Development of Business Cases for Fuel Cells and Hydrogen Applications for Regions and Cities

Residential mCHP

Brussels, Fall 2017

This compilation of application-specific information forms part of the study ***"Development of Business Cases for Fuel Cells and Hydrogen Applications for European Regions and Cities"*** commissioned by the Fuel Cells and Hydrogen 2 Joint Undertaking (FCH2 JU), N° FCH/OP/contract 180, Reference Number FCH JU 2017 D4259 .

The study aims to **support a coalition of currently more than 90 European regions and cities** in their assessment of fuel cells and hydrogen applications to support project development. Roland Berger GmbH coordinated the study work of the coalition and provided analytical support.

All information provided within this document **is based on publically available sources** and reflects the **state of knowledge as of August 2017**.

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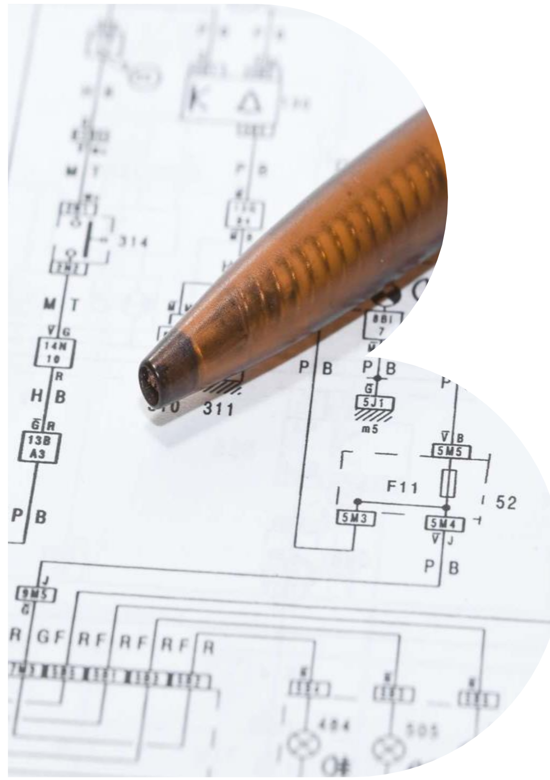
A. Technology Introduction



A

Fuel cell mCHPs provide heat and electricity to residential and small commercial buildings, using natural gas and existing infrastructure

Fuel cells for residential and small commercial buildings (fuel cell micro-CHPs) 1/4

Brief description: fuel cell micro combined heat and power units (FC mCHPs) use natural gas as fuel to generate electricity and heat through a fuel cell stack reforming natural gas on site to hydrogen. Combined with an auxiliary boiler, they can replace entire residential heating systems or they can supply base-load electricity with add. heat supply

Use cases: Cities/regions can promote FC mCHPs in 1/2-family dwellings, SMEs or other residential / small commercial developments (e.g. in municipal housing developments, office complexes) to lower carbon emissions, improve efficiency and enable smart grids. Using natural gas, they build on existing fuel infrastructure

Fuel cell for residential use (ranges reflect industry portfolio, selection of companies)

Key components	Fuel cell stacks, system module, inverter, heat exchanger, auxiliary condensing boiler, combined storage tank
Fuel cell technologies	Proton Exchange Membrane (PEM), Solid Oxide (SOFC)
Fuel	Natural gas (generally also biogas or other methane)
Electrical / Combined efficiency	35-60% / 85-90% (PEM), 80-95% (SOFC)
Output	0.3-5 kW_{el} (PEM), 0.8-2.5 kW_{el} (SOFC)
Approximate capital cost	EUR 10,000-35,000[1]
Original equipment manufacturers	Viessmann, SolidPower, Elcore, Bosch, BDR Thermea
Fuel cell suppliers	SOLIDpower, Hexis, Panasonic, Elcore, Sunfire
Typical customers	Private home owners, municipal housing providers, residential real estate developers, utilities, SMEs
Competing technologies	Heating systems (e.g. gas boilers), power grid

1) Please refer to the next slide for three examples

Source: Roland Berger

Fuel cell mCHPs are one of the most mature FCH technologies with several European products commercially available

Fuel cells for residential and small commercial buildings (fuel cell micro-CHPs) 2/4

Overall technological readiness: Large scale field tests completed across Europe and esp. in Germany; fuel cell CHP systems of advanced generations from various OEMs now commercially available, other OEMs have announced to follow in the near term (EU catching up to East-Asian markets)

TRL*: 1 Idea – 2 – 3 Tech. formulation – 4 – 5 – 6 Prototype – 7 – 8 – 9 Fully commercial (marked: 9)

Demonstration projects / deployment examples (selection)

Project	Country	Start	Scope	Project volume
PACE		2016	Horizon 2020 funded project to help European mCHP sector take the next step to mass market commercialisation with ~2,650 units by 4 mCHP OEMs	EUR 90 m
European wide field trials for residential fuel cell micro-CHP (ene.field)		2011	Europe's largest demonstration project with ~1,000 residential fuel cell micro CHP installations across 11 countries to demonstrate market potential and push commercialisation	EUR 52 m
Callux field test		2008	Field test of ~500 fuel cell powered heating units for residential use for a period of 7 years demonstrating commercial feasibility and long lifetime of application	EUR 75 m

Products / systems available (selection)

Name	OEM	Product features	Country	Since	Approx. cost[1]
BlueGEN	SOLIDpower	1.5 kW_{el} / 0.6 kW_{th} SOFC mCHP with efficiency of up to 60%$_{el}$ and combined 85% for distributed base-load electricity supply with waste heat for warm-water supply		2012	EUR 10,000 – 25,000 (possibly add. installation cost), strongly dep. on local sourcing cond. and use case
Vitovalor 300-P	Viessmann	FC mCHP as full heating system (incl. aux. boiler) with 0.75 kW_{el} / 1kW_{th}, heat-driven operations, PEM FC from Panasonic with combined efficiency of up to 90%		2014	
Elcore 2400	Elcore	305 W_{el} / 700 W_{th} PEM FC mCHP for base-load electricity supply with waste heat for warm-water supply with combined efficiency of up to 104% (incl. aux. boiler)		2014	

*) Technology Readiness Level ▼ ≤ 5 ▼ 6-7 ▼ 8-9

1) Indicative range – not considering specific use case context, local sourcing conditions (esp. installation cost), subsidies

Source: Roland Berger, FCH2 JU, FC mCHP OEMs, Thermondo

Fuel cell mCHPs significantly reduce local emissions of CO_2 and pollutants while building on existing natural gas infrastructure

Fuel cells for residential and small commercial buildings (fuel cell micro-CHPs) 3/4

Use case characteristics

Stakeholders involved

- FC mCHP OEMs, FC technology providers
- Wholesalers and installers
- Utilities, gas and electricity grid DSOs
- Private consumers, real estate owners, SMEs

Demand and user profile

- Heat and electricity demand of 1/2 family dwellings or small commercial buildings
- 2 basic operating models: heat-driven FC mCHPs follow heat-load profile of building and produce electricity in the process, add-on mCHPs provide base load electricity with waste heat for warm water

Deployment requirements

- Connection to natural gas grid for fuel supply and electricity grid (for feed-in of surplus electricity)
- Typically availability of local installation, service and maintenance force

Key other aspects

- Emerging trend of partial self-sufficient energy supply in households / "self-reliance"

Benefit potential for regions and cities

Environmental

- Low emissions of pollutants and greenhouse gases (esp. CO_2) – reduction of 25-70% of CO_2 in representative German 1/2-family home, reduction of primary energy consumption
- Low noise pollution due to almost silent operation

Social

- Promotion of distributed energy systems, lowering social cost of electricity grid expansion esp. by DSOs (e.g. local combination of FC mCHPs and heat pumps)
- Enabler for more renewables in electricity mix with complementary role of distributed CHP to e.g. heat pumps

Economic

- With reduction of product cost due to volume uptake and learning effects, TCO-competitiveness with other high-end heating solutions in reach (esp. in near term thanks to subsidy programmes) – esp. in markets with high spark spreads for consumers (difference of gas and electricity prices)

Other

- Creation of micro-CHP networks throughout regions and communities to help balancing grid needs – smart grid potential

Source: Roland Berger

Pressure to reduce cost for a fully convincing economic value proposition is a key issue – as is business model innovation

Fuel cells for residential and small commercial buildings (fuel cell micro-CHPs) 4/4

Hot topics / critical issues / key challenges:

> Need to reduce high product cost and CAPEX for consumers (currently still higher capital and maintenance cost than for conventional heating units), obstacle in residential market (even as TCO-competitiveness with other premium systems comes within reach)

> Technical standardisation as lever for cost reduction (inhomogeneity of installation procedures in different countries posing barrier for market expansion)

> Sustaining and improving technical performance (esp. durability and system lifetime, but also electrical efficiency)

> Defining innovative business models, esp. financing solutions and sales channels ("go-to-market")

> Regulatory and policy-support circumstances (demand for FC mCHP systems currently supported by subsidies)

> Public acceptance (lack of public awareness or acceptance of fuel cell powered micro-CHP)

Further recommended reading:

> "Advancing Europe's energy systems: Stationary fuel cells in distributed generation": http://www.fch.europa.eu/studies

> "Business models and financing arrangements for the commercialisation of stationary applications of fuel cells report" (forthcoming): http://www.fch.europa.eu/studies

> http://enefield.eu/

> http://www.pace-energy.eu/

Key contacts in the coalition:

Please refer to working group clustering in stakeholder list on the share folder

https://sharefolder.rolandberger.com/project/P005

Source: Roland Berger

B. Preliminary Business Case

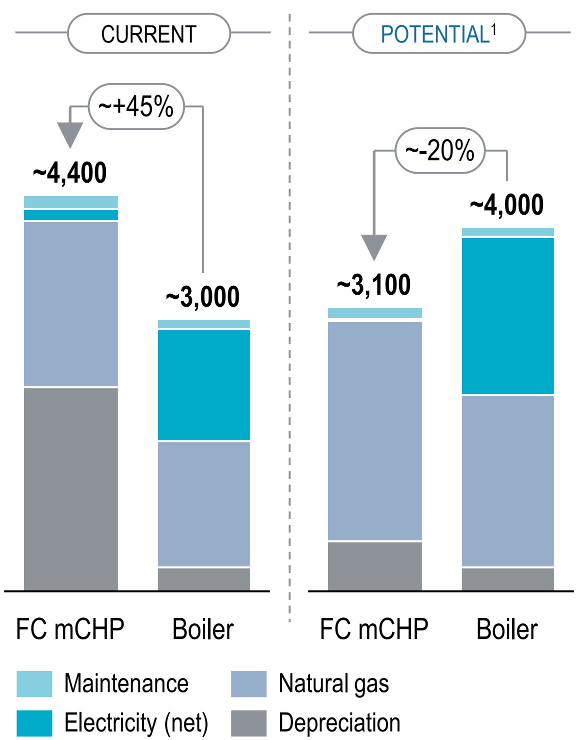
B

FC mCHP saves CO_2 but is hardly competitive with current standard solutions without subsidies – Future economics look promising

Business case and performance overview in two scenarios – INDICATIVE EXAMPLE

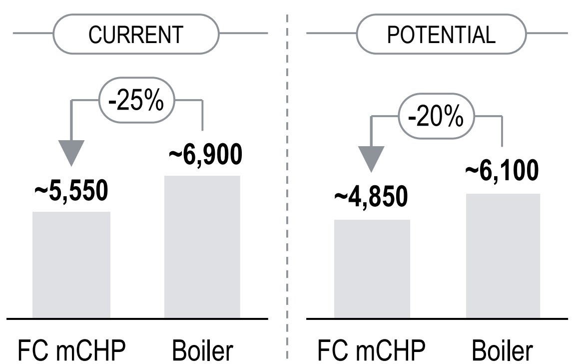
Economic

Total Cost of Energy (TCE) to household [EUR/year, annualized over 15 years]:



Environmental

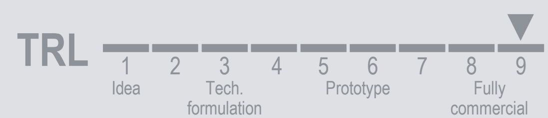
- > Next to zero local emissions of pollutants NO_x, SO_x and fine dust particles – here, e.g. potential elimination of NO_x
- > Total attributable CO_2 emissions dep. on CO_2 intensity of electricity mix and gas grid and "accounting method" – [kg CO_2 p.a.]:



- > Broader analyses across the EU put the estimated immediate CO_2-savings over grid+boiler between 20% and 85% dep. on specific use case, electricity mix and FC mCHP deployed

Technical/operational

- > One of the most mature FCH technologies overall: large scale field tests completed across Europe; adv. generation systems from various OEMs now commercially available, others have announced to follow in the near term (EU catching up to East-Asian markets)
- > Ready for large scale deployment as FC mCHP builds on existing natural gas infrastructure
- > For FC mCHP, system and fuel cell stack lifetime currently below conventional heating systems, expected to be met as systems progress along learning curve
- > Typically more physical space required in home than for simple condensing boiler, ideally separate room for heating equipment



1) One exemplary long-term scenario (of many possible scenarios) with a set of changes in key variables (performance, cost, energy prices) – please see following slides

Source: FCH2 JU, Roland Berger

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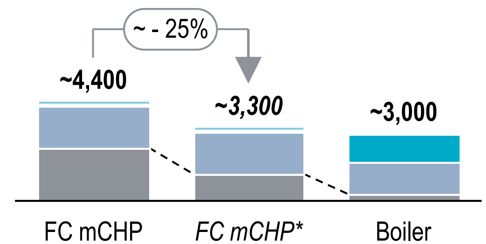
Capital cost, spark spread, efficiency and use case characteristics are the key business case determinants

Key performance determinants and selected sensitivities[1] – INDICATIVE EXAMPLES

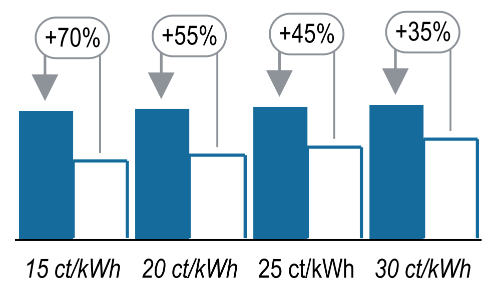
1. **Cost of FC mCHP:** significant potential for cost reductions and hence reduced purchase price (in current scenario, cutting CAPEX in half would lead to ~25% lower TCE in this use case) – key drivers are volume uptake / growing cumulative production per manufacturer
2. **Energy price levels / "spark spread":** high electricity prices and comparatively low gas prices support business case, especially when maximising in-house power consumption **– strong regional differences!**
3. **Electrical efficiency:** potential increases in electrical efficiencies (expected to grow to up 42% in next generation FC mCHPs) increase electricity production during FC mCHP operations and hence might reduce heating costs (see potential case)
4. **Use case characteristics and mCHP operations:** longer operating hours (e.g. in heat-intensive use cases tend to improve the FC's business cases due to higher electricity production **– strong regional differences!**
5. **Decarbonisation of electricity and gas grid:** significant savings in CO_2 and primary energy with FC mCHP, especially over the medium term and when grid electricity supply is dominated by conventional power generation; long-term greening of gas grid (via green hydrogen, biogas, etc.) helps sustain env. edge of distributed, gas-based generation over grid supply (with conv. gas or electr. heating) **– strong regional differences!**

Estimated TCE impact
[EUR/year]

Re. #1 Cutting CAPEX in half ...



Re. #2 Diff. electricity prices ...



Maintenance | Electricity (net) | Natural gas | Depreciation | FC mCHP | Boiler + grid

1) Unless otherwise stated, all statements shall be considered *ceteris paribus*, i.e. "all-other-things-equal"

Source: Roland Berger

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We consider a representative residential use case, established technology assumptions and selected EU energy mix and prices

Preliminary business case components and key assumptions – INDICATIVE EXAMPLE

Application-related assumptions

current/potential	**FC micro-CHP**	**Gas Boiler** (+ Grid)
Technical specifications	Fully-integrated 1 kW_{el} / 1.5 kW_{th} fuel cell mCHP heating system incl. 20 kW_{th} auxiliary condensing boiler, combined heat storage	State-of-the-art 20 kW_{th} gas condensing boiler, connection to central electricity grid
CAPEX[1]	EUR 16,600 / *8,000*	EUR 4,000
Heating fuel	Natural gas	Natural gas
Ø net efficiency	37%$_{el}$, 52%$_{th}$ / *42%$_{el}$, 53%$_{th}$*	90%$_{th}$
Lifetime	10 / *15* years with 2 / *0* fuel cell stack replacements	15 years
Maintenance	EUR 140 / *120* p.a.	EUR 110 p.a.
Other aspects	Heat-driven operations of the FC mCHP acc. to standard load profiles, feed-in of any electricity not consumed in-house, some (peak) electricity demand covered by grid	All thermal energy from gas condensing boiler, all electrical energy from electricity grid

Use case and exogenous factors

Strongly dependent on reg. circumstances

> Partially renovated residential house in continental Europe with ca. 110 m^2 heated space, 5-person family, central heating system, connection to local gas and electricity grid

> Annual heat demand (incl. hot water): ~21,000 kWh

> Annual electricity consumption: ~5,000 kWh

> Resulting annual operations of the fuel cell mCHP in this use case:

- ~6,000 full load hours
- ~45% of thermal energy covered by FC mCHP, ~55% by aux. boiler
- ~6,000 / *~7,100* kWh_{el} produced (~65% / *~60%* consumed in-house)

> Cost of natural gas to household: 0.06 / *0.09* EUR/kWh

> Cost of grid electricity to household: 0.25 / *0.35* EUR/kWh

> CO_2 intensity of natural gas: 185 / 165 g/kWh

> CO_2 intensity of grid electricity: 510 / *350* g/kWh

> CO_2 balancing method for mCHP: power feed-in credits at average CO_2 intensity of power grid

> No public support schemes considered (subsidies, tax credits, feed-in tariffs, CHP premiums, etc.)

Strongly dependent on reg. circumstances

1) Incl. installation and stack replacements as re-investments (e.g. short-term cost to be assumed at cost levels of 500 units per manufacturer, i.e. already significantly lower cost levels than actual current prices: system cost of EUR 11,000; installation cost EUR 1,600; stack replacement cost of 4,000)

Source: FCH2 JU, Eurostat, European Commission, Roland Berger

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Please note the following:

> *Today's analysis showed an exemplary case of a fully-integrated fuel cell mCHP application with a heat-driven operating model. Several* ***other mCHPs with a baseload power model*** *exist as well; their business case (as well as market approach) has some important similarities and differences. We will briefly revisit their business case again for the sake of completion*

Source: Roland Berger

Please do not hesitate to get in touch with us

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Source: FCH2 JU, Roland Berger