CHEMICAL ENGINEERING TRANSACTIONS, Volume 12, 2007
Edited by Jiri Klemeš

The potential of the EMINENT tool in the screening and evaluation of emerging technologies for CO_2 reduction related to buildings

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The EC supported project EMINENT has resulted in a tool for evaluating the potential impact of emerging energy technologies. It consists of an integrated resource manager, a demand manager, an Early Stage Technology Manager, and an Analysis tool. The various tools are linked to a number of complex and comprehensive databases. It is a web flexible based tool. This paper describes how the EMINENT tool can be used to analyse and evaluate polygeneration and trigeneration technologies related to carbon emission reduction associated with energy use in buildings.

1. Introduction

Leading researchers and manufacturers throughout the world are developing novel energy related concepts and prototypes. The problem is identifying them, evaluating their practicality and speeding up the time of getting them into the market. The lead-time for development of an early stage energy technology (EST), from first idea to commercial application can take many years. A tool has been developed enabling evaluation of ESTs within different national and economic contexts and described by Klemeš et al (2007). It provides a rapid appraisal of the geographic potential and a reduction in market lead-time of promising ESTs. It is a universal tool and can be used for screening emerging technologies for CO_2 reduction in buildings.

2. Brief Description of the EMINENT Tool

As the availability and price of primary energy resources and the geographical conditions, demand and price differs significantly worldwide, there is a need to evaluate the impact of ESTs within a national energy supply system. The overall concept is shown in Fig.1. The EMINENT Software Tool (ST) has the aim to design possible energy supply chains and to evaluate each of them based on weighting factors given by the user. It consists of integrated resource manager, demand manager, EST manager, databases on resources, demand and the EST analysis tool (Fig 2). The Resource Manager describes details of resources available in the country, allows entry and modification of data, can select data for technology assessment. Seven energy resources can be handled: electricity, fuels including biomass and waste, geothermal, hydro energy, ocean tidal energy, wave energy and wind energy.

The Demand Manager describes details of energy demands per sub sector in a given country, modifies data, allows re-entry of new data and selects data for technology assessment. 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 technology database is a major component of the ST. It contains key data for a number of technologies that are either commercially available on the market or are still ESTs.

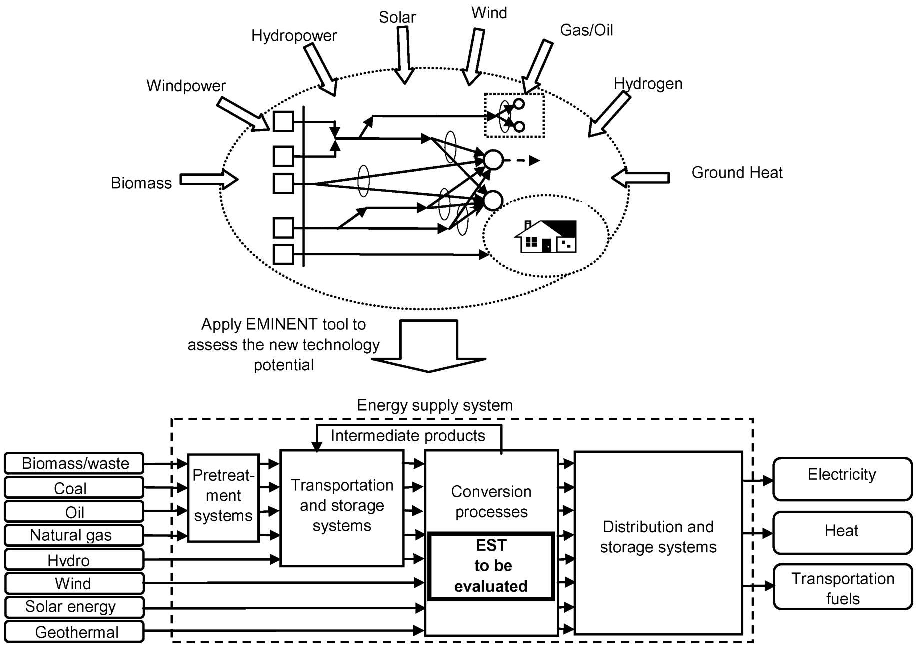

Figure 1. Methodology used in EMINENT tool

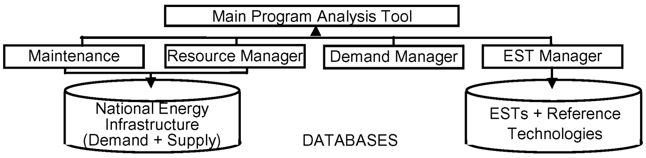

Fig 2. The EMINENT ST

For each technology, the database contains data about the current stage of development and the expected year of commercial availability. This information is used in the assessment tool to identify which of them are commercially available. The energy chains can consist of single or combinations of ESTs and a number of standard technologies. Technologies within the database may have a maximum of 3 inputs and 3 outputs. An example is a gas engine, with natural gas as input and heat and electricity as outputs. The technologies may be operated in up to 3 different operating modes. E.g. a heat pump that can be used both for heating and cooling purposes, depending on the outdoor temperature. The Analysis Tool provides the market assessment of full energy chains. The input can have several items: used energy, fuels, electricity, shaftwork, solar radiation, wind, hydropower, tidal, wave and geothermal energy; the output heating and cooling, fuels, electricity, shaftwork. For each input and output, technical specifications can be provided to describe the circumstance in which the technology could be applied. These specifications are related to capacities in which the technology is available, temperature levels, types of fuels that can be used, etc. The relationship between the inputs and outputs is specified using an efficiency matrix. Financial data can be entered to evaluate the costs of application of the technology. The technology database manager has two modes of operation: (i) Viewing/entering/editing data (the active mode); (ii) Viewing and selecting data to be used in an analysis (the passive mode).

Besides traditional power and heat generation - e.g. the grid, natural gas (NG) heating - a range of alternative technologies can satisfy electricity and heating needs of the residential sector with lower carbon footprint. Those technologies include community CHP (combined heat and power), μCHP (at the household level), heat pumps, biomass, photovoltaics (PV), solar heating and cooling, wind turbines etc.

3. Application of EMINENT Tool to Analyse CO_2 Reducing Technologies Related to Buildings

The reduction of CO_2 emissions in all the sectors has become of great concern. Buildings are responsible for considerable share of them, e.g. in UK, up to 50% of emissions come from running buildings. Analysis of ESTs that provide CO_2 reduction by EMINENT tool can contribute to their faster implementation and market penetration. In reference to Fig.1, several technologies have been analysed using EMINENT tool: μCHPs, fuel cells (FC), photovoltaic cells and heat pumps were analysed.

3.1 μ-CHPs

Decentralized power generation combined with heat supply is an important technology for improving energy efficiency, security of energy supply and reduction of CO_2 emissions. μ-CHPs are especially interesting for market sectors such as single family houses, smaller multifamily houses and business enterprises due to their technical and performance features:

- A high overall energy conversion efficiency (e.g. up to 90 % for Stirling engines)
- Low maintenance requirements compared to a domestic gas boiler.
- Very low noise and vibration levels for installation in the home.
- Lower emissions of NO_x, CO_x, SO_x and particulates compared to traditional technologies.

An early adoption of domestic combined CHP could potentially lead to sales and service contracts worth over 2.2 B€ in Europe by 2010 (CCL, 2007). The EMINENT tool includes several μ-CHP types that can be used in buildings of various sizes (Tab. 1). Peacock at al (2005) analysed two types of μ-CHPs: Stirling engines and FC. They report that for Stirling engines, the overall annual savings vary from £52 to £90 relative to the non-CHP base case. Under the optimal control strategy, the Stirling engine provides daily savings of 2.5+ kg CO_2 in winter and less than 1 kg CO_2 in summer.

The fuel-cell system can increase the production of electricity generated and exported without causing a thermal surplus compared to a Stirling engine. The 1 kW FC system meets only 18 % of the annual heat requirement of the dwelling, which suggests that CHP systems of greater prime mover capacity could be employed if they are of high electrical efficiency. Increasing the prime mover size from 1 kW to 3 kW brings the annual savings associated with its deployment to rise from £142 to £273 (Peacock at al, 2005). The reduced thermal output of the 1 kW FC system causes significantly less seasonal variation and yields daily savings of 3+ kg CO_2 in winter and 2+ kg CO_2 in summer. μCHP systems can offer considerable CO_2 emissions reduction compared to a condensing boiler and network electricity.

Table 1. CHP applications related to buildings included in EMINENT database

Technology	Company	Brief description
μCHP Stirling	Solo Stirling	μCHP based on Stirling engine
Distributed CHP based on ORC	Tri-o-gen	YTI Finland coupled an organic rankine cycle with hermetic high speed turbine of Tri-o-gen to an existing biomass plant with an unused heating capacity – a saw mill. Outputs: 7.6 MWth and 0.3 MWe
Biogas-fed MCFC 250 kWe for DH/CHP	MTU CFC Solutions GmBH	The MTU molten carbonate FC Hot Module cogeneration unit with capacity of 250 kWe utilises natural gas or biogas as a fuel.
CHP with gas engine 8 cylinders	Zantingh	With Waukesha gas engine
CHP with gas engine 12 cylinders	Zantingh	With MAN gas engine

Hubert et al. (2006) describe Small Proton Exchange Membrane (PEM) FC systems fed with natural gas (NG) that can deliver 1–10 kW of AC low voltage (LV) power and are usually connected to a LV grid. Standalone systems are fed with propane. They deliver up to 4 kW of AC power and about 6 kW of heat. At full load, the whole system has an electrical gross efficiency of 27 % (Gigliucci at al, 2004) to about 35%. Gross efficiency is the ratio of DC power produced by the stack to the LHV of total inlet NG. It is the product of the fuel processor and the PEMFC stack efficiencies. The fuel processor consumes water, while the FC produces some. Water balance is the difference between collected water by condensation and needs ofwater for the fuel processing. It can be positive if enough liquid water is recovered, or negative if not then additional water has to be brought. (Hubert et al., 2006) report of the following performance (Tab.2)

Table 2. Performance of PEM FCs (Hubert et al. 2006)

Conversion of CH_2 (%)	99.5	99	97	95.5
Fuel processing efficiency (%)	37.5	42.2	52.7	56.2
Utilisation rates of hydrogen (%)	52.0	57.9	73.8	75.5
Heat from stack in cooling circuit	2.5	3.4	5.5	7.8
Water balance (mLs^{-1})	-0.35	-0.41	-0.44	-0.57

3.2 Comparative analysis of photovoltaic cell application in domestic sector

Electricity and heat produced from PV has a far smaller impact on the environment than traditional methods of electrical and heat generation. During their operation, PV cells use no fuel other than sunlight, give off no atmospheric or water pollutants and require no cooling water. A selection of ESTs included in the tool database is in Tab. 3.

Table 3. Some Photovoltaics (FV) applications in EMINENT database

Technology	Company	Brief description
PV CdTe	First Solar	CdTe photovoltaic modules
Solar collector evacuated	Viessman	Solar hot water system Vitosol H20 and H30
Solar collector Glazed	Helyodine	Glazed solar hot water collector
Biological-Base Solar Cells	MIT	Make solar cells from spinach
Hynrid solar diesel complex	JV LMW Windenergy Company	Solar complex (5 kW) with 2 solar water heater for remote locations. A diesel aggregate of 3.5 kW for backup
Bifacial PV modules	Intersolar Center	Produce of energy by both sides. The back side receives the radiation reflected from the earth/sea as a result of albedo and scattered radiation. This cuts the costs dramatically.

The EMINENT ST has been tested and applied to evaluate potential applications of the solar film photovoltaic cells in the UK. In a similar way it is being applied for other related technologies, sectors and other countries. It shows 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 CO_2 emissions (Tab 4). If economic incentives are applied at the national and local levels to stimulate the use of the solar technology, it can become commercially viable in the household sector in the UK. The details of the analysis are given in Klemeš et al (2005).

Table 4. Third generation solar cell analysis

Capacity of the technology	5 kWp
Chain efficiency	30 %
PV Area	40 m^2
Amount of electrical energy delivered to the load by PV system	4.465 MWh
Total costs	3 863 €
Energy supply costs	866 €/MWh
A household installed unit: CO_2 reduction vs the reference (grid electricity) f	5 t/y

3.3 Heat pumps

Heat pumps transfer heat from natural heat sources in the surroundings (air, ground, water or industrial or domestic waste), to buildings or industrial applications by using a relatively small amount of high quality drive energy (e.g. electricity). Heat pumps can be used reversely for cooling. EMINENT database includes several of them (Tab.5). The Best Practice Programme Monitoring Report (2000) describes heat pump systems. The heating system consists of a water-to-water heat pump with a capacity of 3.96 kW at an output temperature of 45 °C. It is sized to provide only 50 % of the design heat load so the system includes an in-line direct electric heater (3 x 2 kW) for auxiliary heating. Heat is delivered either to the domestic hot water or to space heating. The hot water is heated via an exchange coil in a mains pressure cylinder (capacity 210 L) which has a 3 kW electric immersion heater as a back-up. The total energy supplied for space heating was 15,255 kWh/y, and domestic water heating was 3,425 kWh/y. The total electricity consumed to provide the space and water heating was only 7,825 kWh, as the heat pump provided 10,855 kWh of energy from the ground. This saved the emission of approx 5 t of CO_2 compared with conventional electric heating. The heat pump provided 91.7 % for space and 55.3% for water heating.

Table 5. Some of Heat pump (HP) technologies included in the EMINENT database

Technology	**Company**	**Brief description**
HP medium scale electric	Hautec, Ochsner	Medium scale electric HP for more family dwellings
Diffusion absorption HP	NEFIT	Diffusion absorption HP, small scale, for one family dwelling
Gas engine HP	TNO-MEP	Gas engine driver HP with ambient air as heat source
Electricity driven HP	TNO-MEP	Electricity driven HP with earth heat as heat source

5. Conclusions

Reduction of carbon emissions from buildings by applying novel technologies requires fast penetration of them to the market. EMINENT ST has been developed for acceleration of this process by realistic analysis of the resource base, demand side and the technologies. The tool proves to be useful in analysing the market potential of ESTs for buildings. From this viewpoint, several technologies are of special interest for analysis: μ-CHPs of different types, PV, heat pumps, biomass and wind. The analysis shows that some of them still require considerable improvement in performance, some can be implemented already, and the others will need some sort of legislative framework.

5. Acknowledgement

The financial support from the European Community EMINENT2 project TREN/05/FP6EN/S07.56209/019886 is gratefully acknowledged.

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