and grown on marginal, or surplus farmlands. Biomass-fired power plants will evolve to combined heat and power plants. They will become modular, distributed power systems.

The stated goal in the US is to triple the use of bioenergy and bio-based products by 2010, while the long-term goal of the EU is to reach a potential 20% of current primary energy supply. Japan is also looking for significant increase of biomass use for energy.

Wind Energy

Wind energy is one of the big success stories in our effort to develop sustainable energy options. The global installed wind energy capacity reached 16,500 MW by the end of 2000. Most of this installed capacity is in Europe, followed by the US Growth in capacity has been 20-30%/y and predictions are that global capacity will exceed 150 GW by the year 2010, a tenfold increase from current levels. Production in 2000 was about 36 TWh. In addition to the energy and environmental benefits, the wind energy commercialisation is providing economic and industrial benefits. At current market deployment rates, the global wind turbine industry has sales exceeding US$2 billion/y and growing. The industry is growing faster than the personal computer industry and almost as quickly as the cellular phone industry (IEA presentation).

The key to the commercial success of wind energy lies in the fact that, through R&D and market experience, generation bid prices have been lowered significantly in good wind regimes (in 2001). In parallel, several European countries decided to boost market introduction of wind turbines by providing financial incentives. The two factors combined have resulted in the current success story.

From an environmental point of view, wind-electricity generation consumes no feedstock or fuel, emits no greenhouse gases, and creates no waste products. If wind-electricity replaces coal or diesel generation, about 1 tonne of CO_2 is saved for every megawatt hour of wind power production. The estimated total CO_2 saved as a result of the 36 TWh/y produced from the globally installed wind turbines is of the order of 30-35 Mt/y.

To continue the momentum of wind energy development and market adoption, it is still necessary to continue with R&D in a number of areas.:

- resource assessment and siting (IEA/US/Japan);
- better models for aerodynamics/aeroelasticity (IEA);
- new intelligent structures/materials and recycling (IEA/US);
- reduced uncertainties in mechanical loads (IEA);
- improved standards and testing services (IEA/US);
- new concepts for intelligent solutions for load reduction (IEA);
- more efficient generators, converters (IEA/EU);
- reliability/maintainability (IEA/US/EU);

- high-performance 100 kW turbines for remote islands (Japan);
- demonstration and dissemination of promising wind energy technologies to overcome bottlenecks in commercialisation (EU);
- next-generation machines (US);
- ocean and underwater turbines (US/EU).

Minimise environmental impacts:

- combined use of land (IEA/EU);
- visual integration (IEA/EU);
- reduced nose from turbines (IEA/EU);
- increased knowledge of effects on flora and fauna (IEA/EU).

Enable large-scale use:

- forecasting power performance (IEA/EU);
- electric load flow control and adaptive loads (IEA);
- better power quality (IEA/EU);
- hybrid systems, including hybrids with natural gas (IEA/US);
- new storage techniques for different time scales (IEA);
- large-scale integration of wind energy into the grids (EU).

According to the IEA specialists, in order to accelerate deployment, there is a need for results in the next 5-10 years in better forecasting techniques, grid integration, public attitudes and visual impact. In the next 10-20 years there is a need for results in making the wind turbine and its infrastructure interact in close co-operation. Adding intelligence to the complete wind system and allowing interaction with other energy sources will be essential in areas of large deployment. Storage techniques for different time scales (minutes to months) will increase the value at penetration levels above 15-20%.

The commercial success of wind energy has led some presenters to comment that wind energy technology is now commercial, hence there is less need for R&D.

Geothermal

The geothermal resource is the internal heat of the earth. The use of this indigenous and environmentally friendly resource covers a large range of options from power generation to space heating and/or air conditioning. In terms of global electricity production, geothermal power plants produce over 42 TWh/y through a total installed capacity of over 7,000 MWe (IEA presentation). The total avoided CO_2 as a result of the geothermal energy produced is over 40 Mt/y.

The potential for additional energy from this resource is still significant in a number of countries and needs to be quantified. The US believes it is possible, through geothermal, to provide 10% of the US non-transportation energy needs and those of over 100 million people in developing countries by 2010. New plants are being built through DOE solicitations and technologies are improving. One of the big advantages of geothermal energy is the fact that it is viewed as baseload power competing directly with gas-fired generating plants. The priorities for R&D identified in the workshop are as follows:

- better exploration/resource confirmation and management tools (IEA/US/Japan);
- power generation by improved conversion efficiency cycles (IEA/US/Japan);
- enhanced geothermal systems in hot dry rock (US/Japan/EU);
- development of deep geothermal resources-improved drilling and production technologies (IEA/Japan);
- geothermal co-generation (IEA);
- shallow geothermal resources for small-scale individual users (IEA);
- direct use of geothermal heat for space/district heating and multi-purpose cascading (IEA).

Hydropower

Hydro now provides over 20% of the world's electrical generation and there is potential to double this contribution (IEA presentation). The major 'problems' for hydro when it comes to additional capacity are the long lead times required for project approvals through the public/political/financial acceptance process. Because of the size of the projects, the construction phase itself takes a long time. The priorities for R&D include both cost reduction targets and revenue increases. The R&D needed to raise revenues may be more in the social science (public awareness). The main R&D priorities identified by the IEA presenter can be summarised as follows:

- technology improvements such as fish-friendly turbines in order to address environmental issues;
- improvements in generators, transmissions, control systems and other infrastructure;
- quantification of ancillary services;
- optimisation of power systems based on several renewable energy sources (solar, wind, with hydro acting as storage);
- social sciences R&D to quantify the benefits of clean hydroelectric energy as a means to address climate change issues and seek higher revenues;
- quantification of the negative externalities (depletion and other).

Solar Heating and Cooling

World-wide interest in low- and medium-temperature solar heating and cooling has been strong for several decades. The technologies involved are not complex and market deployment has been very successful in some countries (Australia, Mediterranean region, Austria). Economics and system reliability have acted as constraints to wide commercialisation. Government incentives are still necessary in many countries, but with improving technologies, higher cost of fossil fuels and perhaps credits for environmental benefits, the future appears rosier. It has been estimated that it is possible to provide as much as 50% of the heating demand of a house through passive solar design and the use of solar collectors. The best opportunities for3 solar heating and cooling are thought to be in:

- low-temperature heat (hot water, space heating, swimming pools);
- drying processes;
- industrial heat;
- cooling and ventilation of buildings;
- lighting;
- passive solar through design.

The key R&D needs for solar heating and cooling identified at the workshop are:

- improvements in product development (innovative and less costly materials, advanced glazings, new concepts such as photo chemical conversion, etc.) (IEA/US/EU);
- better heat storage (IEA/US);
- integration of options with the goal of ultimately having energy-producing houses and buildings (IEA/US/EU);
- testing and evaluation (IEA/US/EU);
- understanding users for better market implementation policies (IEA).

Solar Concentrating Collectors

High-temperature Concentrating Solar Power (CSP) systems hold good promise for electricity generation and perhaps hot water. These technologies include parabolic troughs, central receivers and parabolic dishes. Results from demonstration projects to date hold promise for cost-competitive generation. It was suggested that such ambitious targets can be achieved through a widespread implementation of such systems in either hybrid form with fossil fuels or solar-only applications. Plants will need to have minimum capacities of 10 MWe for the solar share.

One of the most interesting advantages of this technology is that it can provide power on demand, through the storage systems involved. The technology can also be combined in hybrid form (with fossil fuel boilers) to improve flexibility and costs. The possible production of fuels and chemicals using solar radiation directly as well as solar detoxification of hazardous materials can extend the application of concentrating solar systems in the long-term (IEA presentation). In order to achieve the potential of this technology, it is necessary to follow on with R&D and demonstrations in a number of areas including:

Build confidence in the technology through:

- pilot applications based on proven technologies (IEA/EU);
- high reliability of unattended operation (US);
- increased system efficiency through higher design temperatures (US);
- hybrid (solar/fossil fuel) plants with small solar share (IEA/US).

Reduce costs through:

- improved designs, materials, components, subsystems and processes (IEA/US/EU);
- exploitation of economies of scale (IEA/EU).

Increase solar share through:

- suitable process design (IEA);
- integration of storage (IEA).

Extend field of applications through:

- solar chemical energy storage (IEA/EU);
- solar fuels and chemicals (IEA/EU);

- solar detoxification (IEA/EU);
- demonstration of products for distributed generation (US/EU).

Market deployment is currently limited, but it was reported that four new plants are currently in the planning stage, to be funded by the World Bank.

Photovoltaics (PV)

The PV solar option is showing great promise and there is increasing interest in the technology as costs continue to come down and market deployment grows. World-wide sales of PV systems are now of the order of US$ 1 B/y and growing by about 30%/y.

The technology has a high potential in many remote regions of the world that have poor access to energy services. In developed countries, PV is seen as a clean sustainable energy option that can help address climate change and other environmental concerns. For this reason, governments have initiated major programs to encourage the integration of PV in housing and buildings.

The following R&D priorities were outlined at the workshop by the IEA, regional presenters and some of the generic theme speakers.

For the short term:

- technology-related work (IEA/US/Japan/EU)

  autonomous systems (including storage);
  building-integrated PV;
  in-line process controls;
  balance of systems (inverters/storage);
  optimisation of crystalline silicon process technologies and wafer production;

- environmental aspects (IEA)

  solar cells and modules/support structures and storage equipment;
  marketing and finance such as: product-market combination/market analysis/business models.

For the mid-term:

- technology-related (IEA/US/Japan/EU)

  hybrid systems/distributed generation/grid support/modelling;
  thin film solar cells/polycrystalline cells;
  solar cell evaluation;
  innovative concepts for cells and modules and cost reductions for other promising components and systems;

- environmental issues (IEA/EU)

  energy and material fluxes/dynamic modelling/recycling;

- marketing and finance (IEA/US)

  PV contribution to energy system/impact distributed generation;
  market and economic modelling.

For the long-term:

- technology (IEA/US/Japan/EU)

  large-scale systems/storage systems in grids/interaction with grids in distributed generation;
  higher efficiency contacting mechanisms and super high-efficiency cells;
  encapsulants that will work in large-scale systems;
  plastic solar cells and other material systems;
  multi-junction cell designs;
  low-cost and high quality silicon feedstocks;
  monolithic compounds in PV;
  organic cells and semi-conductor cells based on tailored materials as the future or beyond-the-horizon technologies.

- environmental issues (IEA)

  disposal, effects on urban environment, biosphere.

The cost goals for PV technology development would be:

- $3.00/Wp installed by 2010; and
- $1.50/Wp installed by 2020.

Ongoing system improvements, development of standards and testing and evaluation will be priority directions. In addition, there will be a need for improved manufacturing processes, demonstration of systems and information dissemination to ensure cost-effective and reliable PV products.

Opportunities exist for increased international collaboration in applied R&D, including: environmental issues; grid modelling; and distributed generation; reliable, standardised BOS components; hybrid systems; and storage technologies, as well as market studies to improve access to new products, work on partnerships, collate and disseminate feedback, etc.

Hydrogen

Hydrogen today is primarily used as a chemical feedstock in the petrochemical, food, electronics, and metallurgical processing industries, but is rapidly emerging as a major component of clean sustainable energy systems. Refineries currently produce and use over 70 billion standard cubic metres of hydrogen per year, much of which is produced from natural gas.

Growing environmental concerns over the impact of continued fossil fuel use are leading to the development of decarbonization technologies. These emerging technologies should provide a near-term avenue for climate-friendly, low-cost hydrogen production. In the mid-term, hydrogen may also be produced through the thermal processing of biomass, which should result in a net reduction in carbon emissions. In the longer term, hydrogen will be produced directly from sunlight and water by biological organisms and using semiconductor-based systems, leading to a nearly inexhaustible supply of hydrogen.

Hydrogen can provide a significant benefit to the electricity supply market for baseload (geothermal), seasonal (hydroelectric) and intermittent (PV and wind) renewable resources. Coupling these renewable-based electricity generation technologies with hydrogen storage helps maximise dispatchability and reduce the impact of low capacity factors by providing electricity and fuel when and where it is needed. Efficient and cost-effective hydrogen storage is key to achieving the benefits of this approach to providing renewable power on demand.

The main long-term strategic needs in this field are:

- modelling tools for design (IEA);
- storage possibilities in metal hydrites, carbon-based nanostructures and other materials (IEA/US);
- integrated systems of production/storage/transportation and use (IEA/US/Japan/EU);
- safety issues-codes and standards (IEA/US/Japan/EU);
- decarbonization technologies to improve environmental behaviour of fossil fuels (IEA);
- longer term production of hydrogen directly from sunlight, biological organisms and renewables (IEA/US/Japan);
- fuel cells (US/EU);
- demand/load scenarios for renewable energy-powered electrolysis (US);

- integration of hydrogen with other technologies (hybrids) (US);
- refuelling systems (US).

In terms of additional international collaboration, it was suggested that a concerted and co-ordinated effort needs to be made to address safety and education issues, and to ensure that the entire hydrogen community is working towards the same common goal. Hydrogen codes and standards only partially exist. Education of the public sector is often done in an incomplete fashion.

Cross-cutting Issues

During the workshop, a large number of cross-cutting issues for the further development of RETs was also identified. They included:

- improved resource assessment;
- close integration of RETs with energy efficiency efforts in buildings and communities;
- energy storage;
- distributed and integrated generation, transmission and distribution;
- sensors and controls;
- power electronics;
- development of fuel cells;
- information dissemination.

It is beyond the scope of this report to describe all of these options but a short summary of some key ideas is outlined.

For improved resource assessment, the main goal would be to achieve improved productivity of RETs through faster and more accurate selection of the deployment locations. To this end, R&D priorities should include:

- satellite imagery for climatological modelling and real-time forecasting;
- expanded measurement networks for validation models;
- development of low-cost, robust meteorological instrumentation;
- development of high-resolution, GIS-based renewable resource mapping techniques for all RETs.

In the case of buildings, a number of presenters mentioned that the potential exists for achieving the goal of zero-energy or even net-energy generation through the integration of many solar options in close synergy with energy efficiency improvements. The RET options could include design improvements for passive solar benefits, collectors for solar heating and cooling, and PV panels on facades and/or roofs. In the longer term, there is the potential for electrochromic switchable windows, and roofs and facades covered with active organic membranes that can serve as insulators and/or collectors of solar energy. The rapid development of micro-generators (combining heating, cooling and power) and storage technologies will further advance the integration of renewable energy into buildings and communities.

Energy storage improvements can be found in both the technology and systems arenas. Advances in batteries, flywheels, compressed gas, pumped hydro and other technologies may result in improved efficiency of individual RETs and hybrid systems. System concepts that can contribute to overall energy efficiencies include those associated with utility operations (e.g. round-the-clock efficiency), vehicles (energy capture and acceleration), and home co-generation alleviating power peaking demands on the grid. The major hurdle to market deployment of storage technologies is still the high costs of these options and hence there is a need for R,D&D.

The increasing penetration of renewable energy sources and decentralised generation (heating/cooling and electricity) in the energy supply systems may lead to numerous technical and non-technical challenges. Integration of renewable energy sources and decentralised generation refer to the integrated or stand-alone use of small, modular energy conversion close to the point of consumption. This differs fundamentally from the traditional model of central generation and delivery in that it can be located near end-users. Locating renewable energy sources and decentralised generation downstream in the energy distribution network can provide benefits for customers and the energy distribution system itself. In addition, decentralised facilities can be operated remotely and used in a broad range of customer-sited and grid-sited applications where central plants would prove impractical.

R&D needs were identified for the development of new devices for the integration of renewable energy sources in:

- distribution networks;
- stand-alone and hybrid systems;
- small turbines;
- interconnection standards and testing protocols;
- systems for load management and shaping;
- socio economic aspects and pre-normative research for decentralised energy markets.

In addition to the above points associated with the development, installation and optimal operation of RETs, a whole host of other technologies and techniques can play an important role. They include: sensors and controls required for maximum efficiency at minimum cost; power electronics and machinery impacting system efficiency; and computational sciences playing an important role in modelling and simulations of RETs and systems. Improvements in all these areas through R&D can have a significant impact on the overall effort to advance RETs to the point where they can be cost effective and, therefore, closer to commercialisation.

Conclusions and Suggestions for Future Action

Participants in the recent IEA REWP workshop on long-term R&D needs for the development of renewable energy technologies identified a number of important opportunities that may point the IEA in new directions for international co-operation. There have been significant advancements in the development and market deployment of these sustainable energy options and there is strong confidence about the outlook for further improvements in cost effectiveness through appropriate and consistent actions. New initiatives may involve research, development, demonstration and temporary market support incentives to achieve the desired transition from reliance on fossil fuels and the associated risks of supply disruptions and harmful environmental impacts. Additional deliberations may be needed to arrive at the optimum set of IEA initiatives.

The current status of many renewable energy options confirms the optimism about the future. Renewable energy currently supplies 6% of total primary energy in OECD countries, and over 10% world-wide. It is derived from biomass, hydroelectric and geothermal sources. The contribution of non-hydro renewable energy in IEA countries is expected to grow by 2.8%/y between now and 2020. Of equal importance is the fact that new RETs such as wind turbines are being deployed in the marketplace at rates comparable to the deployment of personal computers. Annual sales of wind turbines are of the order of US$2 billion, while those of PV systems are about US$1 billion. The total installed capacity for wind energy systems is now over 16.5 GW while that of PV systems is over 500 MWp (IEA presentations and reports).

Estimates on the potential global impact of renewable energy systems confirm that the world can make the transition to a diversified energy mix based on increasing the supply of renewable energy while gradually reducing fossil fuels within just a few decades. Economic development would continue with GDP growth rates consistent with current planning scenarios. Such a move must be accompanied by an equally strong and effective effort towards a leaner energy demand achieved through energy efficiency and recycling of many materials. The potential benefits of such a strategic transition will be a superior environment, reduced disruptions associated with the unhealthy reliance on fossil fuels, and broadly distributed social benefits associated with the implementation of local resources to meet the demand for energy services.

It is clear that potential cost reductions can advance the commercialisation of renewable energy in many segments of the energy market. To quote one of the presenters at the workshop, "...the future can be oversold, but it is equally under-imagined". The experience with progress in technology evolution so far suggests that most of the estimated improvements can be exceeded. Targets of just a few years ago about the unit costs of both wind and PV power have been surpassed.

Opportunities for significant reductions in the cost of energy derived from renewable energy sources exist for all options. Such cost reductions can be achieved through breakthroughs in research and development as well as during the manufacture and deployment stages through the learning/experience curve process. In order to arrive at the potential payoff matrix, it is necessary to assess not only the probable future cost levels but also the projected supplies at a given stage of technical maturity. Under the prevailing conventional energy costs, for example, it appears that several renewable energy options can be more competitive on the assumption that they are widely available. It may be appropriate for the IEA to assist member and non-member countries to carry out a better resource assessment and ranking of RET potential for deployment, in a given region and application, in light of the expected cost reductions.

The global discussions about climate change and the commitments towards actions to remedy the situation (Kyoto protocol) are now pointing to the need to cost out the ‘right to pollute’. If such measures are widely implemented in the form of a carbon or greenhouse gas tax, the corollary will be that clean and sustainable energy options will be ‘credited’ for the equivalent CO_2 savings. In such a case, there will again be a need to establish international standards on the net benefits of each RET and, hence, there may be a role for complementary IEA co-operation.

Another possible area for intensified international co-operation may be in training, education and information transfer. Such an initiative would expose potential users/adopters of renewable energy to the merits and opportunities of the advancing technologies and guide them towards selecting the most appropriate option(s) for their needs. Existing efforts such as the IEA CADDET should be assessed and either strengthened or complemented.

Finally, the synergy of renewable energy options with energy efficiency (EE) was a very clear conclusion of the Paris workshop. Even though there are IEA Implementing Agreements in both RE and EE, there may not be sufficient communication and co-ordination between the two efforts. Everyone could benefit if the IEA followed up with efforts to remove this barrier. An RE-EE workshop might be a useful event to organise. In addition to the presentations, a brainstorming session could identify future action items, such as areas for potential co-operation to advance IEA objectives.

Selected References

In addition to the workshop presentations, the following documents were used for information presented in this report:

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US Department of Energy - Office of Power Technologies, 1997. Renewable Energy Technology Characterizations. A joint project of the Office of Power Technologies, Energy Efficiency and Renewable Energy, US Department of Energy and Electric Power Research Institute

Appendix 1 - Summary of Presentations

Keynote Presentations

Presenter	Main R&D Themes	Context and/or Goals
Hans Joergen Koch and Roberto Vigotti	Purpose of the workshop: to complement the ongoing IEA renewable technology collaboration; need to define a roadmap of major R&D collaborative initiatives within the IEA member countries, non-member countries and the private sector to advance the technical and economic maturity of renewable energy.	Global concerns about environmental degradation and the follow-up to Kyoto, as well as oil market disruptions have strengthened the resolve by the international community to promote renewable energy.
Chris Luebkeman	The future is oversold and under-imagined.	Advancing technology breakthroughs allow societies to move towards solving many inconveniences in ways that cannot be easily imagined.
Peter Hennicke	Possible to Double Wealth while Halving Resource Use - Factor Four analysis points to: • energy efficiency ('hypercar', 50-80% less energy for basic requirements of mobility, heating, lighting, refrigeration, etc.); • increased use of renewable energy; • recycling; • use of hydrogen as energy carrier.	By systematically looking at the 'energy services' sectors of shelter, mobility and production on a global scale, and generally accepted GDP growth scenarios, it has been estimated that the world can, by 2050, halve CO_2 emissions while doubling wealth.
Joachim Luther	R&D towards cost reductions in today's technologies can help but, to achieve the quantum leaps needed, we must move the search to the new, next and beyond-the-horizon technologies such as: • thin film technologies for PV; • monolithic compounds, organic cells and semi-conductor cells based on tailored materials; • improved solar envelope using intelligence systems; • optimised - switchable windows using electrochromics and gas chromics; • optically selective paints; • fuel cells, advanced heat pumps; • systems as opposed to 'component' solutions.	Although markets for many renewable energy technologies and services have grown dramatically over the last few years, their share of the total energy market is still minimal. Only through R&D can societies expedite the development and commercialisation of renewable energy sources.
Gerrit Jan Zijlstra	Enabling technologies/techniques to the transition to renewables could be: • process automation and (tele)process control; • new materials and new conversion techniques (solar, fuel cells); • storage (batteries, regenesis); • societal recognition of the 'values' of solar/renewables (security, home made-local benefits, independence, reliability, environmental, etc.).	Environmental pressures will force efficiencies in the consumption of energy and the optimal use of renewables. The 'energy service supplier' will be convinced through customer demand to provide a mix of energy products and services that conform to society values for sustainability, security, cleanliness, high technology, status, etc.
Graham Baxter	Need for focus on sustained R&D in: • continued development of cell and thin film technologies; • improved performance/reliability of proven technology; • improved manufacturing process; • limited high-risk projects on new concepts at selected laboratories to avoid 'championship R&D'.	R&D funding must be sustained over a period of time targeted at improved manufacturing process and product development. In addition to R&D, there should be assistance towards demonstrations of promising technologies and systems.

Agreement	Future R&D Priorities	Context and/or Goals
Bioenergy	• improved economics of market-driven applications such as combustion for heat and power by addressing biofuel characterisation and standardisation, development of improved low-power stoves and boilers and medium-power CHP plants (0.1-10 Mwe); • ash, aerosol and corrosion problems associated with biomass combustion; • gasification of solid biofuels and improved gas quality and gas utilisation systems; • improved liquid fuels technologies such as biodiesel, ethanol from lignocellulosics and bio-oils from flash pyrolysis.	Current use of bioenergy is about 50 EJ/y, or 12% of total energy (406 EJ) Future potential 200-300 EJ/y.
Geothermal	• advanced resource development; • proven sustainability of geothermal use; • co-generation; • shallow geothermal resources; • development of deep resources; • power generation (1-100 MW); • heat supply for space/district heating; • individual users - small scale.	Geothermal already accounts for over 7,000 Mwe installed capacity. Large potential needs to be quantified.
Hydrogen	modelling tools for design; • storage possibilities in metal hydrites, carbon-based nanostructures and other materials; • integrated systems of production/storage and use; • safety issues - codes and standards; • decarbonization technologies to improve environmental behaviour of fossil fuels; • longer-term production of hydrogen directly from sunlight and biological organisms and/or renewable sources of energy.	Major improvement in storage performance to facilitate acceptance as effective energy carrier. Reducing the delivered cost of hydrogen through improved delivery infrastructure and small-scale distribution systems.
Hydropower	• environmental issues require technology improvements such as fish-friendly turbines; • improvements in generators, transmissions and other infrastructure; • optimisation of system based on several renewable energy sources (solar, wind, with hydro acting as storage); • social sciences R&D to quantification of negative externalities, ancillary services.	Hydro is often complementary for big solar and wind projects. Major problem for big hydro is long lead times required for public/political acceptance.
PV	For the short term: • technology-related work such as autonomous systems (including storage)/building-integrated PV; • environmental aspects such as solar cells and modules/support structures and storage equipment; • marketing and finance such as product-market combination/market analysis/business models. For the mid term: • technology-related such as hybrid systems/distribution generation/grid support/modelling; • environmental issues such as energy and material fluxes, dynamic modelling, recycling; • marketing and finance such as market and economic modelling.	The technology-specific goal is to support R&D in national programs and industry for cost reduction, product diversity, engineering and design, operational experience, quality assurance, safety and pre-standardisation. The environmental aspects goal is to assess environmental indicators from an international perspective and provide regular updates for energy payback, emissions, materials, recycling and disposal.

Agreement	Future R&D Priorities	Context and/or Goals
	Long term: • technology such as large-scale systems, storage systems in grids, interaction grids in distributed generation; • environmental issues such as disposal, effects on urban environment, biosphere; • marketing and finance: PV contribution to energy system/impact of distributed generation.	The marketing and finance goal is to assess market-related issues and provide comparative overviews of barriers and opportunities. Co-operation with other Agreements could be beneficial in addressing storage technologies/environmental issues/grid modelling and distributed generation/hybrid systems and market analysis and modelling.
Solar Heating and Cooling	• new conversion technology (photo chemical); • better heat storage; • integration of options; • understanding users; • better market implementation policies.	In theory, solar heating could supply up to 50% of house demand. Best opportunities are in low-temperature heat, drying, cooling-ventilation and passive.
Concentrating Solar Power	Build confidence in the technology through: • pilot applications based on proven technologies; • hybrid (solar/fossil fuel) plants with small solar share. Reduce costs through: • development and demonstration of improved components, subsystems and processes; • exploitation of economies of scale. Increase solar share through: • suitable process design; • integration of storage. Extend field of applications through: • solar chemical energy storage; • solar fuels and chemicals; • solar detoxification.	Four new plants are being planned to be funded by the World Bank.
Wind	Continue cost reductions: • improved resource assessment and siting; • better models for aerodynamic/aeroelasticity; • new intelligent structures/materials and recycling; • reduced uncertainties in mechanical loads; • improved standards; • more efficient generators, converters; • reliability/maintainability; • improved stand-alone systems. Minimise environmental impacts: • compatible use of land; • aesthetic integration; • quieter turbines; • flora and fauna. Enable large-scale use: • forecasting power performance; • electric load flow control and adaptive loads; • better power quality; • hybrid systems; • new storage techniques; • improved power quality.	Installed capacity projected to be 150 GW by 2010. For 2020 scenarios may vary from 500 to 1200 MW. Offshore location will be needed in Holland, Denmark and elsewhere for large machines (2-5 MW).
CERT Experts Group	• R&D priorities being considered now by the Experts Group.	Long-term R&D priorities are being established to 2050. Initial emphasis is to identify priorities in the transportation sector followed by others.

Country	Future R&D Priorities	Context and/or Goals
United States	Wind energy: • natural gas hybrids; • smaller and larger next-generation turbines; • lightweight materials; • reliability; • wind characteristics for taller tower designs; • testing services; • ocean and underwater turbines.	Outlook is for: • larger scale systems (1MW) moving offshore; • interest in smaller, distributed systems emerging. Cost goals: • 2 c/kWh by 2010 (before tax credit), on the assumption that R&D funding will be doubled by 2002.
	Photovoltaics: Process and fundamental research needed to meet goals, especially in: • in-line process controls; • higher efficiency contacting mechanism; • encapsulants that will work in large-scale systems; • plastic solar cells; • other material systems; • multi-junction cell designs; • balance of plant (inverters, storage).	Outlook is for: • more hybrids; • utility market beyond 10-year horizon; • intermediate market will be in space applications and building-integrated PV; Cost goals: • \$3.00/Wp installed by 2010; • \$1.50/Wp installed by 2020.
	Concentrating solar power: • products for distributed generation; • high-reliability unattended operation; • increased system efficiency through hither design temperatures; • cost reduction through improved design, advanced materials and manufacturing economics.	Goals: • reduce energy costs; • demonstrate products for distributed generation.
	Buildings: • ongoing R&D on HVAC technologies, lighting, windows, building envelope, appliances; • more emphasis on cooling loads, natural gas, fuel cells and micro co-generation (combined heating, cooling and power); • materials research (e.g. polymers); • testing and evaluation.	Outlook is for: • integration of renewables and energy efficiency (pushing towards zero-energy buildings or net generators); • advances in electronics and shift to sunbelt increased cooling loads and demand for reliable power.
	Bioenergy: • fundamental research (plant biotechnology, kinetics for processes); • process modelling; • integrated process development; • sensor and control systems; • gas clean-up capabilities;	Outlook is for: • biorefinery that produces fuels and chemicals using biological and/or thermal conversion processes; • expanded feedstocks from residues to energy crops that are genetically modified; • power plants will evolve to combined heat and power plants; • trend toward modular, distributed power systems; • goal is to triple use of bionergy and bio-based products by 2010.
	Geothermal: Better conversion cycles through: • enhanced efficiency cycles; • better performing components; • tailored working fluids.	Outlook is for: • new capacity built through private sector investment with production tax credits in short term (green power);

Country	Future R&D Priorities	Context and/or Goals
	Enhanced systems through: • systems that use heat in hot, dry, permeable formations; • better techniques to condition and manage the almost inexhaustible resource; Better exploration/confirmation tools: • identify resources that have no surface expression; • reduce risk of 'cold' or 'dry' holes; • advanced drilling technology.	• geothermal viewed as baseload power competing with gas-fired plants; • need ways to enhance and promote direct use of geothermal heat. Goal is to develop technology to enable industry to supply electric power, and heating, cooling and hot water needs of 7 million US homes by 2010. Meet the needs of 100 million people in developing countries by 2010 Supply 10% of US non-transportation energy needs via geothermal in years subsequent to 2010.
	Hydrogen: Fundamental R&D in conversion: • photo-biological-molecular biology to modify algae and bacteria to produce hydrogen from water; • photo-electrochemical/PV cells to directly split water; • thermochemical-pyrolysis, gasification to produce hydrogen (and other gases) from biomass. Process development and testing on all scales Systems engineering/integration; • demand/load scenarios for renewable energy-powered electrolysis; • fuel cells; • integration of hydrogen with other technologies (hybrids); • storage R&D for transportation applications; • refuelling systems.	Outlook is for near-term: • H_2 from steam reforming of natural gas. Mid-term: • H_2 will power fuel cells for DG, from pyrolysis of biomass gasification. Long-term: • H_2 from renewables such as PV-direct electrolysis. Goal is to develop cost-competitive hydrogen technologies and systems that will reduce the environmental impact of energy use and enable the penetration of renewable energy.
	Cross-cutting activities: • resource assessment; • distributed energy resources; • energy storage; • transmission and distribution; • power electronics; • sensors and controls; • computational sciences; • analysis; • education; • technical information/information services.	Outlook for all these areas is gaining importance because of the rapidly changing knowledge and information-based sciences and the strong link they have with all efforts to advance renewable energy technologies.
Japan	Wind energy • mproved resource assessment; • high-performance 100 kW turbines for remote islands.	Objectives are: • accurate prediction of wind resource in complex geography; • survival of turbine at wind speeds over 80 m/s and construction without large cranes.
	Photovoltaics: Cell improvement: • hin film solar cells; • poly-crystaline cells; • super high-efficiency cells; • solar cell evaluation; • system improvement; • design technologies; • balance of systems (BOS); • demonstrations.	Objective is to reduce cost through improvements in cell technology, and materials and system application and evaluation.

Country	Future R&D Priorities	Context and/or Goals
	Geothermal: • binary cycle power generation technology; • MWD system for geothermal wells; • HDR power generation system; • drilling and production technology for deep-seated geothermal resources; • deep-seated geothermal resources survey; • technology for reservoir mass and heat flow characterisation.	Objectives are to reduce costs and develop new applications.
	Biomass: • improve efficiency of energy generation from wastes.	Objective is to improve the contribution of biomass to Japan's energy supply over the next few years.
	Hydrogen: • production, especially from renewables; • transportation; • storage; • standardisation.	Objective is to contribute to the international effort to resolve the various H_2 production, distribution, utilisation and public acceptability issues.
European Commission	The key target actions for energy R&D are: • large-scale generation of electricity and/or heat with reduced CO_2 emissions from coal, biomass and other fuels, including combined heat and power; • development and demonstration, including for decentralised generation, of the main new and renewable energy sources, in particular, biomass, wind and solar technologies, and fuel cells; • integration of new and renewable energy sources into energy systems; • cost-effective environmental abatement technologies for power production; • technologies for the rational and efficient use of energy; • technologies for the transmission and distribution of energy; • technologies for the storage of energy; • more efficient exploration, extraction and production technologies for hydrocarbons; • improved efficiency of new and renewable energy sources; • elaboration of scenarios on supply and demand technologies; Under the above major targets the R&D priorities for renewable energy are:	The EU believes there are three driving forces for which technical and socio-economic R&D in the energy field is needed: climate change; strong socio-economic demand for clean, affordable energy sources; and liberalisation of energy markets and globalisation of the economy. Under the Kyoto protocol, the EU is committed to reduce CO_2 by 8% compared to 1990 levels, double the share of renewable energy sources from 6-12%, improve energy efficiency and maintain security of supply. Another key point in the EU programs is that renewable energy should be integrated with energy efficiency measures and used in combination with conventional fossil fuels to achieve faster market penetration.
	Biomass (including wastes) conversion: • heat and power; • combustion of biomass and bio-wastes in coal-fired electricity plants; • gasification;	Biomass expected in the long term to reach a potential 20% of current primary energy supply.
	Wind energy optimisation: • need to overcome bottlenecks that h8inder exploitation of onshore wind energy and to stimulate offshore installations; • improve performance through better energy capture, durability, availability, reliability and environmental attributes.	Aim to install 40 GW power by 2010.
	Photovoltaics: Development of cost-effective and reliable PV technologies such as: • low-cost and high-quality silicon feedstock; • optimisation of crystaline silicon process technologies;	Cost targets are 7 Euro/Wp for the short term and 3 Euro/Wp for the medium term. For the long term the aim is a system cost of <1 Euro/Wp.

Country	Future R&D Priorities	Context and/or Goals
	• wafer production; • thin film technologies. innovative concepts for cells and modules and cost reductions for other promising components and systems.	
	Solar thermal concentrating systems.	Target to reduce cost in the short term to 2,500 Euro/kWe for installed systems and generation costs for the longer term the target is for 0.04 Euro/kWh.
	Efficient, reliable and cost-effective fuel cell systems.	Target for <9,000 Euro/kW and >10,000 hrs for stationary applications and <1,000 Euro/kW for mobile applications.
	Integration of renewable energy sources into the grid and stand-alone systems and improved hybrid systems.	Aim to overcome technical problems related to connections to the grid and stand-alone systems. Target is to ensure cost-effectiveness and system availability higher than 95% For hybrid systems the target is to operate more than half the time and ensure cost-effectiveness. Demonstrate solutions to noise abatement, visual intrusion and other non-technical barriers.
	Improved acceptability of renewables.	
	Rational use of energy: Eco-buildings • combine energy efficiency concepts with renewable energy sources, especially solar energy.	Aim to double the share of renewable energy in the built environment to 12% of total energy consumed.

Appendix 2

International Energy Agency (IEA) Renewable Energy Working Party (REWP)
October 11, 2000 – Paris, France

Agenda and List of Speakers

Registration	8:30-9:00
1: Introduction and Presentation of the Objectives ■ Hans Joergen Koch, IEA Secretariat ■ Roberto Vigotti, REWP	9:00-9:15
2. Keynote Speaker Presentations Moderator: Joachim Luther, Fraunhofer ISE ■ Chris Luebkeman, Ove Arup R+D ■ Graham Baxter, BP Solarex ■ Gerrit Jan Zijlstra, EnergieNed ■ Peter Hennicke, Wuppertal Institute	9:15-10:45
Coffee break	10:45-11:00
3. The Perspective of IEA Moderator: Fernando Sánchez Sudón, REWP Member, Spain ■ Josef Spitzer, IEA Bioenergy ■ Ladislaus Rybach, IEA Geothermal ■ Neil P. Rossmeissl, IEA Hydrogen ■ Lars Hammar, IEA Hydropower ■ Erik H. Lysen, IEA Photovoltaic Power Systems	11:00-12:30
Lunch	12:30-14:00
■ Lex Bosselaar, IEA Solar Heating and Cooling ■ Robert Pitz-Paal, IEA Solar Paces ■ Jaap't Hooft, IEA Wind ■ Rainer Schneider, IEA CERT Experts' Group on R&D Priority Setting	14:00-15:00
4. The Regional Perspectives Moderator: Allan Hoffman, REWP Member, USA. ■ Stan Bull, NREL, USA. ■ Ryutaro Kadoi, NEDO, Japan ■ Manuel Sanchez-Jimenez, CEC DG RTD	14:00-16:30
5. Conclusions and Follow-up Moderator: Roberto Vigotti	16:30-17:00