Fuel Cell Distributed Generation Commercialisation Study

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Preliminary – pending publication

Mandated by the FCH JU, the study explores paths to broader commercialisation of stationary fuel cells in Europe

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Background and objectives of the study

Background

> Sponsored by the Fuel Cells and Hydrogen Joint Undertaking (FCH JU)

> Developed by Roland Berger Strategy Consultants together with a coalition of more than 30 stakeholders of the stationary fuel cell industry

Objectives

> Establish a common view on future market potential of fuel cell distributed generation

> Understand various technologies, potential applications, prospects and business opportunities in light of macroeconomic scenarios

> Document and disseminate findings of the study to opinion leaders and decision makers in industry and policy community

Source: FCH JU Coalition, Roland Berger

The coalition is composed of more than 30 stakeholders - Results reflect common understanding of this group

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Coalition members

20 members of the fuel cell industry

Ballard, AFC Energy, Convion, Proton Motor, IRD, IE-CHP, Sunfire, Hydrogenics, Abengoa, SOFCpower, Vaillant, Elcore, Topsoe Fuel Cell, Viessmann, FuelCell Energy Solutions, Ceres Power, Baxi Innotech, Dantherm Power, New Energy World JU, Ceramic Fuel Cells

6 players in adjacent industries

E.ON, GDF Suez, Danfoss, RWE, Element Energy, Alstom

4 key associations

HyER, COGEN Europe, NOW, Netzwerk Brennstoffzelle und Wasserstoff NRW

2 research institutes

Next Energy, ENEA

3 public sector bodies

Greater London Authority, Scottish Enterprise, Hydrogen Implementing Agreement

Source: FCH JU Coalition, Roland Berger

The study is the most comprehensive assessment of the commercialisation potential of stationary fuel cells in Europe

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Core dimensions of the study

4 focus markets	
6 generic fuel cells	Defined by relevant industry players
35 years time horizon	Forecast of potential market developments
45 different use cases	Example applications
>30 benchmark technologies	Conventional vs. fuel cell
>34,000 resulting data points	Evaluation of outcomes
>3 energy scenarios	Analysis of sensitivities of results

Source: FCH JU Coalition, Roland Berger

The European energy system changes fundamentally to help meet ambitious climate goals

Political framework and general market conditions

Natural gas as low-carbon, complementary fuel
- Cleanest fossil fuel with lowest carbon footprint
- Possibility to decarbonise and use for storage
- Well-developed infrastructure in large parts of EU

Growing share of renewable energy sources in the mix
- Intermittent supply from wind power and solar PV

Growing emphasis on energy efficiency
- Primary energy savings and less energy imports
- Growing role of cogeneration (CHP)

Decentralisation of energy supply
- Avoidance of transmission losses
- Better alignment of supply and demand

Contributions of fuel cells
- Efficient, distributed conversion technology of low-carbon gas and zero-emission potential

Source: FCH JU Coalition, Roland Berger

Fuel cells are the highly efficient and complementary choice to future energy systems based on more and more renewables

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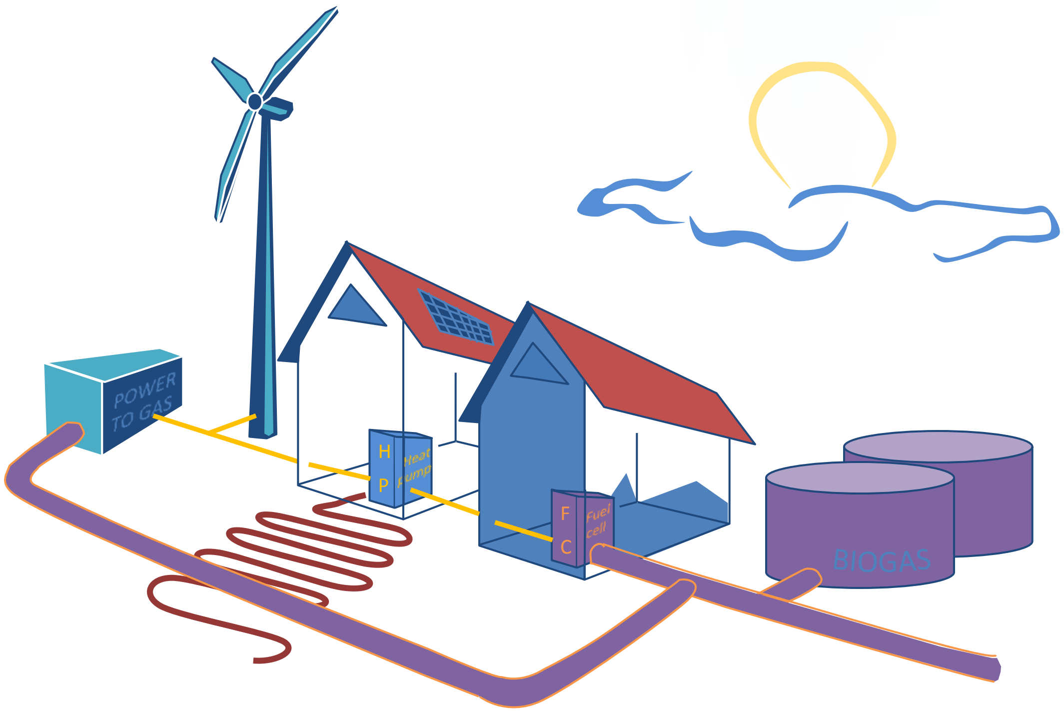
European vision for stationary fuel cells



Fuel cell vision

- Highly efficient conversion of natural gas (and eventually green gas or pure hydrogen)
- In distributed generation, i.e. at the site of consumption
- Lowering the carbon footprint of energy supply
- Playing a complementary role to renewables[1)]

1) E.g. Stationary fuel cells as operating reserve with good performance at partial loads, complementary cycles of heat-driven CHP with electric heating demand

Source: FCH JU Coalition, Roland Berger

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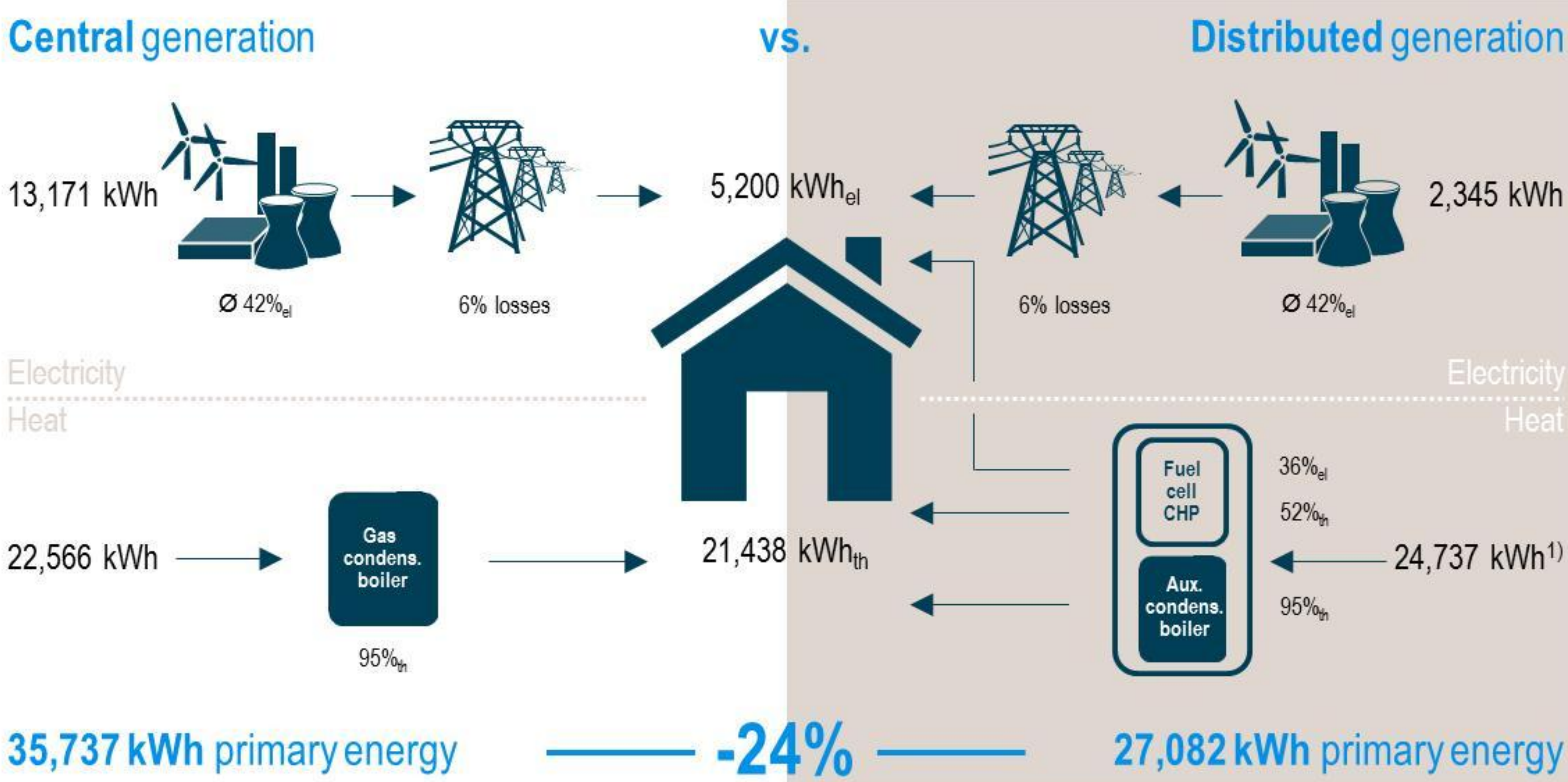
Typically, distributed CHP is more efficient than central generation due to superior technologies and avoidance of transmission losses

Comparison of central and distributed generation in terms of energy efficiency



1) Exemplary case of a German, partially renovated 1/2-family dwelling 2) Net gas consumption after crediting the primary energy equivalent of power feed-in from CHP

Source: FCH JU Coalition, Roland Berger

Fuel cells may substitute conventional distributed generation technologies in all fields where power and heat are consumed

European market segments for potential stationary fuel cell applications

Residential

Residential houses (1/2-family dwellings in urban and rural areas)

524 m tons CO_2 emissions[1)] p.a., equivalent to ca. 340 m new cars

2,250 TWh final energy consumption annually[4)]

Commercial

Apartment buildings and non-residential buildings (e.g. offices, schools, agencies, hospitals etc.)

860 m tons CO_2 emissions[2)] p.a., equivalent to ca. 555 m new cars

2,850 TWh final energy consumption annually[4)]

Industrial

Industrial applications (e.g. data centres, wastewater treatment facilities etc.) with heterogeneous energy needs

1,255 m tons CO_2 emissions[3)] p.a., equivalent to ca. 810 m new cars

3,300 TWh final energy consumption annually[4)]

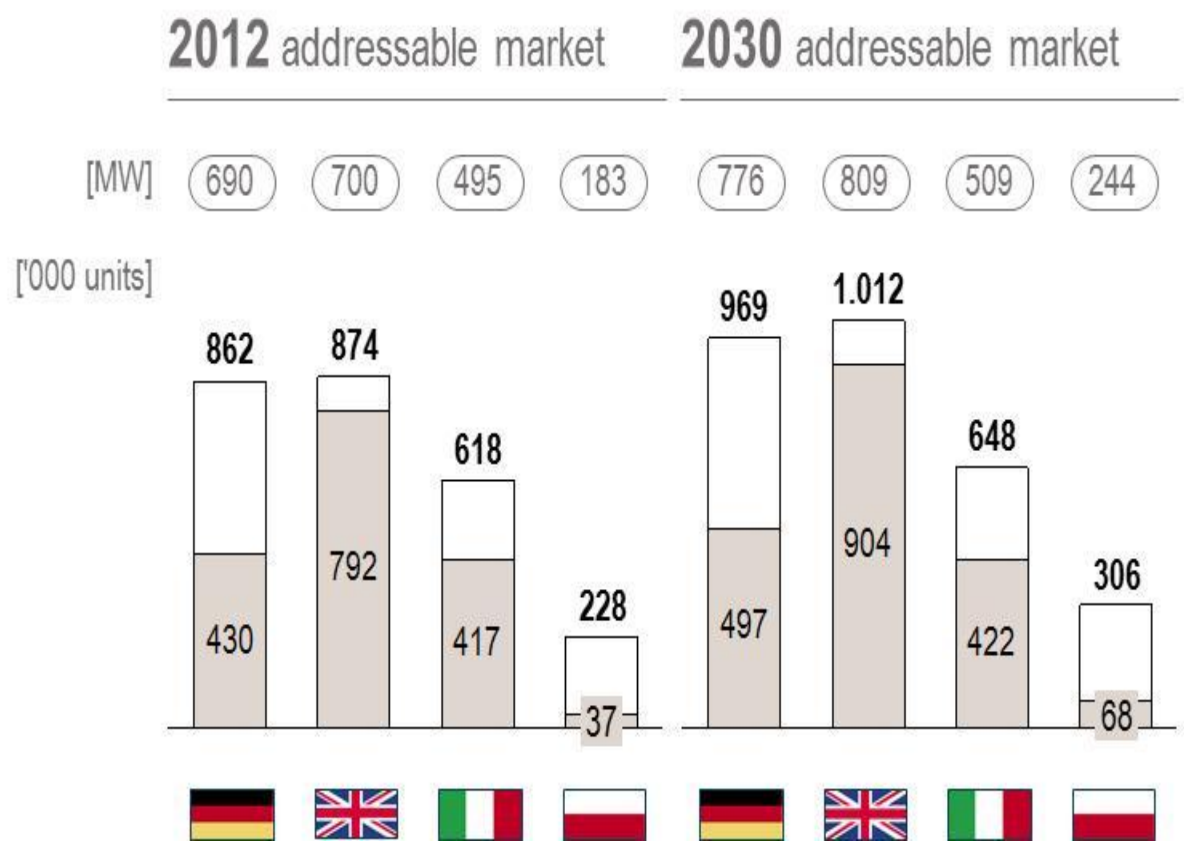
1) Calculated as share of total residential CO_2 emissions (heat and electricity), assuming 1.55 tons per new car and year 2) Other sectors and share of total residential CO2 emissions
3) Manufacturing industries and construction and other energy industry own use 4) EU 28 countries
Source: International Energy Agency CO_2 emissions statistics 2013; Eurostat; EEA; TopTarif; Roland Berger

In the residential segment, fuel cell mCHPs can tap a mass-market of more than 2.5 m units annually in core European countries

Overview of annually addressable market in four focus countries

Residential

- Integrated fuel cell mCHPs for the heating market
- Primary markets include all dwellings with gas heating
- Conversion markets comprise buildings with non-gas technologies
- New installations and replacements drive volume[1)]



Conversion markets [installable capacity] | Primary markets [same as conversion] | Primary and conversion markets [installable capacity]

1) As another type of fuel cell systems, add-on mCHPs for base-load power target all buildings with access to gas, irrespective of replacement cycles.

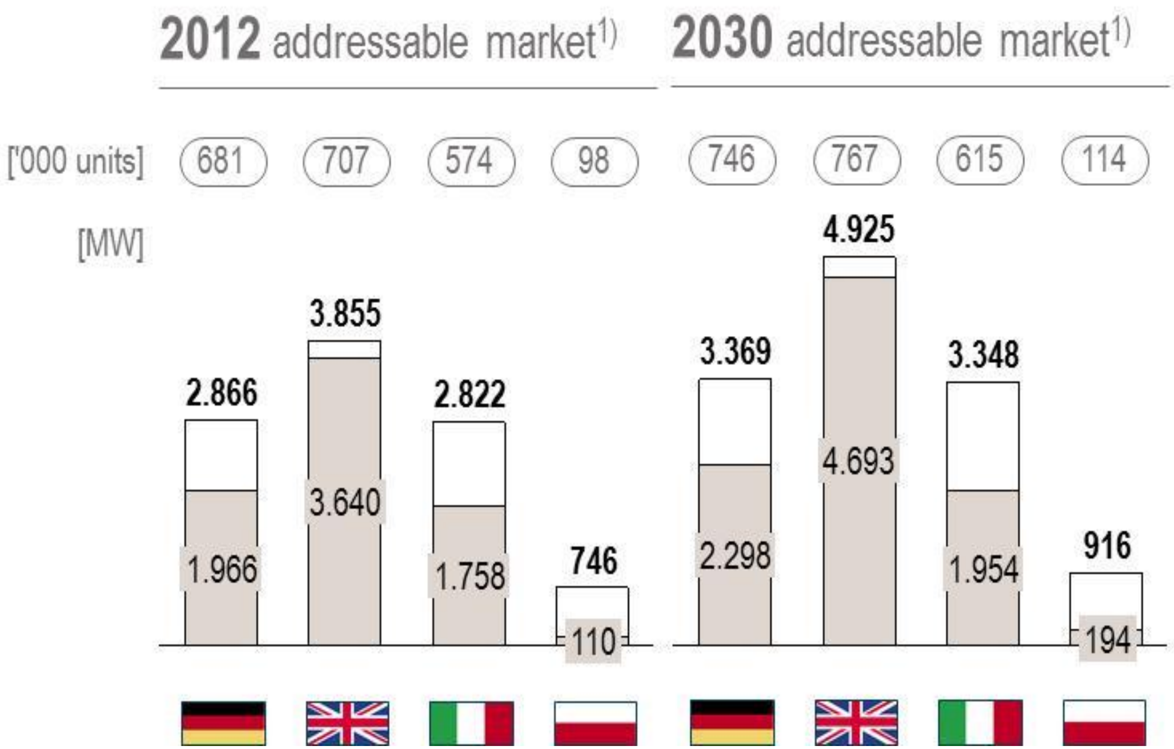
Source: IHS; National statistics institutes; Shell; Roland Berger

The commercial segments offers an annual market potential between 7.5 and 10.3 GW installable capacity in the focus countries

Overview of annually addressable market in four focus countries

Commercial

- Integrated fuel cell CHPs in power ranges from 5 to 400 kW for the heating market
- Primary markets include all buildings with gas heating
- Conversion markets comprise most non-gas solutions
- New installations and replacements drive volume[2)]



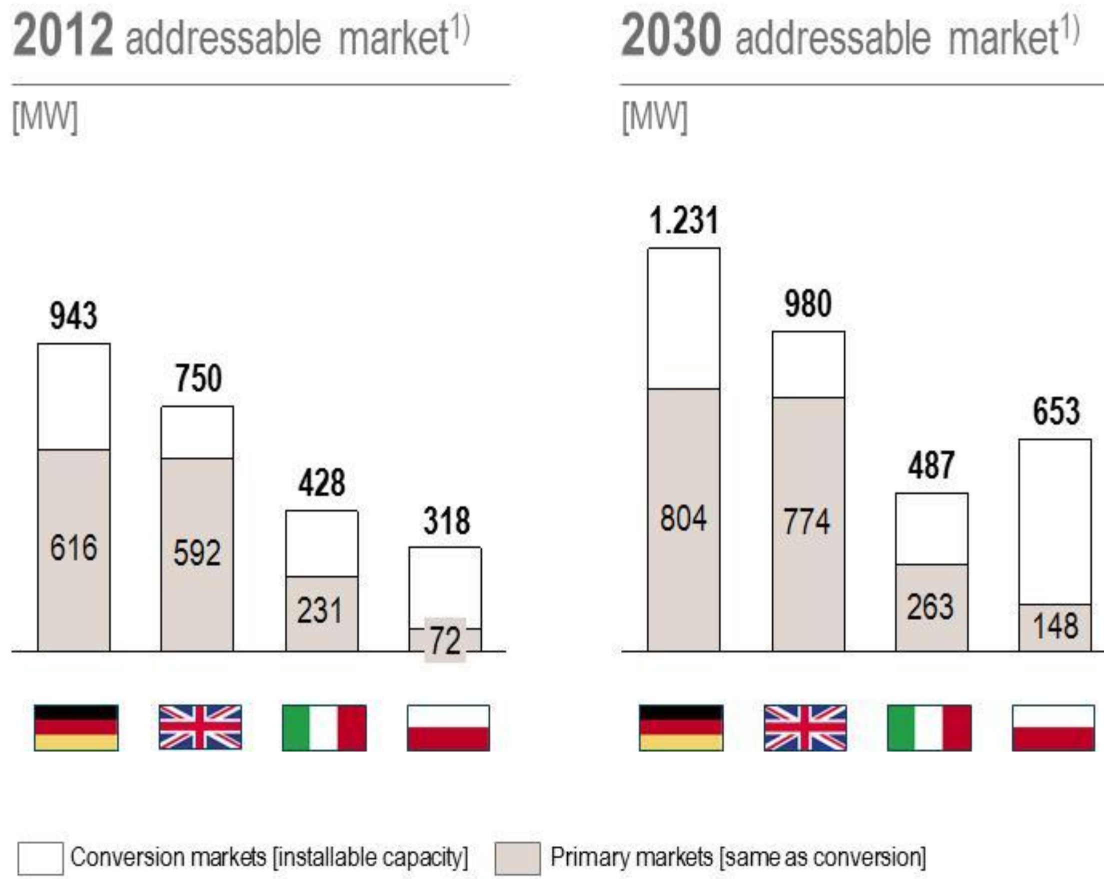
1) Excluding "other buildings" category, including decentralised heating in apartment buildings.
2) As another type of fuel cell systems, add-on mCHPs for base-load power target all buildings with access to gas, irrespective of replacement cycles.
Source: IHS; National statistics institutes; Shell; Roland Berger

In industrial distributed generation, fuel cells can tap a gas-fired installed capacity of more than 2.4 GW in core EU markets

Overview of annually addressable market in four focus countries

Industrial

- Fuel cell CHPs and prime power in power ranges above 400 kW_{el} for industrial applications
- Primary markets include gas-fired distributed generation
- Conversion markets comprise non-gas distributed generation
- Forecast based on expected market growth



1) Addressable market derived from installed distributed capacities

Source: IHS; National statistics institutes; Oxford Economics; Roland Berger

Overview of technology benchmarking

Use cases

Focus market

Residential	New built 1/2 fam. dw.	In scope of the study	In scope of the study	In scope of the study	In scope of the study
Residential	Fully renovated 1/2 fam. dw.	In scope of the study	In scope of the study	In scope of the study	In scope of the study
Residential	Partially renovated 1/2 fam. dw.	Example presented today	Example presented today	In scope of the study	In scope of the study
Residential	Non-renovated 1/2 fam. dw.	In scope of the study	In scope of the study	In scope of the study	In scope of the study
Commercial	Partially renovated apartm. build.	In scope of the study	In scope of the study	In scope of the study	Example presented today
Commercial	Non-renovated apartment build.	In scope of the study	In scope of the study	In scope of the study	In scope of the study
Commercial	Office building			Example presented today	
Commercial	Shopping centre	In scope of the study			
Commercial	Hospital			In scope of the study	
Industrial	Data centre	In scope of the study	In scope of the study	Example presented today	In scope of the study
Industrial	Pharmaceutical production fac.	In scope of the study	In scope of the study	In scope of the study	In scope of the study
Industrial	Chemical production facility	In scope of the study	Example presented today	In scope of the study	In scope of the study
Industrial	Brewery	In scope of the study	In scope of the study	In scope of the study	In scope of the study
Industrial	Wastewater treatment facility	Example presented today	In scope of the study	In scope of the study	In scope of the study

In scope of the study | Example presented today

General findings

- **The fuel cell has a clear emissions advantage** over competitors: greenhouse gases, pollutants, particulates
- **The fuel cell yields the lowest net energy costs** given its high efficiencies
- **However, at current capital cost, the fuel cell is uncompetitive** in terms of total cost of ownership
- **With sufficient CAPEX reductions,** economic competitiveness can be reached
- **Use-case characteristics, energy prices,** operating strategy and competing innovations determine performance

Source: FCH JU Coalition, Roland Berger

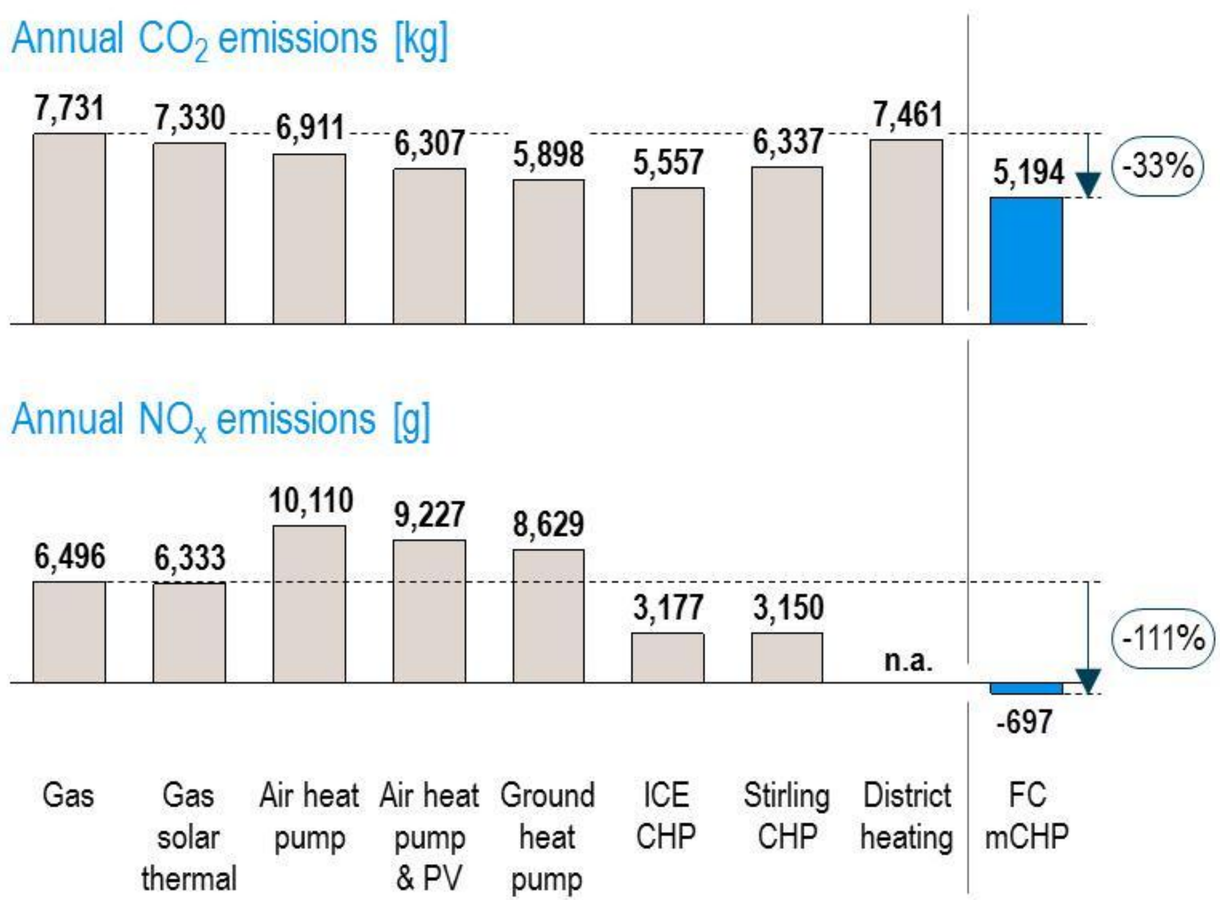
Today FC can reduce CO_2 emissions by more than 30% compared to the condensing boiler - NO_x emissions can be eliminated entirely

Residential segment – Example

Use-case specific environmental benchmarking[1)]

MUNICH

Residents	4
Heated space	103 m^2
Year of construction	1962
Heat demand	21,438 kWh
Electricity demand	5,200 kWh
Central heating	



1) Considering the total annual balance of emissions attributable to the building, i.e. for power and heat consumption. Any power feed-in is thus credited with the primary energy equivalent.
Source: FCH JU Coalition, Roland Berger

However, to become economically competitive, capital costs must be reduced substantially by increasing production volumes

Residential segment – Example

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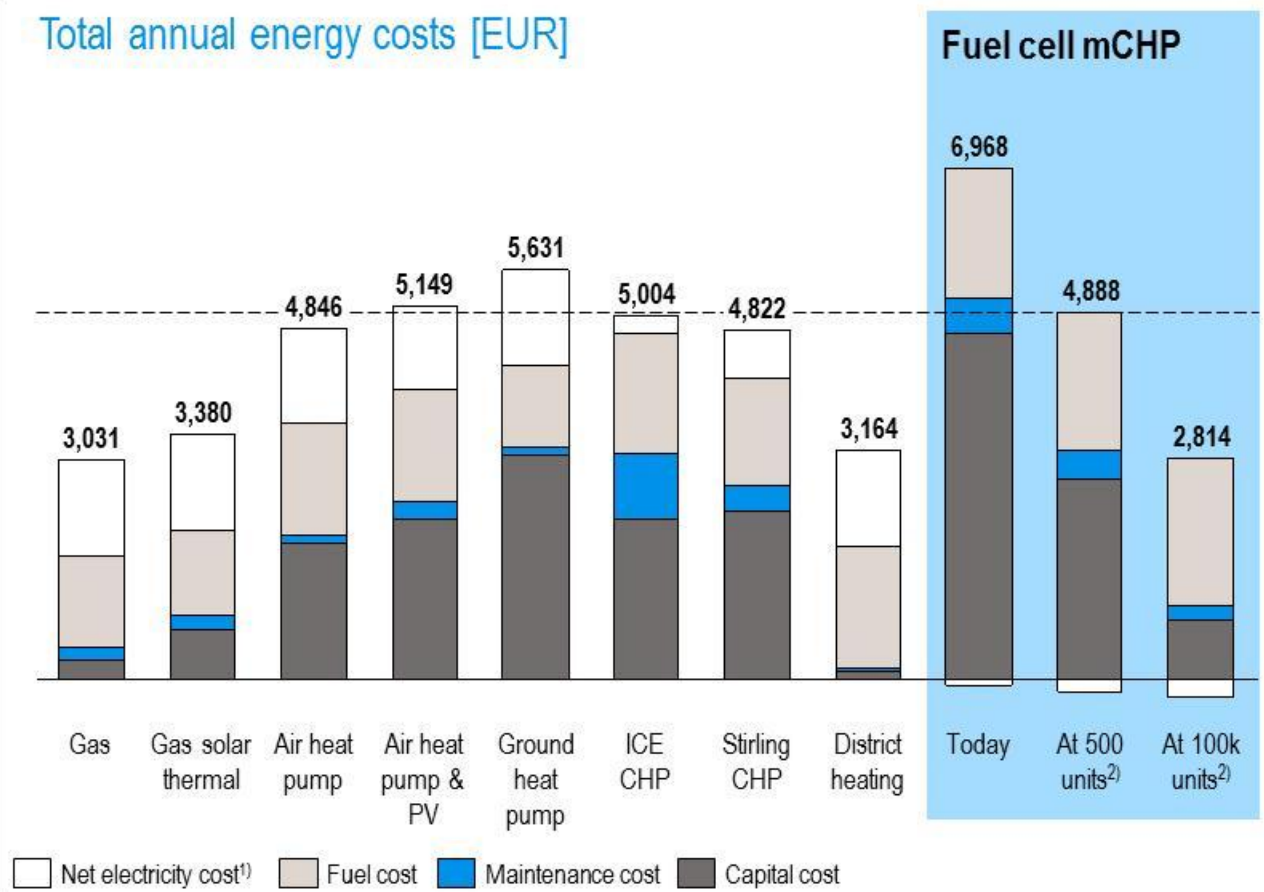
Use-case specific economic benchmarking

MUNICH

Fuel cell micro-CHP system

Electric capacity	1 kW_{el}
Thermal capacity	1.45 kW_{th}
Electric efficiency	36%
Thermal efficiency	52%
System lifetime	15 years
Required stack replacements	2



1) Negative electricity cost reflect higher earnings from power feed-in than residual purchase of grid power. 2) Cumulative production volume per company.

Source: FCH JU Coalition, Roland Berger

Today FC can reduce CO_2 emissions by nearly 40% compared to the condensing boiler - NO_x emissions can be eliminated entirely

Commercial segment – Example

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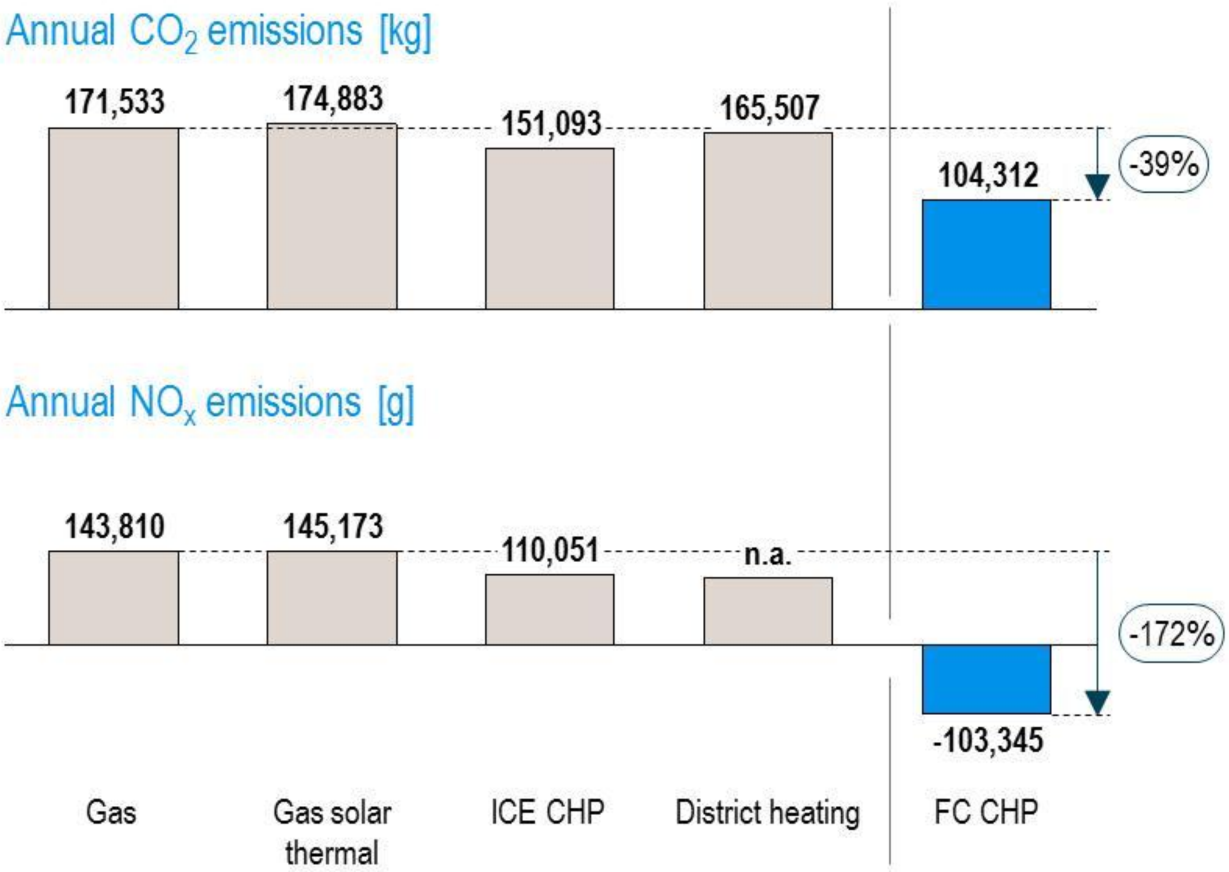
Use-case specific environmental benchmarking[1)]

MILAN

Heated space	6000 m^2
Construction	1970
Total heat demand	477,000 kWh
Electricity demand	159,000 kWh
Central heating	yes



1) Considering the total annual balance of emissions attributable to the building, i.e. for power and heat consumption. Any power feed-in is thus credited with the primary energy equivalent.

Source: FCH JU Coalition, Roland Berger

However, to become economically competitive, capital costs must be reduced substantially by increasing production volumes

Commercial segment – Example

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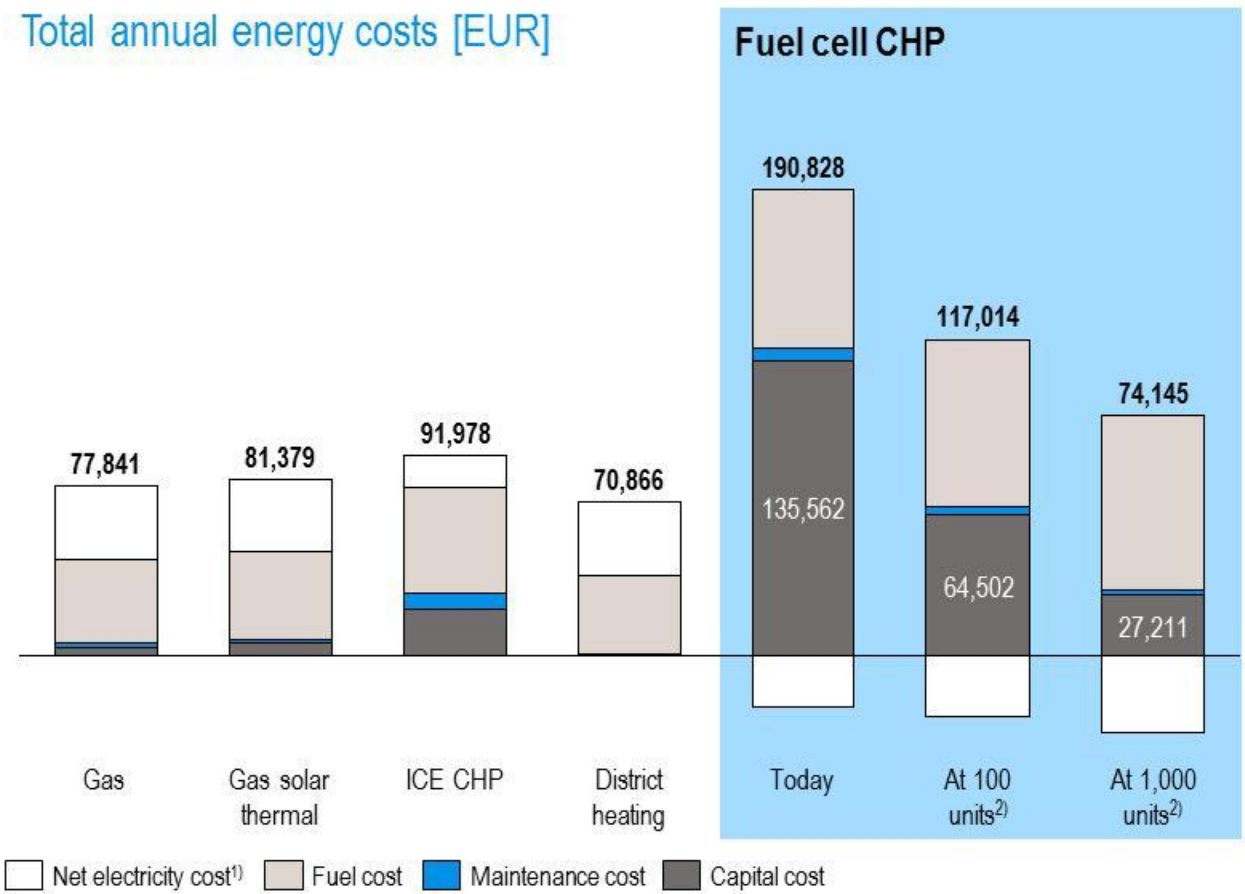
Use-case specific economic benchmarking[1)]

MILAN

Fuel cell CHP system

Electric capacity	50 kW_{el}
Thermal capacity	40 kW_{th}
Electric efficiency	53%
Thermal efficiency	32%
System lifetime	10 years
Required stack replacements	2



1) Negative electricity cost reflects higher earnings from feed-in than purchase of grid power. 2) Cumulative production per company.

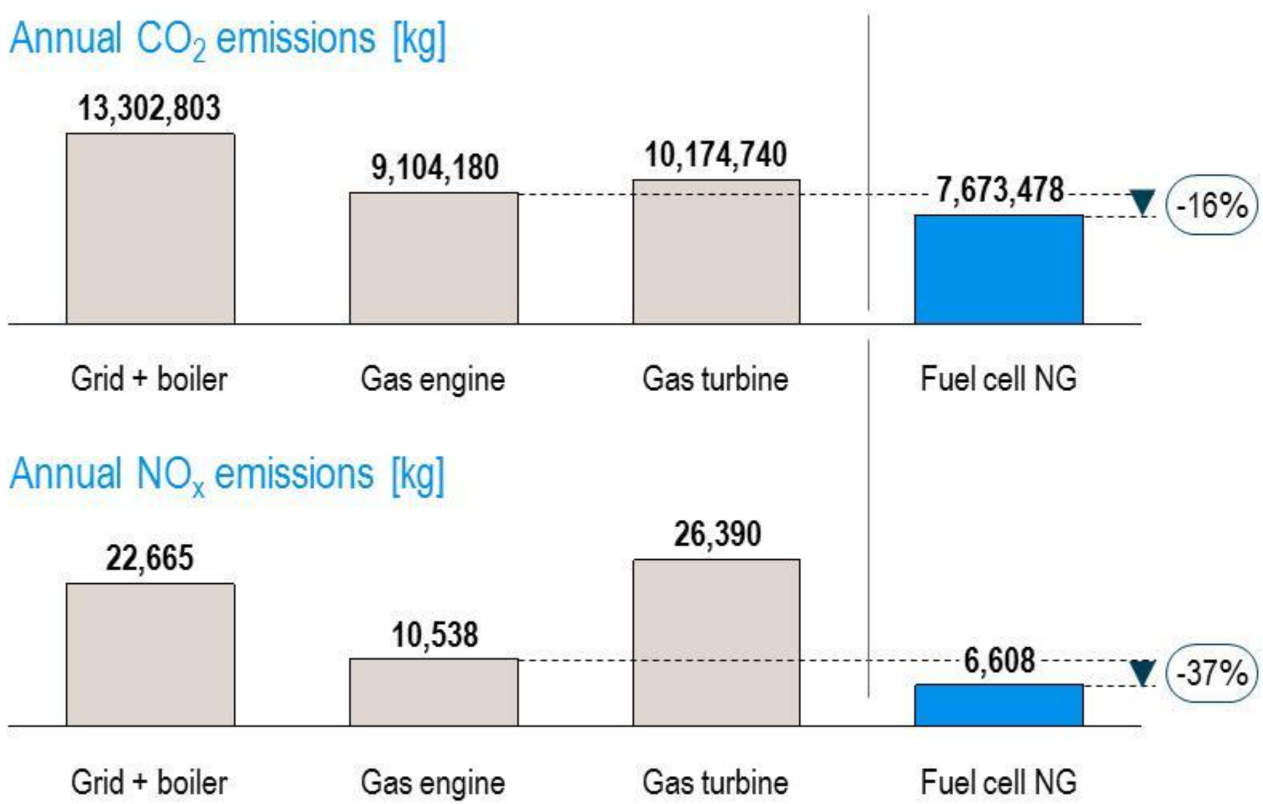
Source: FCH JU Coalition, Roland Berger

The fuel cell is the cleanest technology in terms of CO_2 and NO_x emissions for chemical production facilities

Industrial segment – Example

Use-case specific environmental benchmarking[1)]

Base-load power demand	11,600 MWh
Heat demand	29,000 MWh
Heat temp. req.	> 130 ° C
H_2 emissions	2,000,000 m^3
Plant operation	24/7
Gas/ power grid connection	yes



1) Considering the total annual balance of emissions attributable to the building, i.e. for power and heat consumption. Any power feed-in is thus credited with the primary energy equivalent.

Source: FCH JU Coalition, Roland Berger

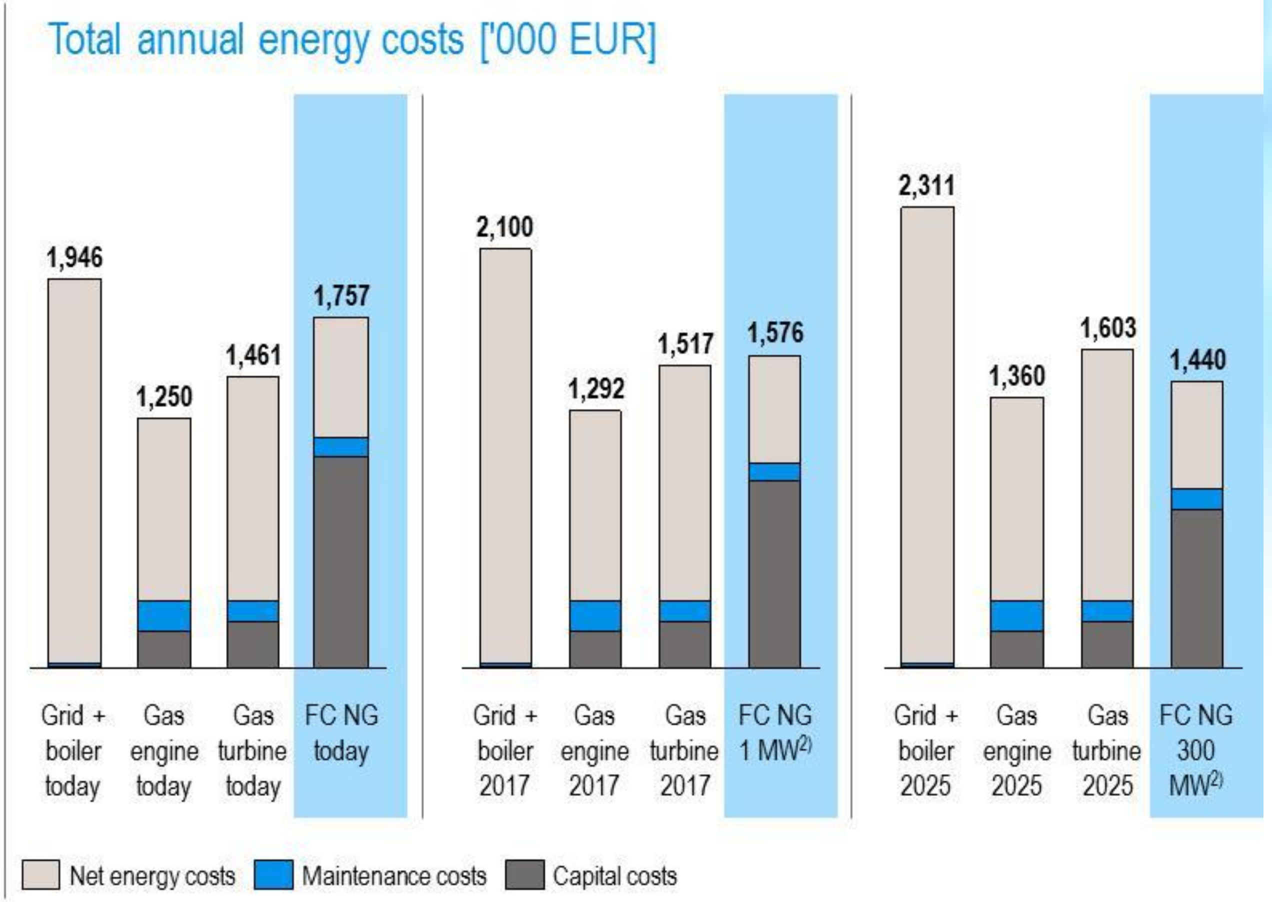
The fuel cell system has the best net energy performance and can further improve its competitivenessby decreasing capital costs

Industrial segment – Example

Use-case specific economic benchmarking[1)]

Fuel cell CHP nat. gas system

Electric capacity	1,425 kW_{el}
Thermal capacity	1,116 kW_{th}
Electric efficiency	49%
Thermal efficiency	31%
System lifetime	16 years
Required stack replacements	3



1) Fuel prices for a patchy progress scenario in the UK assumed. 2) Installed electricla capacity per company.

Source: FCH JU Coalition, Roland Berger

To enable commercialisation, three levers need to be triggered - Decrease CAPEX, sustain performance and establish framework

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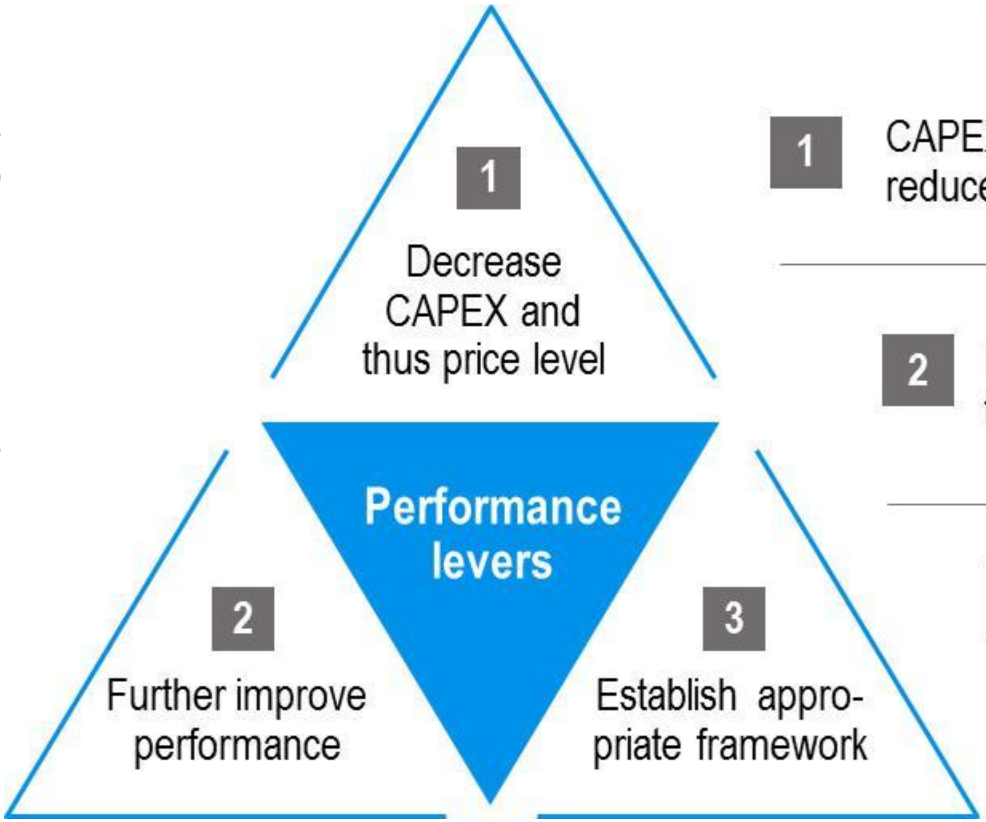
Three levers to unlock the benefits of stationary fuel cells[1)]



1 CAPEX and thus price level must be reduced to **enable FC competitiveness**

2 **Performance must be improved further** to prolong lifetime and increase efficiency

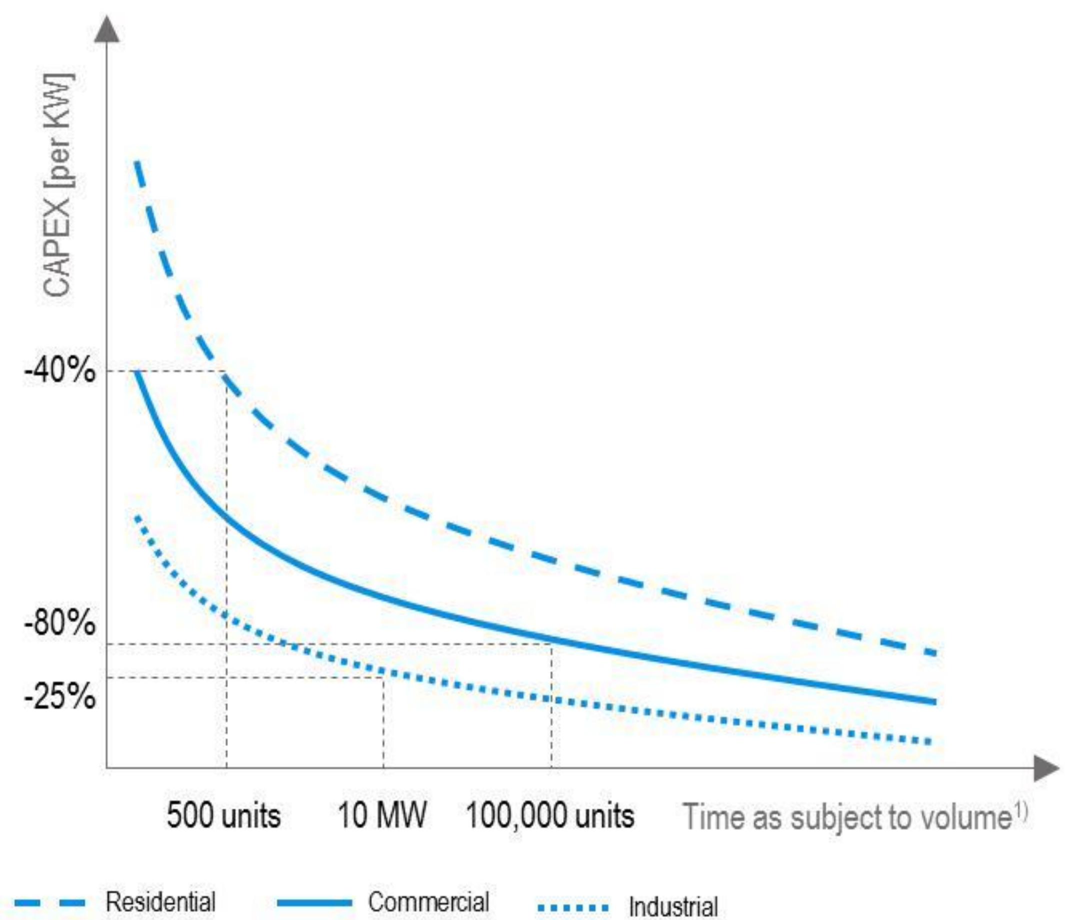
3 **Policy framework must allow to explore FC benefits** (e.g. funding to support initial commercialisation)

1) The three levers are of different importance for different fuel cell product clusters and market segments. Please refer to the Study for detailed information.

Source: FCH JU Coalition, Roland Berger

System costs of stationary fuel cells can be significantly reduced with growing production volume - Industry sees ambitious potential

Expected cost reduction and potential levers with volume uptake and learning effects



1) Cumulative production volume per company

Main levers to reduce CAPEX

> Production volume must go up quickly to enter industrialisation stage

> Many production steps are still manually performed – Learning effects from Japan cannot be adopted

> Larger volumes allow for automation and bundled sourcing strategies

> Standardisation must increase within and across technology lines

> Industry is fully committed to decreasing cost with sufficient installation volumes

Source: FCH JU Coalition, Roland Berger

Industry is committed to further improve performance and prove it in the market - Improvement drivers are production volume and R&D

Overview of performance improvement levers and targets [example]

Fuel cell efficiency [%][1)]

	Today	Potential
Electrical efficiency	36-60	42-65
Thermal efficiency	25-52	34-53
Combined efficiency	**85-88**	**95-99**

> Transition to **more efficient technology lines**
> **Further research** on how efficiency can be improved by **system design**
> Further **optimisation of running modes** and **operating models**

> Transition to **new production processes**
> **Optimisation of operating models**
> Improvement of **joint development initiatives**

	Today	Potential
Stack lifetime	2.75-5	3.5-15
System design life	10-17	14-20

Fuel cell durability [yrs][1)]

1) Depending on the operating strategy of the fuel cell system.

Source: FCH JU Coalition, Roland Berger

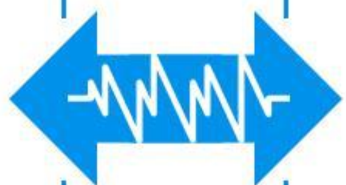
To enable conducive policy framework, industry must take the lead - Policy commitment subject to specific targets that need to be met

General recommendation and support framework

Fuel cell industry

- Commit to and deliver **cost degression targets…**
- Commit to and demonstrate **further quality improvement…**
- **Deliver on ongoing field tests** and demonstration projects

… to sustain/reach market readiness



Policy makers

- Commit to **CHP in general and fuel cells in particular…**
- Commit to **establish larger scale diffusion…**
- Commit to **establish support mechanisms…**

… to enable industry actions

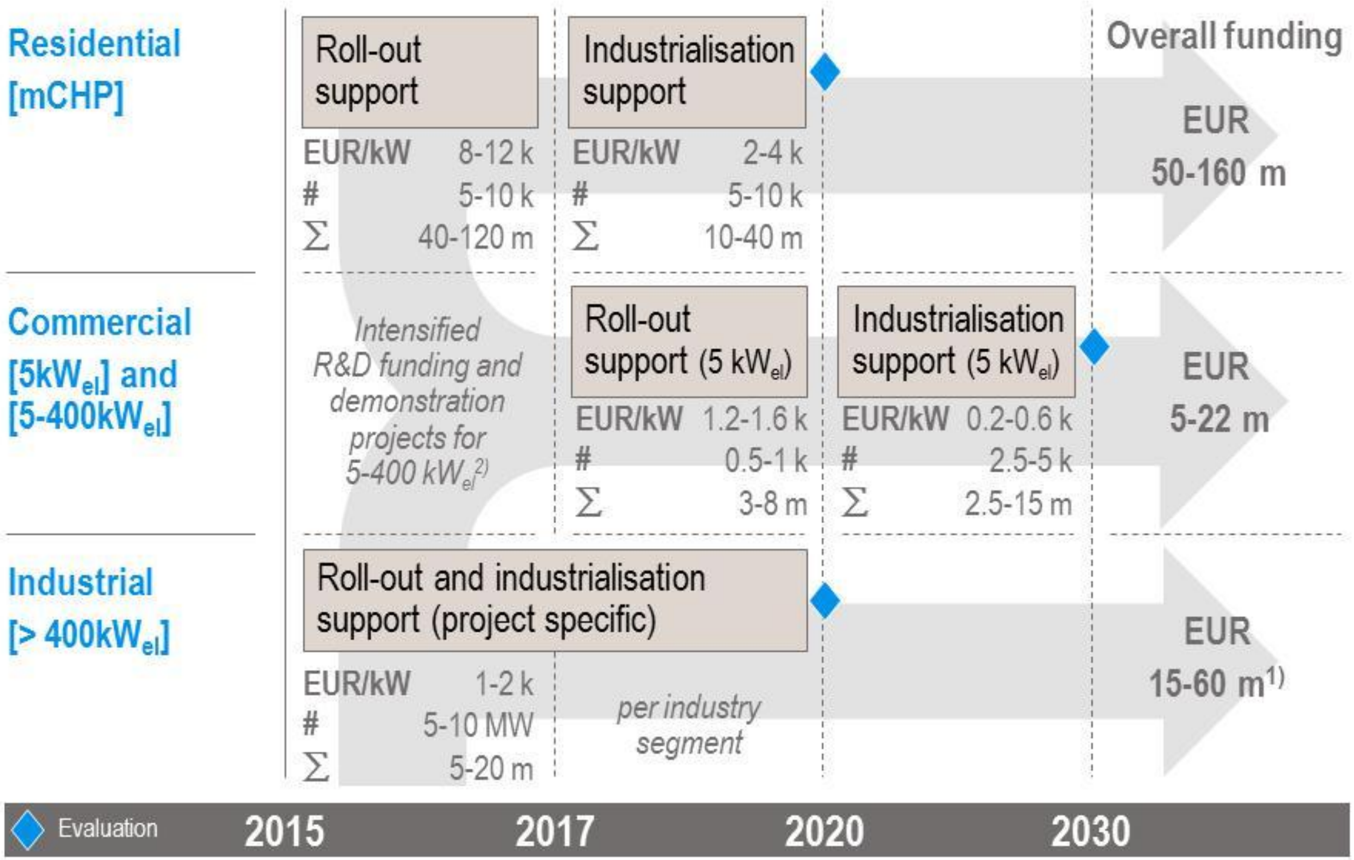
- **Lead** has to be set **at industry level**, i.e. industry takes action and policy makers set up a framework
- **Policy commitment is subject to industry commitment**, i.e. industry targets must be reached
- If selected **industry segments cannot meet targets policy support will not continue**
- Industry targets are set as **target cost/price, target quality, target efficiency/durability at number of produced systems** or units, i.e. at company level system cost are decreased by 40% when 500 systems are brought to the market

Source: FCH JU Coalition, Roland Berger

3

Funding support should enable initial volume uptake where FCs are market-ready - Focus on demonstration projects in other segments

Proposed minimum funding framework for initial commercialisation in the focus markets



Rationale

- Pure focus on initial volume uptake – funding beyond to be evaluated
- Prioritisation acc. to market readiness,. focus on lead markets (e.g. DE)
- Scope based on expected learning effects and required volumes
- Besides, R&D funding to be mobilised for demonstration projects

1) Assuming 3 focus industries selected to reach sufficient volumes for achieving learning effects 2) Roll-out support for 5-400 kW_{el} to be evaluated upon successful demo-projects.

Source: FCH JU Coalition, Roland Berger

It is proposed to align FCH JU funding priorities with R&D needs of the industry beyond volume uptake

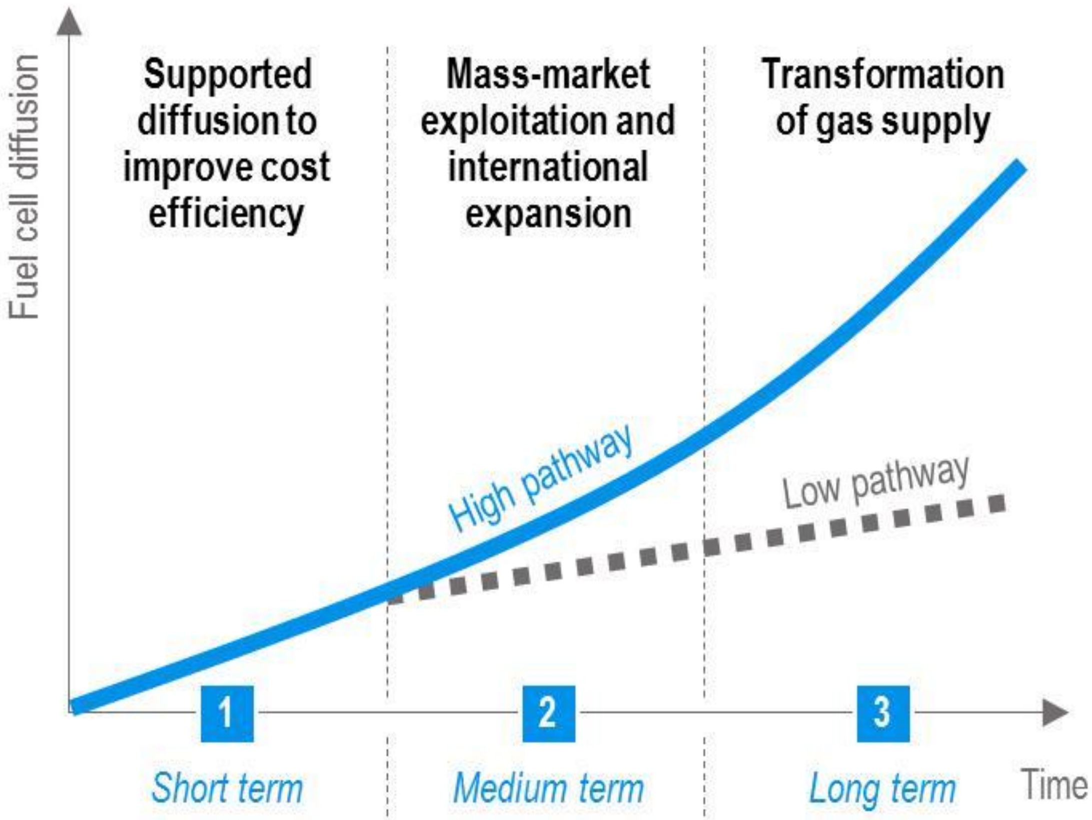
Priority topics for the FCH JU with focus on R&D funding support

Residential segment [mCHP]	> **Implementing design-to-cost**, design-for-manufacture and design-to-assembly processes for stack production and system integration to facilitate volume-driven cost reduction > **Standardising key components** of fuel cell mCHPs, e.g. in the BoP, added system > **Further reducing stack degradation** aiming for 40k operating hours, later 80k operating hours > **Increasing electrical efficiency** to account for increasing heat and decreasing electrical demand
Commercial segment [5-400kW$_{el}$]	> **System integration and real-life field testing of prototype fuel cell CHPs** in commercial use cases at medium power ranges (e.g. office buildings, shopping centres, hospitals etc.) > **Increasing lifetime of stacks** by lowering degradation rates > **Raising efficiency** (especially electrical) to higher levels > **Improving robustness** to reduce risks of stack failure through external shocks (e.g. shut downs)
Industrial segment [> 400kW$_{el}$]	> **BOP standardisation** and reliability improvements for costs savings and reduced delivery times > **Increasing cell power density** and achieving thinner layers at cell level to reduce volume, costs > **Substituting expensive materials** (e.g. stainless steel) with alternative materials to reduce costs > **Reducing fuel cell degradation**, with narrower performance variation to increase stack lifetime > **Increasing total efficiency** of the system to reduce operating costs

Source: FCH JU Coalition, Roland Berger

The commercialisation of fuel cells will go through three main phases - Long-term potential as mass-market technology

Potential development stages and pathways of the fuel cell technology



1 Fuel cell systems reach competitive cost level to high-end heating solutions

- Policy support to trigger market pick-up and thus cost reduction
- Starting point in the residential segment

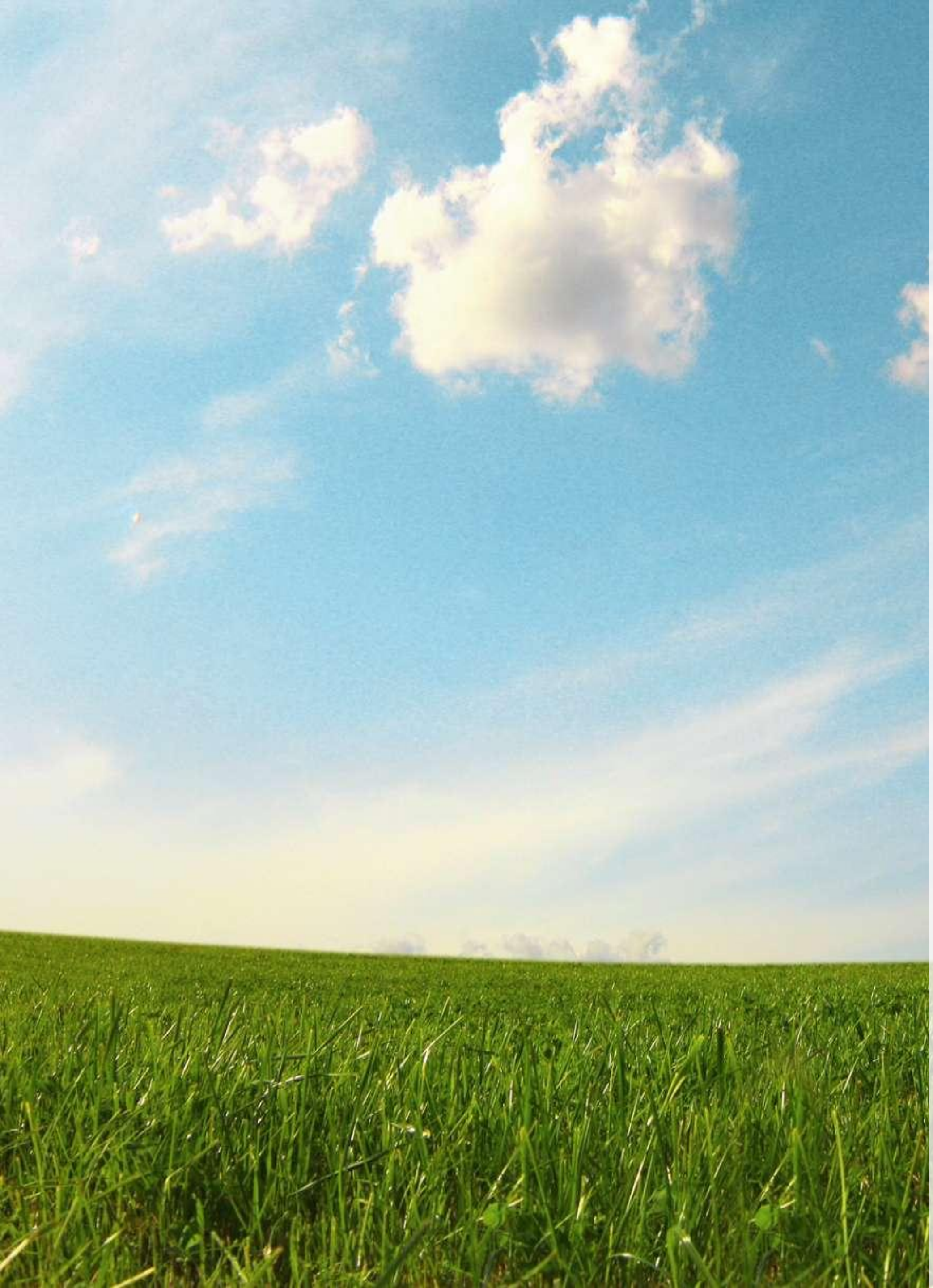
2 Fuel cell systems reach competitive cost level to mass-market solutions

- Continuous support if cost targets are reached
- Commercial segment to be supported

3 Fuel cell systems become a renewable technology through decarbonisation of gas supply

- Further growth and mass-market solution possible if gas supply becomes greener and more domestic

Source: FCH JU Coalition, Roland Berger



Let's think: act!

Roland Berger
Strategy Consultants