Micro-CHP
A tool for increased market access

Jan de Wit, Mads Moeller Melchiors and **Laila Grahl Madsen** present perspectives for increased CHP market penetration, as well as reduced primary fuel consumption and carbon savings based on one year's field testing of fuel cell-based micro-CHP units.

Cogeneration, as a production principle, is an acknowledged method by which primary fuel savings and, consequently, carbon dioxide (CO_2) savings can be achieved. Further, if a change to combined heat and power (CHP) production includes a fuel switch to lower carbon-emitting fuels, the savings can be even more significant.

In a growing number of countries, the majority of new central power plants are now based on cogneration. In addition, many medium-sized and small cogeneration plants based on gas turbines or gas engines are in common operation. These plants may be owned and operated by municipalities, energy companies or industries, or may be based on other models of ownership and operation.

Countries that widely emply district heating networks provide easy access to heat markets. However, there is also a huge potential heat market for micro-cogeneration in the individual heating sector.

This is illustrated by the fact that the number of gas-fired boilers used for heating in the European Union is approximately 60–70 million, with an annual replacement rate of some five million.

Sizing of micro-CHP

A micro-CHP unit can be installed and operated with either electricity or heat supply as the main priority. Continuous operation is best achieved by operating the micro-CHP unit in a heat controlled manner, especially if the system includes a heat storage tank. In contrast, operating the micro-CHP unit in an electricity controlled way leads to transient load conditions if the micro-CHP device is intended to supply more than baseload. electricity.

Because micro-CHP units are more expensive than boilers, it makes sense to ensure their operating hours are kept as close to full load as possible to provide the best return on the additional investment. In many cases, this will lead to heat controlled operation and will, in this way, also pave the way for the best possible utilisation of the heat potential of CHP production.

In general, such operation will result in the exchange of electricity with the public grid, sometimes import and, at other times, the export of surplus electric power However, in some countries, there are unfavourable exchange rates or administrative barriers to such electricity export.

If this is the case, smaller micro-CHP units may be the answer, although this will result in lower electricity and heat production. Such small baseload-only units could lead to higher specific investment costs (€/kW) and reduced utilisation of the otherwise available heat market by a factor of two or more.

Fuel cell micro-CHP demonstration project

A Danish development and demonstration project with micro-CHP based on different types of fuel cells and fuels was launched back in 2006. Micro-CHP is of particular interest because mini, medium and large-scale CHP in Denmark are more or less fully developed. Some 45% of the country's electricity production is based on CHP with some 80% of the heat supplied via CHP-based district networks.

The micro-CHP project was divided into three phases. In the first phase, the most promising fuel cell types and appliances were identified and laboratory tested. In the second phase, micro-CHP units for third-party installation were produced and tested at a limited number of sites. Micro-CHP units with different fuel cell technologies,

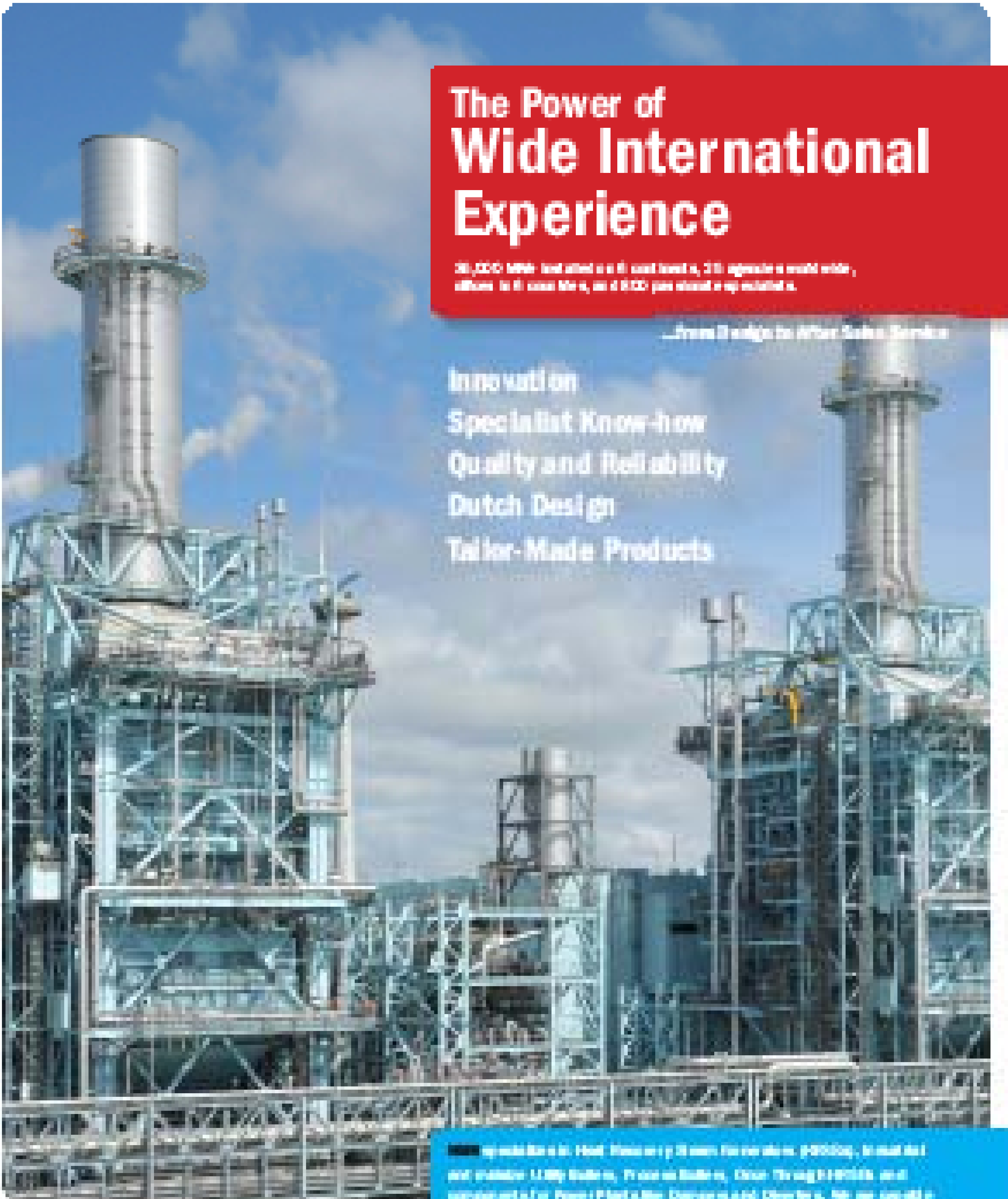
The Power of
Wide International
Experience
Innovation
Specialist Know-how
Quality and Reliability
Dutch Design
Tailor-Made Products

Table 1. Key operational data for the natural gas-fuelled units covering the one-year test period

House #	Operation hours (h)	Availability*** (%)	Power production (kWh_e)	Heat production (kWh)	Number of starts	Electrical efficiency (% LCV ref.) (%)	Total fuel efficiency (% LCV ref.) (%)
1	5077	68	4404	8087	169	35.3	100
2	8743	75	7755	13,500	28	34.1	94
3	7479	70	6663	13,029	35	34.1	101
4	6587	58	5890	10,424	65	35.4	98
5	7533	88	6529	12,552	68	33.8	99
6	6737	87	5990	11,703	53	33.9	100
7	6232	83	5319	10,358	62	33.6	99
8	7553	88	6640	12,483	54	34.5	99
9	6485	81	5837	10,358	42	34.9	97
10	6992	89	6134	11,644	56	34.2	99
11	6029	77	5296	10,803	68	34.0	103
12	8013	86	6611	12,414	57	32.1	92
13	6439	77	5703	11,003	37	34.3	101
14	4998	70	4299	8034	172	33.5	96
15	5794	85	5077	9387	58	34.0	97
16	6502	82	5863	11,525	48	35.0	104
17	5985	74	4994	10,207	78	33.2	101
18	5919	70	4866	9161	121	33.4	96
19	6380	84	5655	10,883	53	34.8	102
20*	(2486)	(65)	(2224)	(4289)	(54)	(34.8)	(102)
Total	127.963	78**	111.749	211.844	1378	34.1**	99**

** This unit was taken out of service in October 2012 at the request of the test site host*
*** Arithmetic average figure*
**** Availability is defined as the percentage of time that the unit is in operation or ready for operation. Planned maintenance is not subtracted from the total time because planned maintenance was not fully known at the beginning of the tests*

such as low-temperature proton exchange membrane (PEM), high-temperature PEM and solid oxide fuel cells have been tested in the project.

The ongoing third phase consists of field tests of improved and selected micro-CHP units.

The project participants include IRD, Topsoe Fuel Cell, Dantherm Power, SEAS-NVE, DONG Energy, the Danish Gas Technology Centre and COWI.

Field test results to-date

Two different micro-CHP unit types have currently been tested in Phase 3. Both are based on low-temperature PEM fuel cells. However, one was natural gas-fuelled with the other fuelled by grid-distributed hydrogen. The natural gas-fuelled units were equipped with a fuel processor.

Approximately 20 natural gas-fuelled test units became operational in early 2012. The average size of the single-family test houses is 209 m², which means they are generally larger than the average Danish single-family house of some 140–150 m². Two-thirds of the host homes have between two and five children residing in them.

Table 1 shows the operational results obtained over the test period. In general, the availability of most units improved during the test period. In the final 17 weeks, close to 90% of the units had an availability higher than 85%.

The micro-CHP unit's actual coverage of the house's electricity and heating needs during the period are shown in Figure 1. It shows that the micro-CHP units are able to cover 25–70% of the total electricity needs of most of the single-family houses. With this operation strategy, many units in private houses could end up exporting 15–40% of their power production.

Figure 1 also shows that the micro-CHP units covered 20–40% of the annual heat demand in the single-family test houses. This is a result of unit sizing, the operation control used and the water-side coupling chosen.

The micro-CHP units were stopped during the summer period because of the low heat need. Thus, the own-coverage during the actual operating period of the units will be higher if a calculation is made for the heating season only.

The operation strategy used for the micro-CHP units leads to favourable operating conditions and a relatively large number of annual full-load hours. However, it also

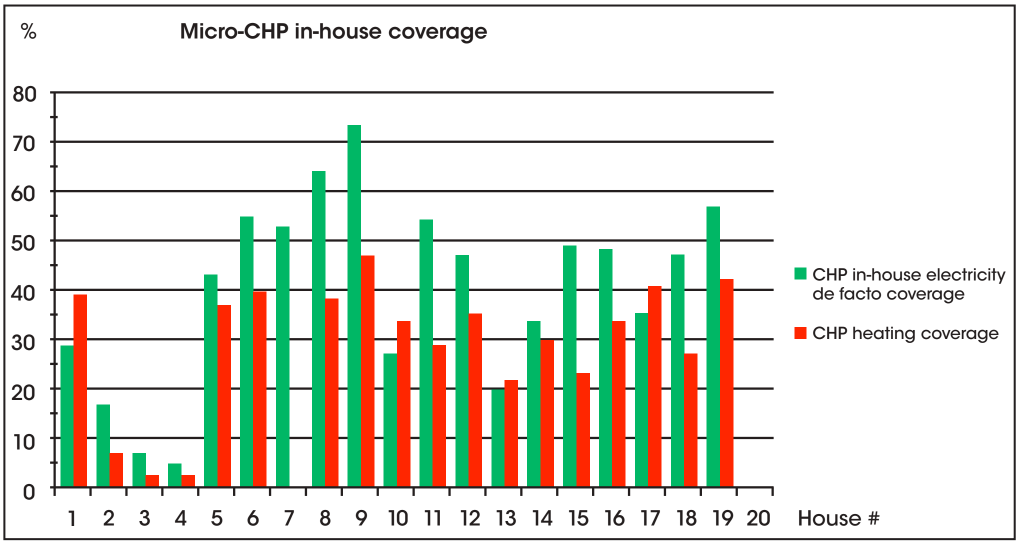

Figure 1. Micro-CHP coverage of the house's own electricity needs and the in-house heating need during the one-year test period. Houses 2, 3 and 4 are large institutions with high electricity and heat consumption, and is the reason for the low own-supply in these installations

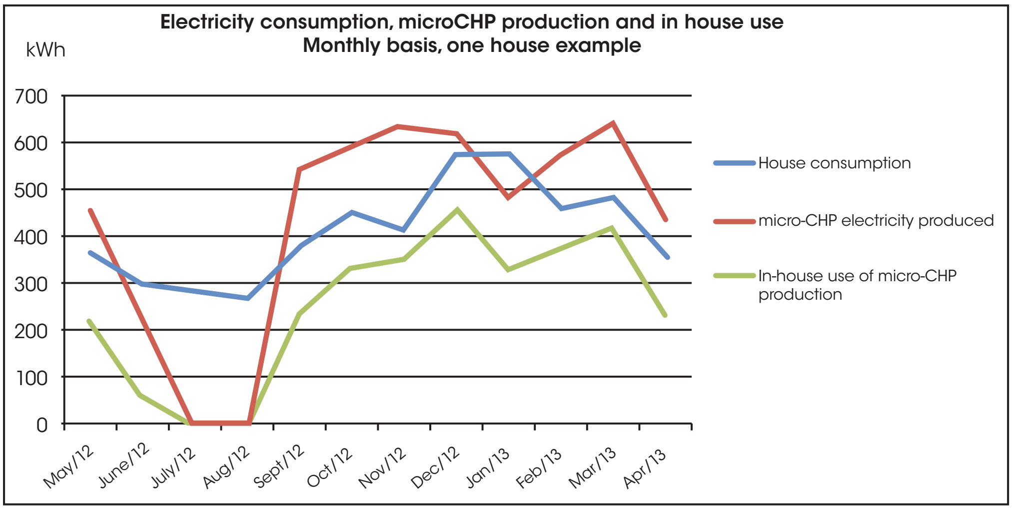

Figure 2. An example, on a monthly basis, of electricity consumption, micro-CHP production and the resulting net own use of the electricity for one test house

leads to periods of some surplus electricity production. This was exported to the public grid, but no payment was received for this export because of the Danish tariff structures and power sales schemes.

Figure 2 shows the electricity production for one of the test houses, its own consumption and the actual in-house power produced in periods where production exceeds consumption. The data presented are shown on a monthly basis.

A number of hydrogen-fuelled micro-CHP units based on fuel cells were also field tested over a heating season.

The hydrogen was supplied from a distribution grid, and is produced by electrolysers to demonstrate the potential use (and storage) of local surplus wind power-based electricity. The hydrogen is stored in 6 bar pressure vessels before entering the 4 bar distribution grid.

The units were installed as the primary heat source, with a 200-litre heat storage tank that includes an electrical coil for peak load heating (see Figure 3). Furthermore, since the units are operated directly on pure hydrogen, there is no need for fuel reforming. This is an advantage in relation to startup time (<1 minute) and load response. It is also an advantage regarding the micro-CHP unit's electricity production efficiency, which is close to 50% with LCV reference.

The supplementary heating requirement for one of the test houses was minimal, but this was not the case for all houses. In several homes, two micro-CHP units are now installed to avoid any excessive supplementary heating.

Significant CO_2 savings

Due to the primary energy saving capability of combined heat and power production, carbon savings will also be obtained.

The CO_2 savings related to the produced electricity can be calculated based on either the average national emissions or the higher marginal CO_2 from each kWh of electricity produced.

The carbon savings related to each of the 20 natural gas-fired micro-CHP test sites in the project were calculated based on the official average CO_2 emissions figure for electricity distributed and sold in Denmark. This figure is 498 g/kWh, whereas the marginal figures could be as high as 750 g/kWh.

The average figure includes non-polluting power production from wind turbines, solar panels and other renewable sources. However, very little of this would be expected to be substituted by the power produced by the micro-CHP units. In reality, it is much more likely that production from less efficient, larger traditional power production units will be the first to be substituted. This fact would lead to the use of the marginal CO_2 factor in the calculations.

However, to avoid any discussion regarding which production is replaced, the average CO_2 emissions figure has been used to calculate the substituted electricity-related emissions.

The micro-CHP units have an additional natural gas consumption compared to a heat-only production, so the carbon emissions from this should be taken into account, leading to reduced savings. Figure 4 shows the net CO_2 savings obtained from the natural gas-fired micro-CHP test houses.

For the hydrogen test series the CO_2 savings were approximately 4.5 tonnes for each house, with an annual full-load operating time of 6000 hours.

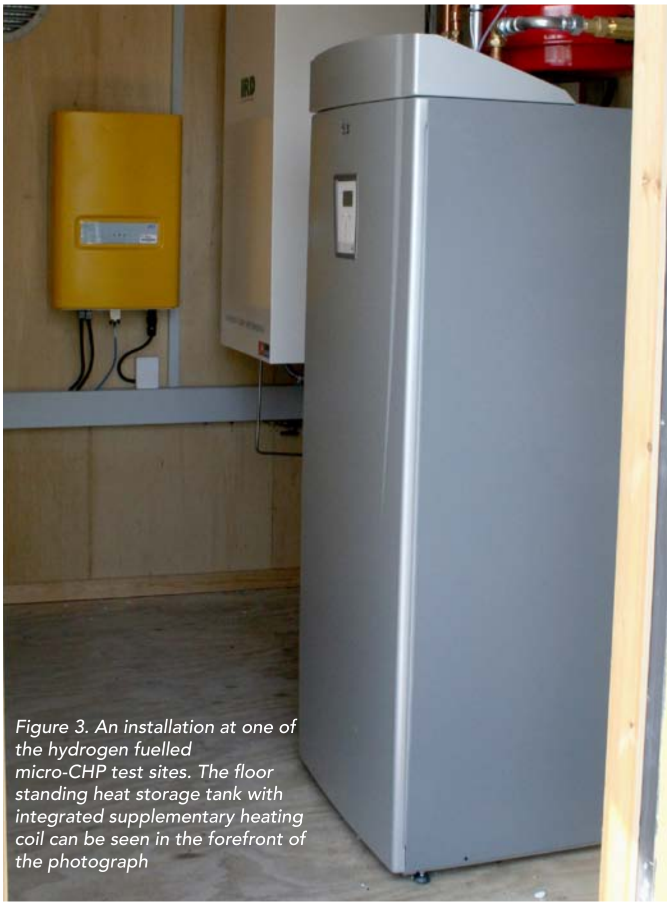

Figure 3. An installation at one of the hydrogen fuelled micro-CHP test sites. The floor standing heat storage tank with integrated supplementary heating coil can be seen in the forefront of the photograph

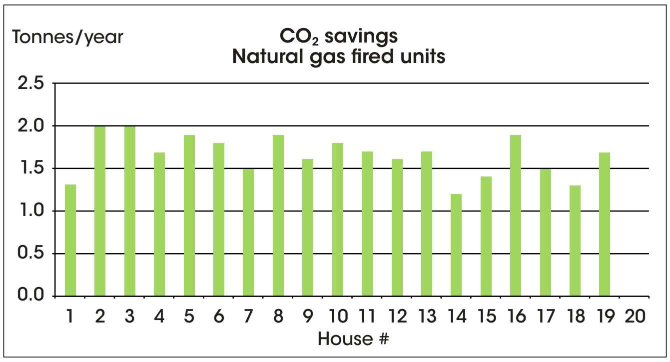

Figure 4. Carbon savings obtained in the 20 natural gas-fired micro-CHP test houses during the one-year test period. Operation in House 20 was stopped during the test period due to administrative issues in connection with the house owner's installation of solar panels at the site

The CO_2 calculation method outlined above shows that the net saving depends on the fuel type used, how much electricity is substituted and the origin of this electricity. The latter is based on country-dependent figures and ensuing savings.

In countries where the substituted electricity is produced from sustainable sources or non-carbon emitting technologies, such as nuclear power, there will be no CO_2 savings.

Domestic sector savings

The tests confirmed that the heating needs of single-family houses can be covered by fuel-efficient cogeneration.

The tests also confirmed that significant primary fuel savings and net carbon savings can be achieved with highly efficient micro-CHP units in the domestic sector, with high availability for this type of pre-commercial appliance.

If this domestic heat market is to be efficiently utilised for CHP, electricity exports can be expected to occur from time to time. With the present tariffs or administrative barriers in some countries this is not beneficial from an owner's point of view. If periodic exports need to be avoided, units that are much too small would need to be used to avoid less efficient part-load operation becoming dominant.

High electrical power production efficiency is the key to obtaining primary energy and high net CO_2 savings if fossil fuel-based electricity is substituted by own-production.

The high-efficiency fuel cell-based micro-CHP units still need development to reduce investment costs, further improve appliance availability, and lengthen the expected lifetime of the fuel cell stack.

Gas-fired cogeneration units, whether large, small or micro, are unique and efficient energy converters that link together power, gas and often heat supply grids. They interact extremely well with renewable sources or can be connected to solar heating, so should be an active player in tomorrow's challenges for a green and low or non-carbon energy market.

Jan de Wit, Danish Gas Technology Centre, (www.dgc.eu); Mads Moeller Melchiors, Dantherm Power (www.Dantherm-Power.com); and Laila Grahl Madsen, IRD Fuel Cells A/S (www.ird.dk).

This article is available on-line. Please visit www.cospp.com