List of figures referenced in the report

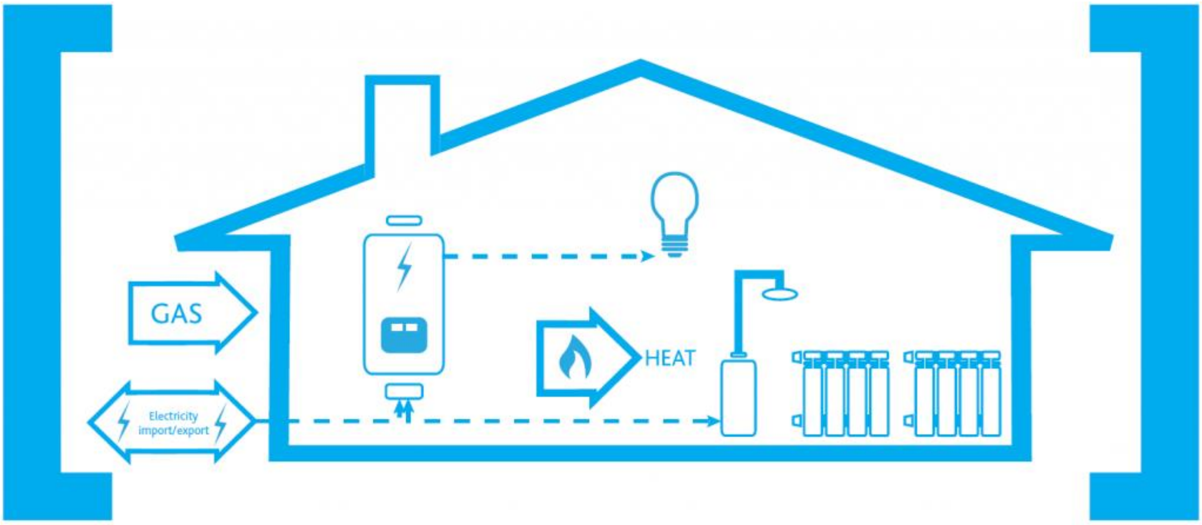

Figure 1

Figure 2. Sketch of the core components (the fuel cell module) of a typical FC micro-CHP unit. The input is natural gas and air; the output is heat, AC power and clean exhaust. The components are: 1) Fuel processor with reformer turning natural gas into hydrogen, 2) Fuel cell stack (power section) converting hydrogen into heat and DC power and, finally, 3) Inverter (power conditioner) converting DC into AC. The reformer and the FC stack may be separate or integrated.

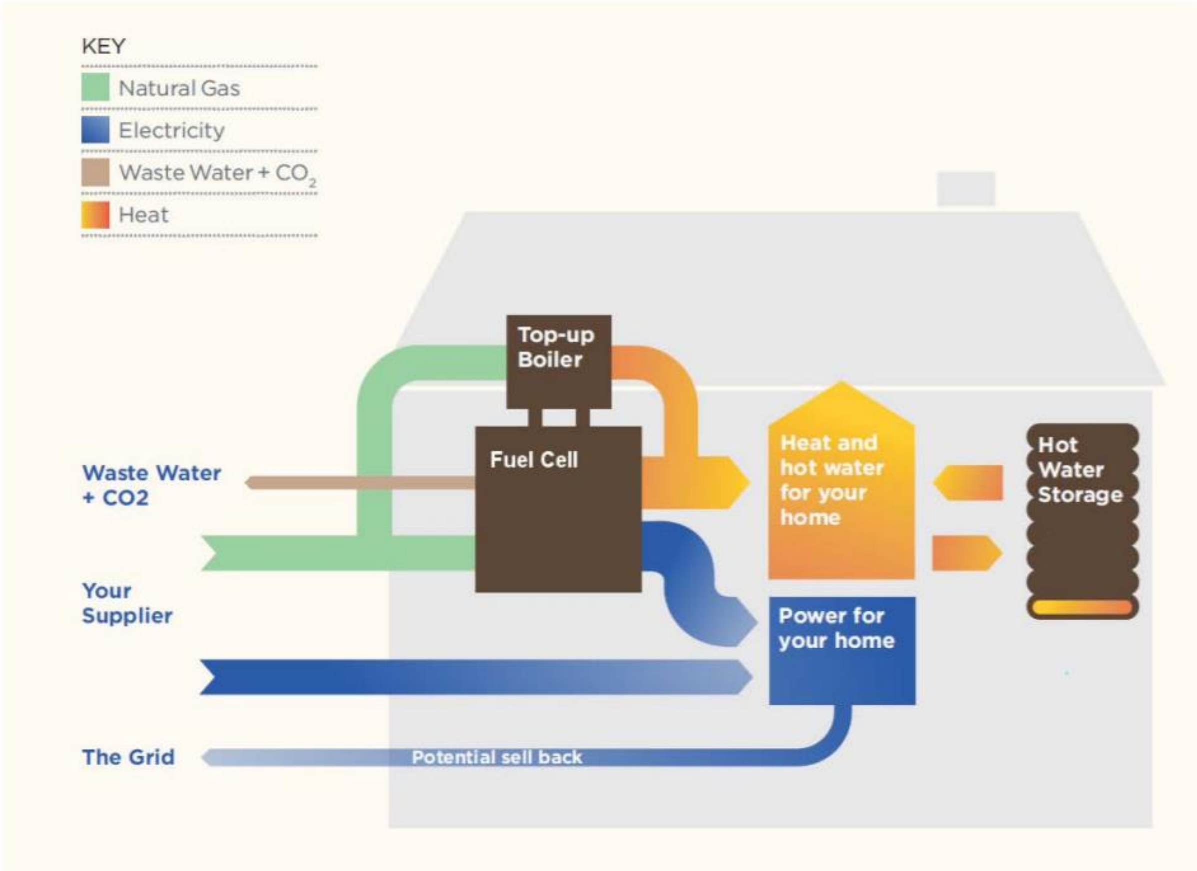

Figure 3. Simple sketch of a complete FC micro-CHP unit including gas condensing boiler for back-up (peak load) and hot water storage tank.

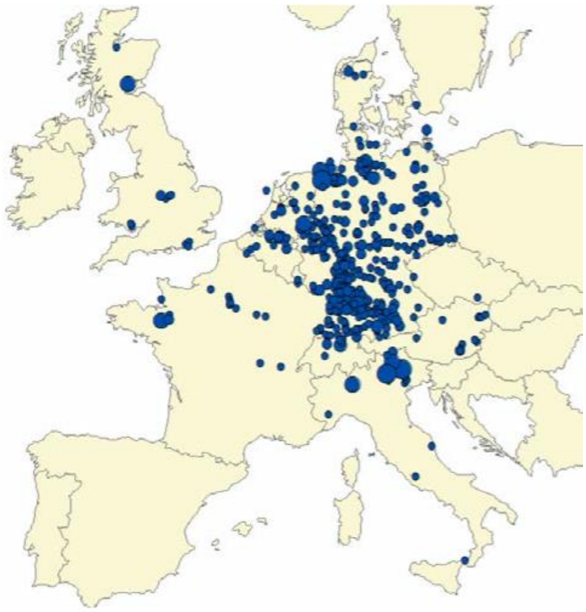

Figure 4. Locations of micro-CHP units demonstrated as of November 2016.

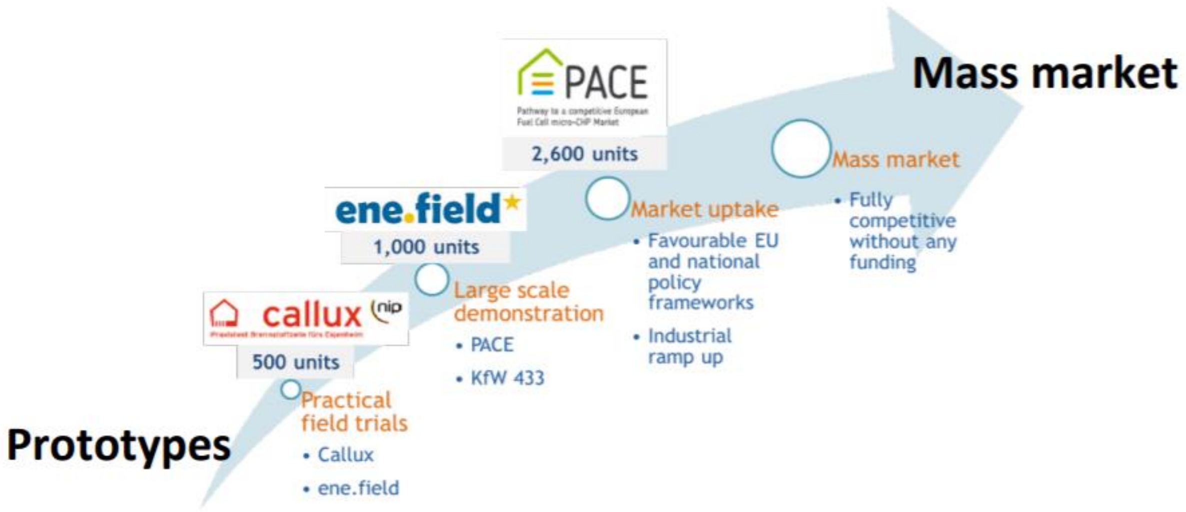

Figure 5. The ene.field project is an important step on the path from demonstration of prototypes to reaching a commercial mass market for FC micro-CHP.

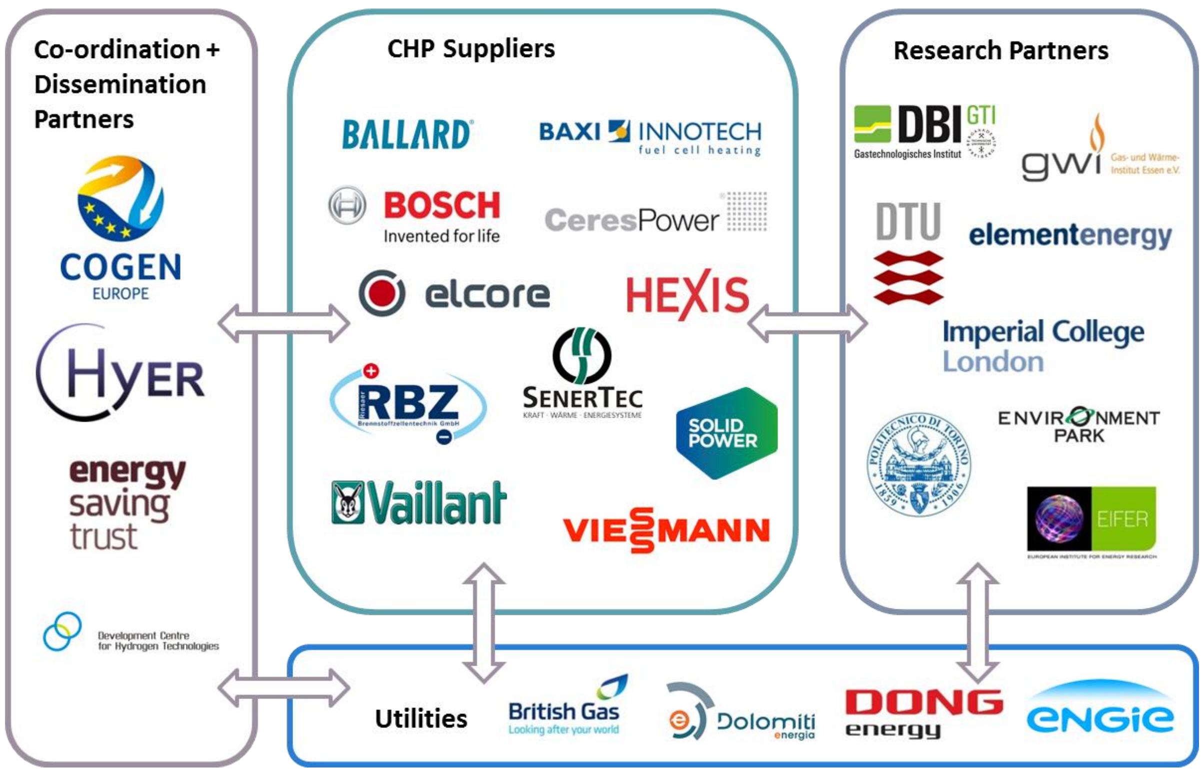

Figure 6. Overview of the ene.field project partners.

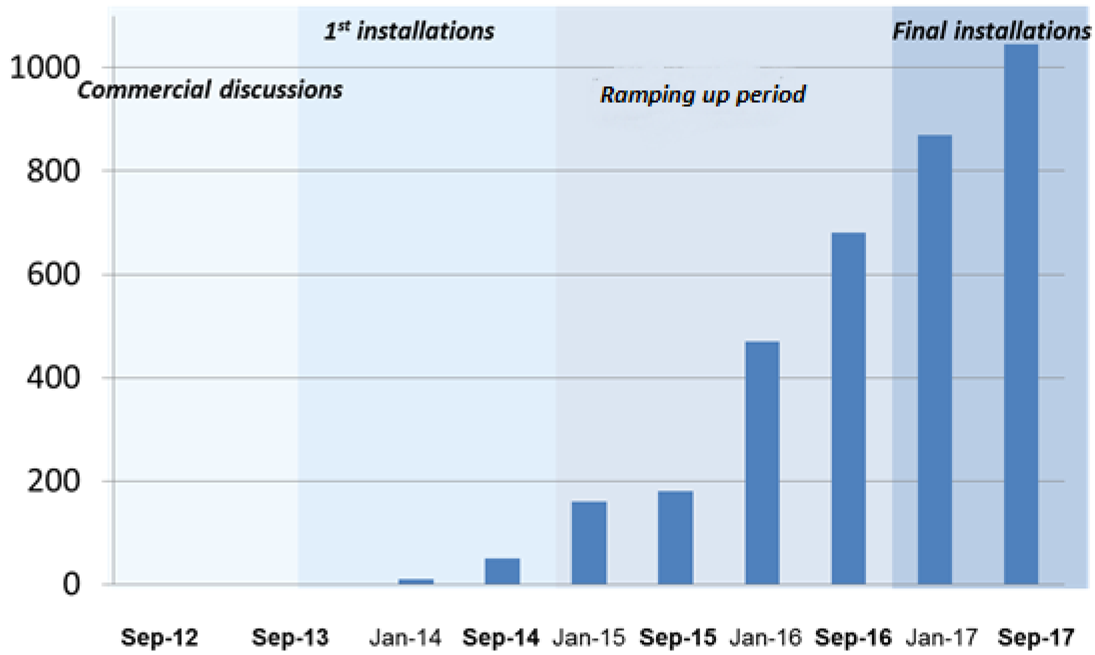

Figure 7. Installations over time during the project.

Elcore 2400	Dachs InnoGen	Cerapower FC10 Logapower FC10	Vitovalor	SteelGen	Galileo 1000 N	Vaillant G5+	PEMmCHP G5	BLUEGEN	ENGEN 2500	Inhouse 5000+
PEM	PEM	SOFC	PEM	SOFC	SOFC	SOFC	PEM	SOFC	SOFC	PEM
300W	**700W**	**700W**	**700W**	**700W**	**1kW**	**1kW**	**2kW**	**2kW**	**2.5kW**	**5kW**
Natural Gas	Natural Gas	Natural Gas, Gas	Natural Gas	Natural Gas	Natural gas+ Biogas	Natural Gas	Natural Gas + Biogas	Natural Gas	Natural Gas	Natural gas + Biogas + H2
Elcore	**SenerTec**	**Bosch Thermotechnik**	**Viessmann**	**Ceres Power**	**Hexis**	**Vaillant**	**Ballard Power**	**Solid Power**		**RBZ**

Figure 8. Characteristics of the various fuel cell micro-CHP units demonstrated in the field trial. The categories are name of model, type of fuel cell, electric capacity, possible fuel types, and manufacturing company.

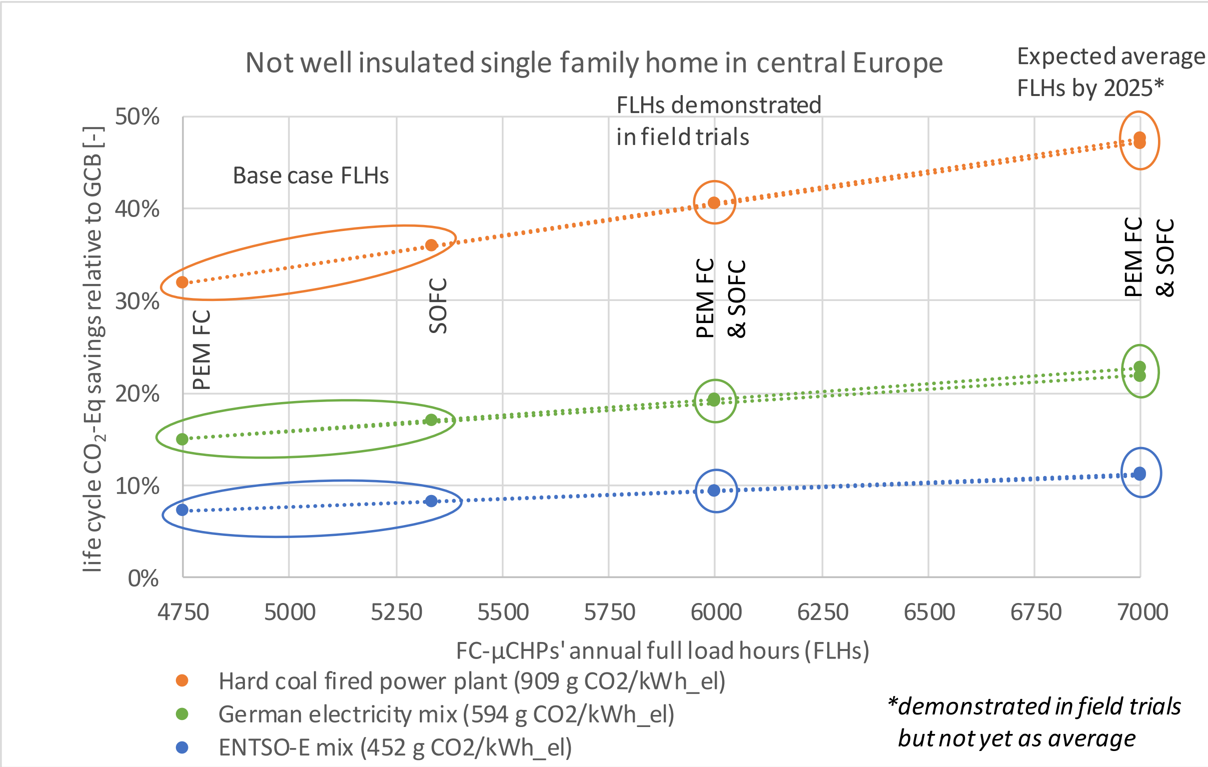

Figure 9. Life cycle CO_2-equivalent emission savings by fuel cell micro-CHP relative to a gas condensing boiler (GCB) as a function of the annual full-load hours (FLH) of the micro-CHP. Results are shown for different power production mixes that are replaced by fuel cell electricity. The scenario shown is existing (i.e. not renovated) single family homes located in central Europe, which is typical for the ene.field units demonstrated in field trials.

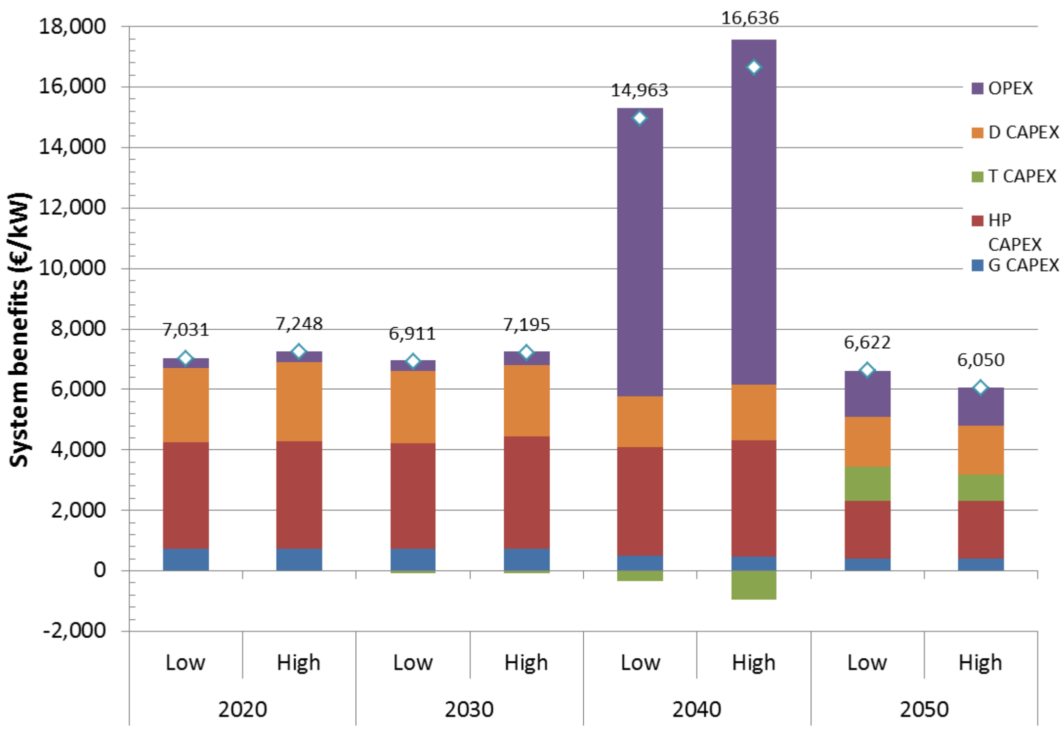

Figure 10. Overall system benefits of micro-CHP

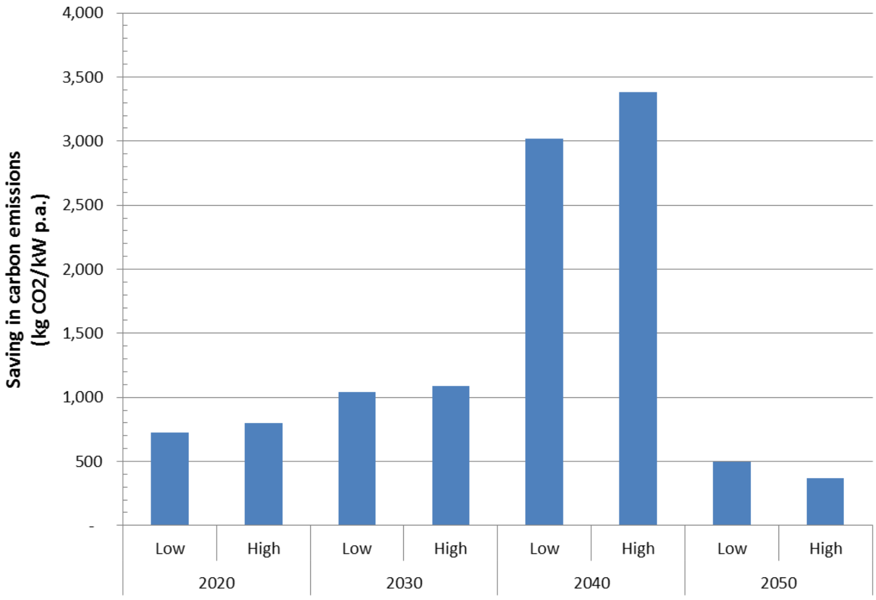

Figure 11. Contribution of micro-CHP in reducing carbon emissions

List of tables referenced in the report

Table 1. Summary of the characteristics of products demonstrated in the ene.field project. The thermal capacity includes the gas condensing boiler for backup/peak load. Efficiencies are under optimal conditions and have been calculated from the lower heating value (LHV) of the used natural gas.

FC Technology	**PEM**	**SOFC**
Electric capacity	0.3 – 5 kW	0.7 – 2.5 kW
Thermal capacity	1.4 – 22 kW	0.6 – 25 kW
System efficiency (LHV)	85 – 90 %	80 – 95 %
Electric efficiency	35 – 38%	35 – 60 %

Table 2. Observed efficiencies of the fuel cell modules in laboratory testing and in the real-life field trial [2]. The data includes all the systems tested even though the products are rather different in size, performance and optimal conditions. The laboratory testing includes 6 different SOFC products and 5 different PEM products. No conclusion can be made regarding performance of individual unit types based on the average numbers presented.

For the real-life data, represent units in operation in the months September – December 2016. The st.dev. intervals represent the minimum and maximum values when calculating "average +/- one standard deviation" for each of the four months. The lower heating value (LHV) of the natural gas has been used for the efficiency calculations.

Note that for the laboratory tests, the thermal and the electric efficiencies cannot be added to calculate a total system efficiency, as the two efficiencies may not have been realised under the same test conditions.

	SOFC		**PEM**	
	Optimal conditions in laboratory test	Real-life data from the field trial	Optimal conditions in laboratory test	Real-life data from the field trial
Thermal efficiency, average	53%	46%	57%	57%
St.dev. interval		*30 – 59%*		*48 – 66%*
Electrical efficiency, average	42%	37%	32%	32%
St.dev. interval		*28 – 47%*		*28 – 39%*

Table 3. Number of failures during the first year of operation and the corresponding availability. Based on units where end-users have participated in the surveys.

Number of failures	Part of systems	Availability (%)
0	45%	100.0
1	19%	98.2
2	24%	98.3
> 3	12%	86.9

Table 4. Description of the scenarios for the future cost and market analysis. After [8].

Scenario	**Degree of distributed generation**	**Policy support for distributed generation**	**Electricity price**	**Gas price**	**Carbon price (cost of CO_2 emissions)**
“Untapped Potential”	Low	Low	Low	High	Low
“Patchy Progress”	Moderate	Existing, but fragmented	Low	Low	Moderate
“Distributed Systems”	High	High	High	Low	High

Table 5. Policy recommendations

Clean Energy Package

- As part the ongoing review of the Energy Efficiency Directive, there is a need to clarify that Member States can count micro-CHP systems installed on-site, at end user level, under the Energy Savings Obligation in Article 7.
- The newly proposed EU Primary Energy Factor (EU PEF) in the Commission's Energy Efficiency Directive review proposal, should adequately reflect the efficiency of the present electricity system. The EU PEF value should only apply to conversions related to the Energy Efficiency Directive. More suitable PEF values should be developed for heating and cooling, taking into account seasonality aspects.
- Smart grid capabilities of FC micro-CHP should be fully recognised under the new "smartness indicator" introduced by Energy Performance of Buildings Directive review
- Priority of dispatch shall continue to be granted to small CHP installations, as part of the Electricity Regulation Recast.
- Self-generation and self-consumption of electricity from micro-CHP should be promoted through fair treatment in grid connection, grid access and grid charges.

Energy Efficiency Directive

- In their implementation of the Energy Efficiency Directive (EED), Member States should clarify that micro-CHP is eligible under the Energy Savings Obligation mandated by Article 7 in the EED.
- Member States should ambitiously implement Article 14 of the EED, thus considering micro-CHP as part of the Comprehensive Assessments on efficient heating and cooling and introducing policy measures to realise the existing potential for micro-CHP.
- In line with Article 15.5 of the EED, Member States should ensure that grid connection, access and dispatch are prioritised for micro-CHP.

Decarbonisation of heat in buildings

- Decarbonising heating and cooling in buildings will require a balanced approach allowing all renewable and low carbon solutions to contribute, including Fuel Cell micro-CHP.
- EU and national strategies on heating and cooling shall consider the future contribution of FC micro-CHP. This can be achieved through adequate methodologies developed for building codes , to consider marginal carbon footprints of CHP systems.
- The decarbonisation potential of renewable gas with FC micro-CHP should be taken into account in national strategies to decarbonise the building stock.

Energy Labelling

- As part of the Energy Labelling Regulation (811/2013) review, the micro-CHP methodology should be adapted to fully account for the efficiency benefits of the technology. In doing so, the principles outlined in the industry backed standard EN50465 should be considered.
- Should an update of the primary energy factor for electricity used in Regulation 811/2013 be deemed necessary, a adequate methodology should be developed to account for the seasonality of heating and cooling and the electricity mix displaced by CHP.

Covenant of Mayors

- The gaps identified in the Covenant of Mayors methodology risk limiting the decarbonisation choices of cities that have signed the Covenant. FC micro-CHPs has numerous benefits for cities, as it not only reduces CO_2 and primary energy at the system level, but also virtually eliminate air pollution in cities and help balance the electricity grids. Addressing the methodology and creating a level playing field between different decarbonisation technologies and energy vectors, will ensure that progressive cities can also rely on FC micro-CHP for their sustainable future visions.