NOVEL ENERGY SAVING TECHNOLOGIES EVALUATION TOOL

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Abstract

The main objective of EMINENT project (Early Market Introduction of New ENergy Technologies) launched by EC DG TREN is to identify and accelerate introduction and implementation of leading edge European energy and environmental technology into the market place in Europe and worldwide.

A software tool and an integrated database on new technologies and sectoral energy supplies and demands were developed and implemented. They are capable to analyse the potential impact of new, yet underdeveloped energy technologies in different sectors of society over different countries.

The case study analysis using the developed software tool was carried out. It proves that third generation solar cells have highest efficiency and lowest costs. Biological base solar cells are the best in terms of slimness and environmental friendliness.

Several biomass processing technologies show high performance and wide range of applications. Geothermal energy applications using compact and enhanced heat exchangers are another innovative and promising field. Power recovery technology in Fluid Catalytic Cracking being efficient in converting waste heat into electricity also showed very short payback period which makes it attractive to the industry.

An important aspect of EMINENT is a range of dissemination activities. They include development of Technology Assessment Reports, organisation of thematic workshops two of which have been already carried out and proved to be very successful, an interactive internet site and other kinds of technology transfer.

The project is described in more details on project website www.eminentproject.com. This website also provides contacts to coordinators and partners as well as previously published papers and presentations.

INTRODUCTION

EMINENT (Early Market Introduction of New ENergy Technologies) project was launched by EC DG TREN in 2003. The main objective of the project is to identify and accelerate introduction and implementation of leading edge European energy and environmental technology into the market place in Europe and worldwide. By the end of its second year the project has achieved substantial results in its key areas and is now moving to its final stage.

The first version of the software tool was developed and implemented, which is capable to analyse the potential impact of new, yet underdeveloped energy technologies (early stage technologies, ESTs) in different sectors of society over different countries. The current work is focused on development of an advanced internet based version to enable users to continuously exchange and work with the most recent data. Along with the EMINENT tool an extensive database has been developed which serves for storing the data both on new technologies and sectoral energy supplies and demands.

The EMINENT tool and the database have been applied to estimate the potential and the prospects of various technologies which are just being developed or have been developed recently. In total twenty case studies were carried out involving different countries, regions. Besides being a good exercise for testing the EMINENT tool, those case studies provided good analytical information on the technologies described. The case studies covered the research in the following areas:

- First to third generations of solar cells including crystalline silicon solar cells, thin film solar cells and biological base solar cells used in the range of applications from households to processing industry in the UK.
Concentrated acid hydrolysis using biomass fermentation;
- Biomass gasification methanol synthesis system;
- Plate fin, printed circuit and corrugated tube heat exchangers in geothermal applications;
- FCC Power Recovery Unit in Refinery.

The results of the case studies include quantified performance data, resources and demand for the relevant chains, emissions, costs and savings. The analysis of ten technologies in these case studies clearly showed the benefits and areas of application.

The case study analysis proves that third generation solar cells have highest efficiency and lowest costs. Biological base solar cells are the best in terms of slimness and environmental friendliness. Several biomass processing technologies show high performance and wide range of applications. Geothermal energy applications using compact and enhanced heat exchangers are another innovative and promising field. Power recovery technology in FCC being efficient in converting waste heat into electricity also showed very short payback period which makes it attractive to the industry. Efficient utilisation of energy by the thermal treatment of wastes processes also seems to be a very promising approach (Bebar et al., 2002).

Another important aspect of EMINENT project is a range of dissemination activities which include development of Technology Assessment Reports, organisation of thematic workshops two of which have been already carried out and proved to be very successful, an interactive internet site and other kinds of technology transfer.

The results of EST assessments produced using the EMINENT tool and the data stored in the EMINENT database is be used for generating consultations for the European Commission on the potential of application of the EST in different countries, covering technology, knowledge, education, market aspects, economics, incentives and partnership arrangements. This is the logical final stage of the project and the focal point is currently being shifted to this activity.

EMINENT SOFTWARE TOOL

A software tool has been developed in the framework of EMINENT project. The tool major tasks are to design possible energy supply chains and to evaluate each of them based on weighing factors given by the user. The EMINENT software tool was described in details by Jansen et al (2004). The principle of its performance is shown in Fig. 1 and one of its screens – General Technology Data – in Fig. 2.

The software tool consists of several parts. The resource manager describes details of resources available in the country, modifies and enters the new data, selects the data for technology assessment.

Another useful EST evaluation tool is presented in the next section. It is an interactive internet site which aims to provide a quick overview of the current status of the EST in Europe. The site is under development and will be launched shortly.
The following energy resources can be handled by the tool: electricity, fuels, geothermal, hydro energy, ocean tidal energy, wave energy, wind energy and solar energy. The type of data to be entered generally relates to capacities available, prices, etc as well as a number of resource specific technical parameters.

The demand manager describes details of energy demands per subsector in given country, modifies data and enters new data, selects data for technology assessment. Five demand types are included in the demand manager: electricity, fuel, heating, cooling, mechanical work, and transportation demands. For the demand manager as well, data to be entered includes required capacities, number of full-load hours per year, number of consumers in a sector, as well as a number of demand type specific technical parameters.

The EST manager operates the databases which are an integral part of the tool, contains key data on a number of technologies that are either commercially available or in their early stages of development.

The analysis tool is the central part of the software package. It provides the evaluation of the market assessment of full energy chains.

**EARLY STAGE TECHNOLOGIES CONSIDERED**

The Early Stage Technology data, which were filled into the EST manager of the EMINENT Assessment Tool, included the developer details, specific technical data and financial data. The data cover the number of technologies that are either commercially available or in their early stages of development.

For demonstration purposes, we selected several of them: Solar Photovoltaic, Biomass, Heat Exchangers and Oil Refining. Case studies from Early Stage Technologies demonstrate the information after combining resource, EST and demand together. A brief description of the technologies selected in the EMINENT tool is provided.

**Solar Photovoltaic Cells**

Recent years have seen rapid growth in the number of installations of PV on to buildings that are connected to the electricity grid. This area of demand has been stimulated in part by government subsidy programmes (especially Japan and Germany) and by green pricing policies of utilities or electricity service providers (e.g. in Switzerland and the USA). The central driving force though comes from the desire of individuals or companies to obtain their electricity from a clean, non-polluting, renewable source for which they are prepared to pay a small premium.

The solar photovoltaic cells have been developed from the first-generation to third-generation. They have got a considerable potential when they are economically competitive (Müller-Steinhagen and Trieb, 2004). The first and second generation cells are being used at present; however, the third-generation of the cells is still in the laboratory stage. Crystalline silicon (c-Si) – first generation cells - is the most widely used solar cells at the present time. Historically, it has been used as the light-absorbing semiconductor in most solar cells, even though it is a relatively poor absorber of light and requires a considerable thickness (several hundred microns) of material. Nevertheless, it has proved convenient because it yields stable solar cells with good efficiencies (11-16%, half to two-thirds of the theoretical maximum) and uses process technology developed from the huge knowledge base of the microelectronics industry. The most efficient production cells use monocrystalline c-Si with laser grooved, buried grid contacts for maximum light absorption and current collection. Each c-Si cell generates about 0.5V, so 36 cells are usually soldered together in series to produce a module with an output to charge a 12V battery. The cells are hermetically sealed under toughened, high transmission glass to produce highly reliable, weather resistant modules that may be warranted for up to 25 years (www.solarbuzz.com). Two types of crystalline silicon are used in the industry. The first is monocrystalline, produced by slicing wafers (up to 150mm diameter and 350 microns thick) from a high-purity single crystal boule. The second is multicrystalline silicon, made by sawing a cast block of silicon first into bars and then wafers. The main trend in crystalline silicon cell manufacture is toward multicrystalline technology.

The high cost of crystalline silicon wafers (they make up 40-50% of the cost of a finished module) has led the industry to look at cheaper materials to make solar cells. Thin film solar cells – second generation cells - have lower cost than the crystalline silicon because they are only about one micron thick; however they have less efficiency than the crystalline silicon cells (www.solarbuzz.com). The high cost of crystalline silicon wafers (they make up 40-50% of the cost of a finished module) has led the research to look at cheaper materials to make solar cells.

The selected materials are all strong light absorbers and only need to be about 1 micron thick, so materials costs are significantly reduced. The most common materials are amorphous silicon (a-Si, still silicon, but in a different form), or the polycrystalline materials: cadmium telluride (CdTe) and copper indium (gallium) diselenide (CIS or CIGS). The emerging thin film technologies have yet to make significant in-roads into the dominant position held by the relatively mature c-Si technology. However, they do hold a niche position in low power (<50W)
and consumer electronics applications, and may offer particular design options for building integrated applications.

Unlike the crystalline and thin film solar cells that have solid-state light absorbing layers, electrochemical solar cells have their active component in a liquid phase. They use a dye sensitiser to absorb the light and create electron-hole pairs in a nanocrystalline titanium dioxide semiconductor layer. This is sandwiched in between a tin oxide coated glass sheet (the front contact of the cell) and a rear carbon contact layer, with a glass or foil backing sheet.

Third generation cells, (www.konarkatech.com) are lightweight, flexible and more versatile than previous generations of products. The manufacturer has a pilot-scale production unit and the products will be available in 2005. Besides that, biological-base solar cells (Das et al, 2004) are also reported to be in the development stage for very small size applications. The third generation cells represent a new type of coatable, plastic, flexible photovoltaic cells, which can be used in many applications where traditional first generation cells cannot compete. The current functioning third generation cells are close to eight percent efficiency and are expected to exceed 10 percent in within a year. This leads the third generation cells to exceed the second generation performance but at lower cost and with more options in the product form factor.

Biomass

Concentrated Acid Hydrolysis. Arkenol Inc. is reported to have developed a technology called concentrated acid hydrolysis (Badger, 2002). The idea is to convert biomass into sugar, which is used as a raw material for fermentation or chemical conversion into any of a hundred different specialty and/or commodity chemicals.

The sugar from biomass is cheaper than corn sugar. The biomass feed stocks can be wood waste, green waste, agricultural residue, crops grown specifically for their biomass and paper.

Biomass Gasification Methanol Synthesis System. Energy from biomass is characterised by zero CO₂ emission, contributes to energy security and can be sustainable if the biomass resources are managed in a sustainable manner. During the combustion process, biomass emits CO₂ but an equal amount of CO₂ is absorbed by the biomass as it grows. Moreover, several studies have shown that there is plenty of sustainably grown biomass available that can be used for energy can be used almost everywhere and it will never dry up.

A six step process to synthesis methanol from biomass has been reported by Mitsubishi Heavy Industries Ltd (2004). First of all, the biomass is dried under the sun and pulverised to 1 mm. Then, the biomass is partially oxidised with steam and oxygen in the gasifier, in which the temperature is about 800 - 1100 °C. Next, the synthesis gas, which consists of H₂ and CO, is cooled and sent to a gas clean up unit. In gas clean up unit, the synthesis gas has the ash and surplus steam removed and pressurised to 3-8 MPa. In the last step, a copper-zinc catalyst is used at 180-300 °C to synthesise methanol.

Heat Exchangers

A variety of advanced heat exchangers can be used as described eg by Stehlik and Wadkar (2002), Reay (1999). Three general types of heat exchangers have been included in the software tool: plate fin (Chart Industries Inc, 2004), printed circuit (Heatric, 2004) and corrugated tube heat exchangers (HRS Process System PVT. Ltd, 2004). Though being quite mature, these advanced process intensification units can find quite promising applications in the areas that have not been considered before.

Oil Refining

Modified Fluid Catalytic Cracking process Unit includes additional power recovery unit and 3rd stage separator installed. The flue gas goes to the 3rd stage separator to remove catalyst fines first and then sent to the expander to drive the turbines. In the expander, the enthalpy from the flue gas is converted to shaft work that used to drive the electricity generator and the air blower. For the start up, the steam turbine will be used to drive the air blower instead of the expander. The electricity generator can be acted as the motor, if the expander does not produce enough power. After the flue gas passed the expander, it will be sent to the CO Boiler to generate steam and release to outside. (UOP, 2004)

ANALYSIS AND RESULTS OF FIRST CASE STUDIES

Several case studies within EMINENT project have been completed so far. In the first case study, the first generation solar photovoltaic cells are chosen to illustrate the functionality of the analysis tool in the EMINENT software. Crystalline Silicon Solar Cells from BP Solar Inc. have solar radiation as an input and electricity as an output. This technology is assumed to be used in domestic houses in the UK.

Resource: From EMINENT Assessment Tool, the population averaged latitude of the UK is 52.77 degree north. Here, the average
Table 1. Performance data for the first generation solar photovoltaic cells in the UK household sector

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity of the technology</td>
<td>5kWp</td>
</tr>
<tr>
<td>Chain efficiency</td>
<td>13 %</td>
</tr>
<tr>
<td>PV Area</td>
<td>38.5 m²</td>
</tr>
<tr>
<td>Renewable energy delivered</td>
<td>4.465 MWh</td>
</tr>
<tr>
<td>Total cost of technology</td>
<td>49896 €</td>
</tr>
<tr>
<td>CO2 emission reduction vs the reference (grid)</td>
<td>4.3 t/y</td>
</tr>
<tr>
<td>Break-even point</td>
<td>20 years</td>
</tr>
</tbody>
</table>

Table 2. Performance data for the second generation solar photovoltaic cells in the UK household sector

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity of the technology</td>
<td>2.8</td>
</tr>
<tr>
<td>Chain efficiency</td>
<td>7%</td>
</tr>
<tr>
<td>PV Area</td>
<td>40 m²</td>
</tr>
<tr>
<td>Renewable energy delivered</td>
<td>2.506</td>
</tr>
<tr>
<td>Total cost of technology</td>
<td>32700 €</td>
</tr>
<tr>
<td>CO2 emission reduction vs the reference (grid)</td>
<td>2.41 t/y</td>
</tr>
<tr>
<td>Break-even point</td>
<td>Over 20 years</td>
</tr>
</tbody>
</table>

Table 3. Performance data for the third generation solar photovoltaic cells in the UK household sector

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity of the technology</td>
<td>7.3</td>
</tr>
<tr>
<td>Chain efficiency</td>
<td>18</td>
</tr>
<tr>
<td>PV Area</td>
<td>40.6</td>
</tr>
<tr>
<td>Renewable energy delivered</td>
<td>6.483</td>
</tr>
<tr>
<td>Total cost of technology</td>
<td>68161 €</td>
</tr>
<tr>
<td>CO2 emission reduction vs the reference (grid)</td>
<td>6.25 t/y</td>
</tr>
<tr>
<td>Break-even point</td>
<td>12.6</td>
</tr>
</tbody>
</table>

solar radiation and the annual average wind speed at ground level are 2.51 kWh/m²/day and 3.53 m/s respectively.

Demand: In 2002, there are approximately 25,800,000 households in the UK. It is assumed that the households used electricity 433 full load hours. As the result, each household uses the electricity about 4.47 MWh/y, according to Euro Stat (2004). The average roof surface area assumed 40m², with 45° tilt and 45° orientation to the south.

Results are shown in Tab 1.

The reference case technology is the electricity provided by the grid.

The comparison of the figures confirms the fact that the first generation solar photovoltaic cells cannot be a viable economic alternative to the conventional electricity provided by the grid, though they reduce carbon dioxide emission level. Therefore the second and third generations of solar photovoltaic cell technologies have been analysed in the work.

The second case study analyses Thin Film Solar Cells. These photovoltaic cells are made from the amorphous silicon and the cost is lower, 780 €/kW electricity output. Their efficiency to convert the solar radiation to electricity is about 7.5 %. The technical lifetime is about 20 years and they can be operated at normal temperature.

Same resource and demand parameters are chosen for consistency of comparison.

Performance results are shown in Tab 2. Same technology– electricity from the grid - is used as a reference chain. Analysis of the figures shows that thin film cells are not economically competitive with the first generation cells reference one, even with substantially lower costs in comparison with the first generation cells, the low efficiency remains an obstacle.

The third case study analyses application of the third generation solar photovoltaic cells. The input of the technology is solar radiation in the UK and the output is electricity, which supply to iron and steel industry in UK.

Same resource and demand parameters are chosen for consistency of comparison.

The figures show (Tab 3) that this type of photovoltaic cells can be a viable solution in economic as well as environmental terms.

Other case studies which will be analysed during the last year of the project are the following technologies: biomass fermentation, biomass gasification methanol synthesis, advanced heat exchangers (plate fin, printed circuit and corrugated tube units) for geothermal energy utilisation and FCC Power Recovery Unit in Refinery.

CONCLUSIONS

The EMINENT software tool initial version has been tested and applied to analyse the solar film photovoltaic cell potential applications in the UK. In a similar way it will be applied for other technologies, sectors and other countries in Europe and worldwide.

The contribution of the solar photovoltaic devices to power generation is small these days – about several hundred MW (Williams et al, 2005) Their impact can become more tangible if economic performance of these technologies becomes economically comparable with the existing and other alternative technologies and if they are implemented en masse in various sectors of the economy. The figures obtained using the
EMINENT tool show that at present rather low efficiency; the first and second generation cells are not economically efficient and are not a sustainable option for the mass scale application in the household sector. The analysis also shows that the application of the third generation solar cells in household sector approaches the point when it can become economically viable and contribute to reduction of CO₂ emissions. If economic incentives are applied at the national and local levels (DTI, Renewable Energy, 2005) to stimulate the use of the solar technology, it can become commercially viable in the household sector in the UK.

Electricity rates in many areas around the world as well as the photovoltaic technology progress bring the solar industry rapidly to the point where commercial on grid market niches will be created in selected countries or regions where electricity rates are high.

The work with these case studies shows that the EMINENT software can be a useful instrument for fast screening and analysis of early stage technologies.

With the EMINENT tool proving its operability, further case studies on possible application of advanced biomass processing, enhanced heat exchange and refinery energy saving technologies are being carried out.

ACKNOWLEDGEMENT

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