Fuel Cells Distributed Generation Commercialisation Study

Results and way-forward

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

Background and objectives of the study

Background

> Commissioned 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

Roland Berger
Strategy Consultants

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 study identifies large addressable markets, emissions savings potentials and a need for cost reduction to become competitive

Main findings concerning the commercialisation of fuel cell distributed generation

Mass-market potential

Stationary fuel cells using natural gas, biogas or hydrogen for CHP or prime power can tap a mass market in different segments – especially in large, gas-dominated heating markets like UK, Germany

Substantial savings in emissions and primary energy

Due to their high efficiencies and technology characteristics, stationary fuel cells reduce primary energy consumption as well as emissions of greenhouse gases, pollutants and particulates

Competitive economic performance with volume uptake

Given their high capital cost, stationary fuel cells are currently economically uncompetitive, but the industry expects to outperform conventional solutions with volume-driven cost reductions

Three levers for commercialising stationary fuel cells

Cost reductions, performance improvements and a favourable market environment (e.g. spark spread, public support framework) will shape the successful commercialisation of the technology

Source: FCH JU Coalition, Roland Berger

A coalition composed of more than 30 stakeholders – Results reflect common understanding of this group

Coalition members

20 members of the fuel cell industry

6 players in adjacent industries

4 key associations

2 research institutes

3 public sector bodies

Source: FCH JU Coalition, Roland Berger

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

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)

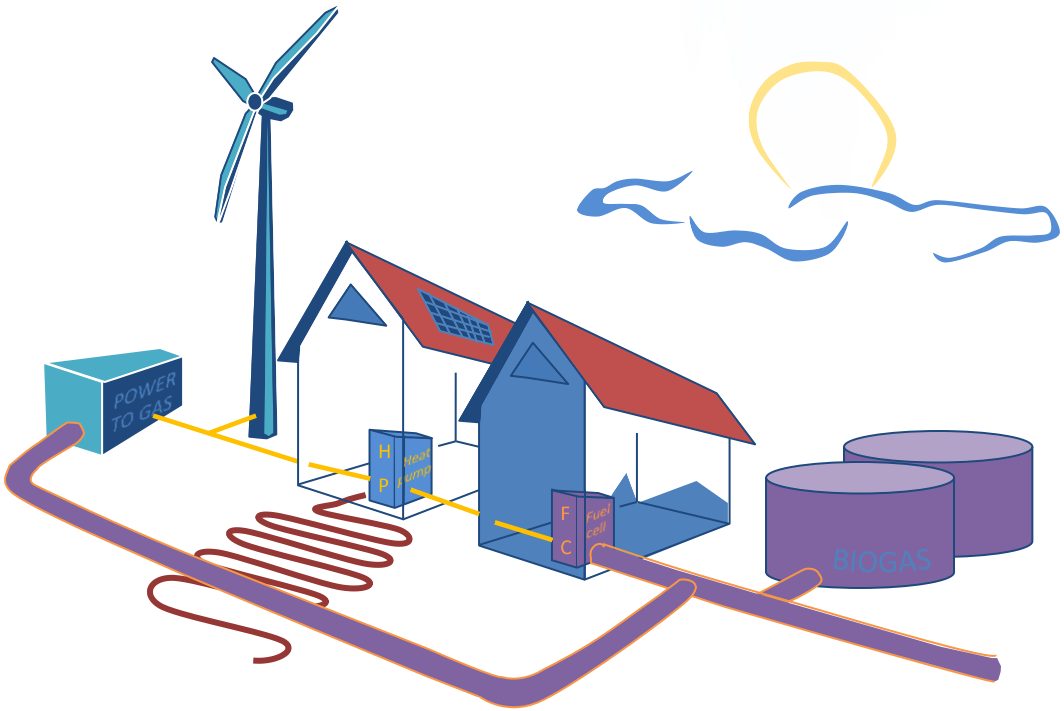
Contributions of fuel cells
- Efficient, distributed conversion technology of low-carbon gas and zero-emission potential

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

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

European vision for stationary fuel cells



Fuel cell vision

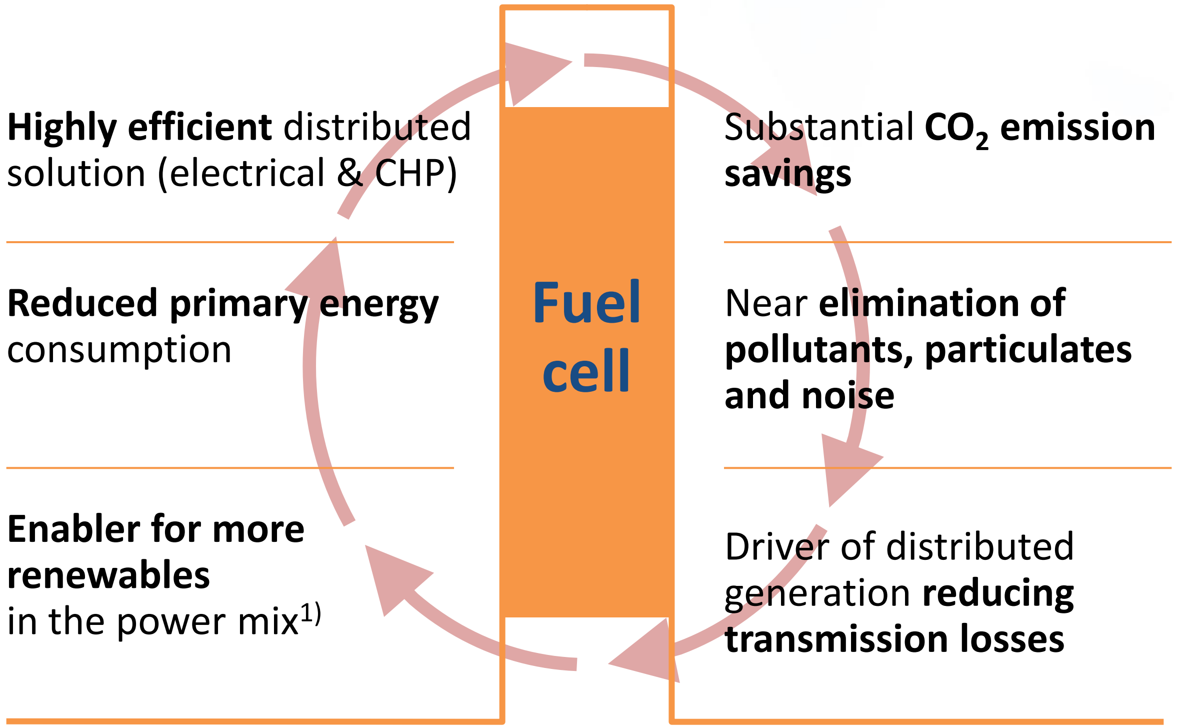
- Highly efficient conversion of natural gas (and eventually green gas or pure hydrogen)
- In distributed generation, i.e. at the site of consumption
- Lowering the carbon footprint of energy supply
- Playing a omplementary role to renewables[1)]

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

Stationary fuel cells bear substantial, interrelated benefits – First a gas-based bridge technology, then carbon-free potential

Stylised overview of main benefits of stationary fuel cells



- > **Fuel cell initially as bridge technology** with significant potential to reduce primary energy demand and emissions
- > **Afterwards, transformation to a renewable technology** through decarbonisation of the gas grid

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

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)]

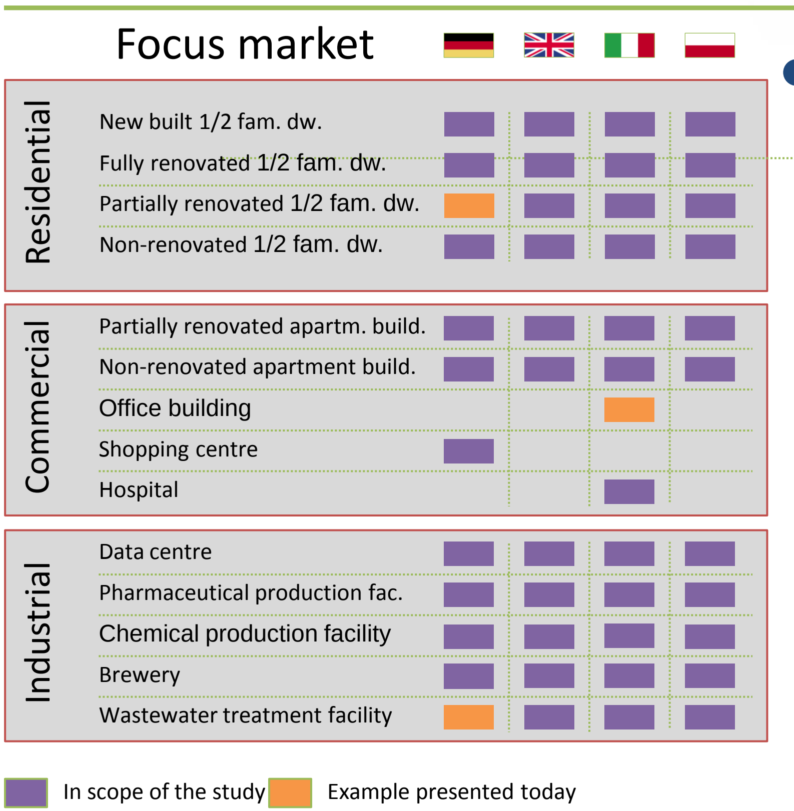
1) Calculated as share of total residential CO_2 emissions (heat and electricity), assuming 1.55 tons per new car and year
2) Other sectors and share of total residential CO2 emissions
3) Manufacturing industries and construction and other energy industry own use
4) EU 28 countries

Source: International Energy Agency CO_2 emissions statistics 2013; Eurostat; EEA; TopTarif; Roland Berger

A rigorous benchmarking in more than 45 use cases shows the superior environmental performance of stationary fuel cells

Overview of technology benchmarking

Use cases



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

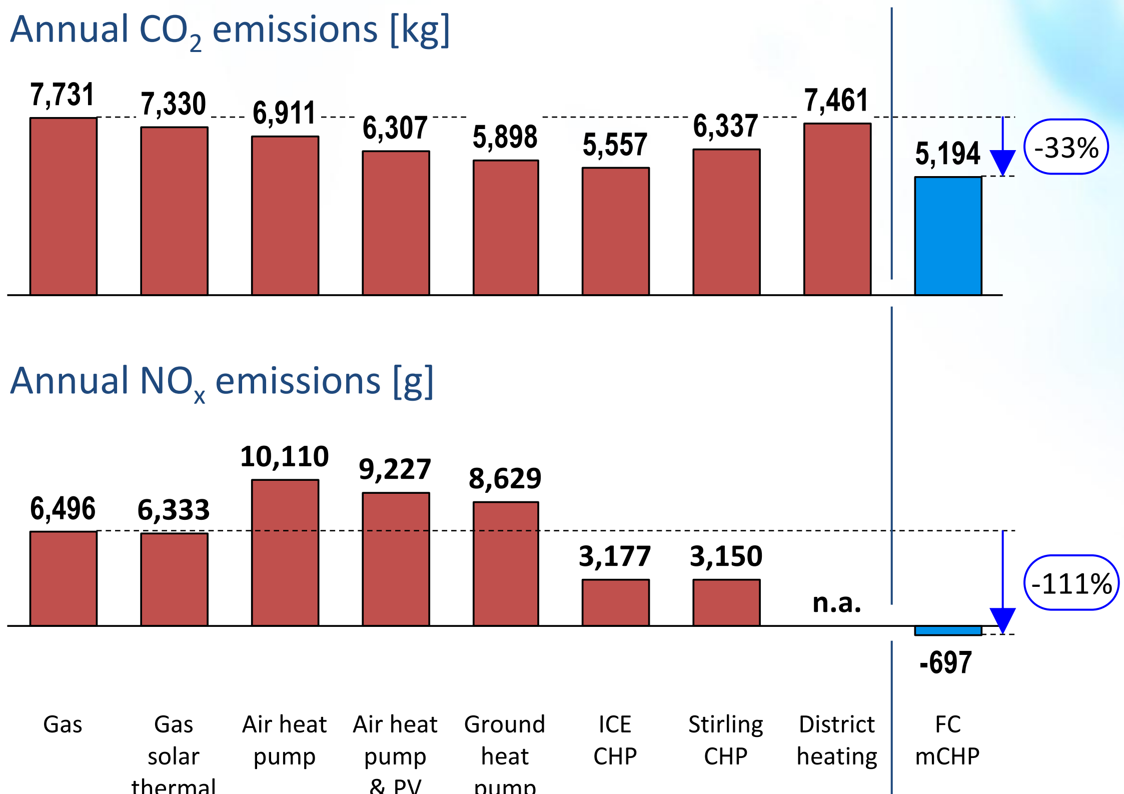
Today FC can reduce CO_2 emissions by more than 30% compared to the condensing boiler – NO_x emissions can be eliminated entirely

Residential segment – Example of Germany

Use-case specific economic benchmarking

MUNICH

Residents	4
Heated space	103 m²
Year of construction	1962
Heat demand	21,438 kWh
Electricity demand	5,200 kWh
Central heating	

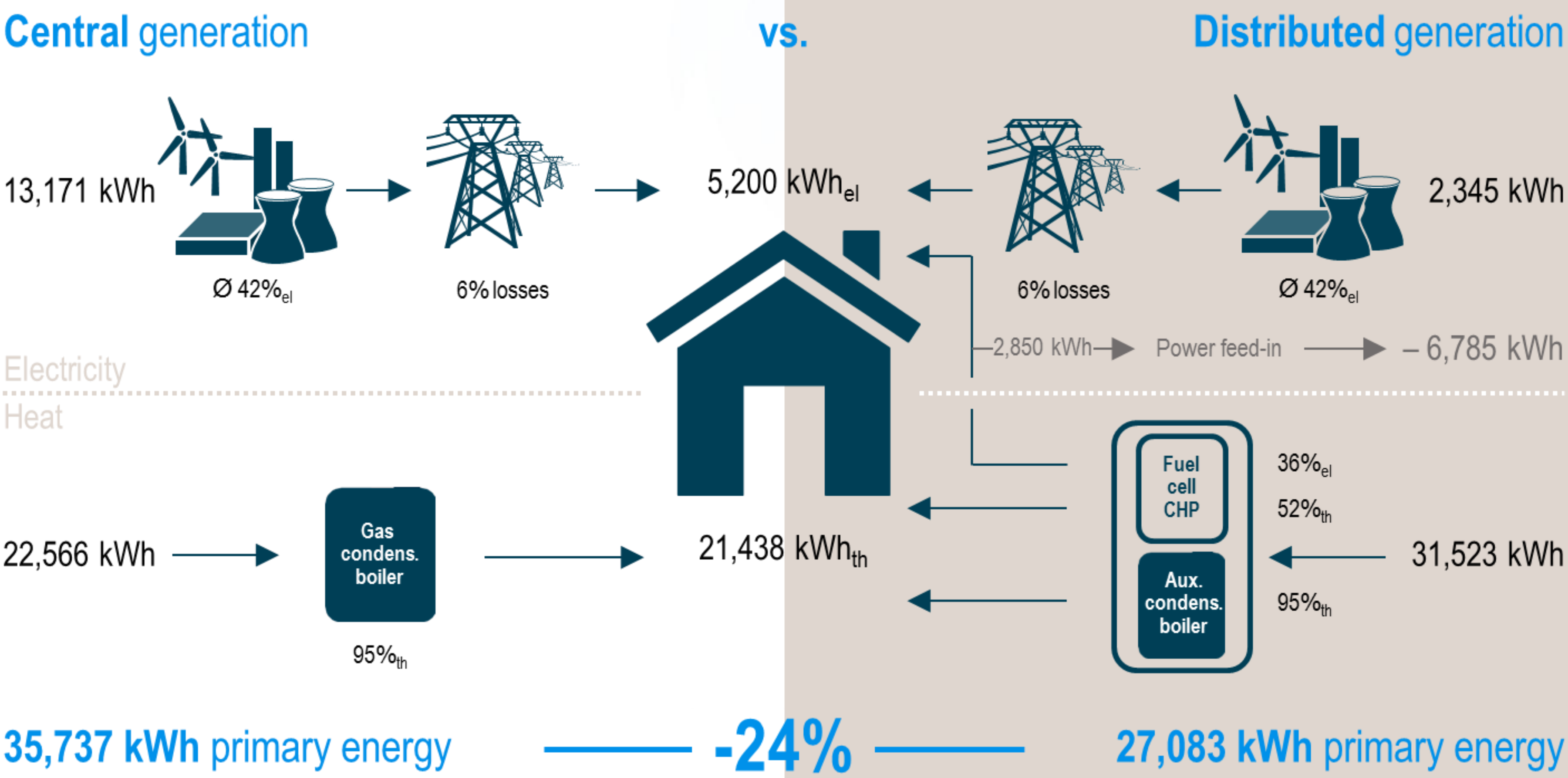


1) Considering the total annual balance of emissions attributable to the building, i.e. for power and heat consumption. Any power feed-in is thus credited with the primary energ

Source: FCH JU Coalition, Roland Berger

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)]



1) Exemplary case of a German, partially renovated 1/2-family dwelling in current conditions (2014), total-balance or power-credit methodology

Source: FCH JU Coalition, Roland Berger

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

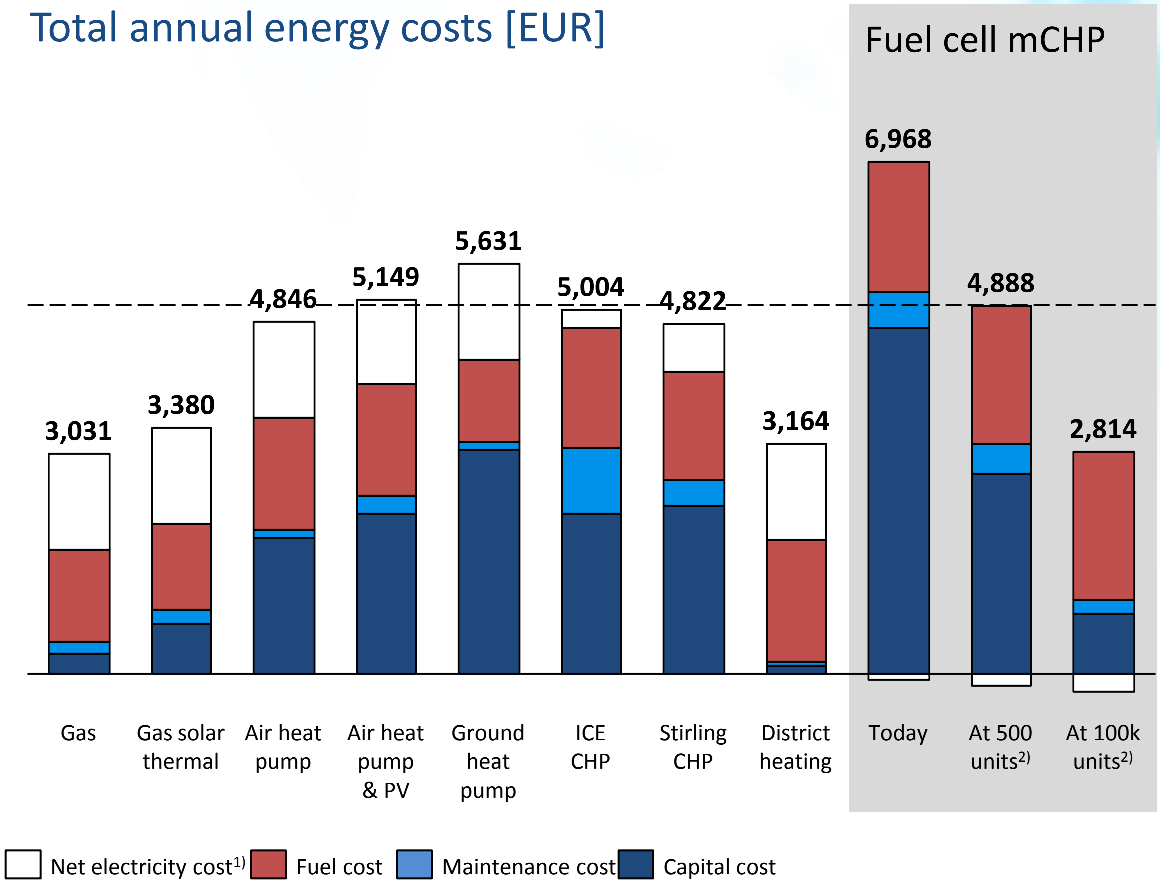
Residential segment – Example of Germany

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 compa

Source: FCH JU Coalition, Roland Berger

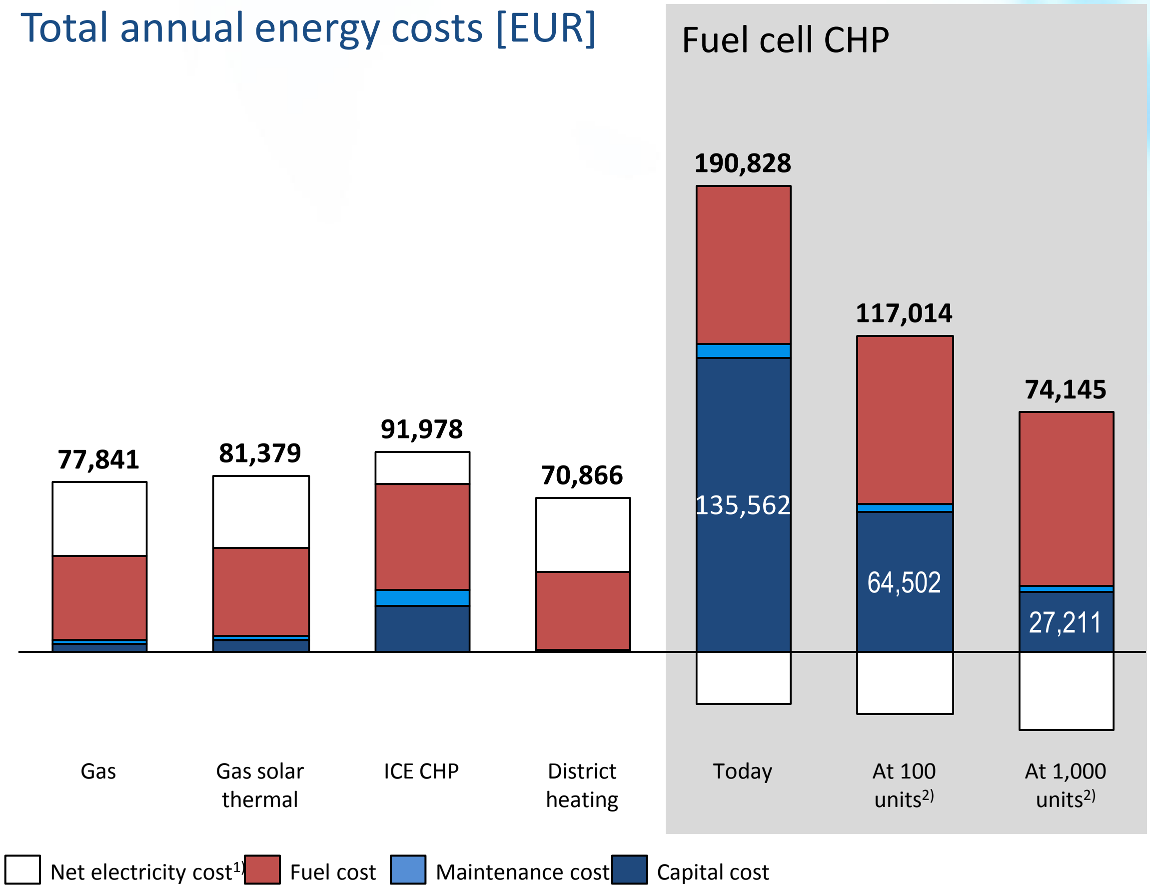
Commercial segment – Example of Italy

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

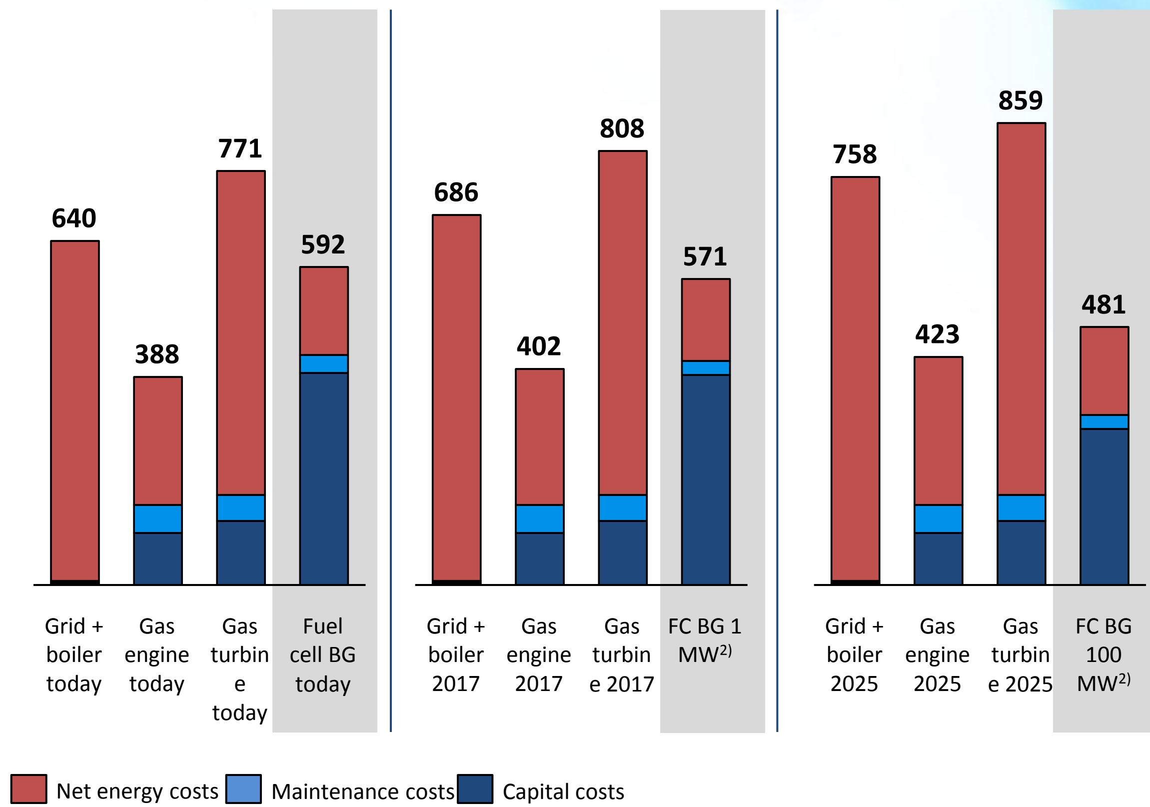
Industrial segment – Example of Germany

Use-case specific economic benchmarking[1)]

Fuel cell CHP biogas system

Electric capacity	400 kW_{el}
Thermal capacity	315 kW_{th}
Electric efficiency	46%
Thermal efficiency	35%
System lifetime	17 years
Required stack replacements	3

Total annual energy costs ['000 EUR]

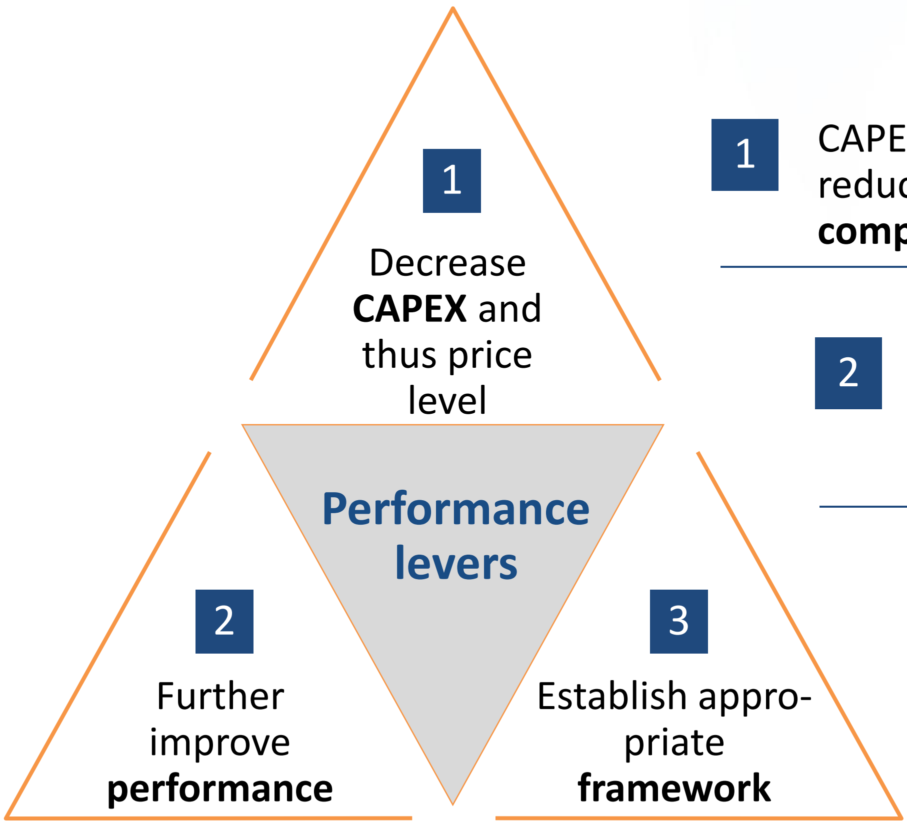


1) Fuel prices for a patchy progress scenario in Germany assumed. 2) Installed electric capacity per company.

Source: FCH JU Coalition, Roland Berger

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

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

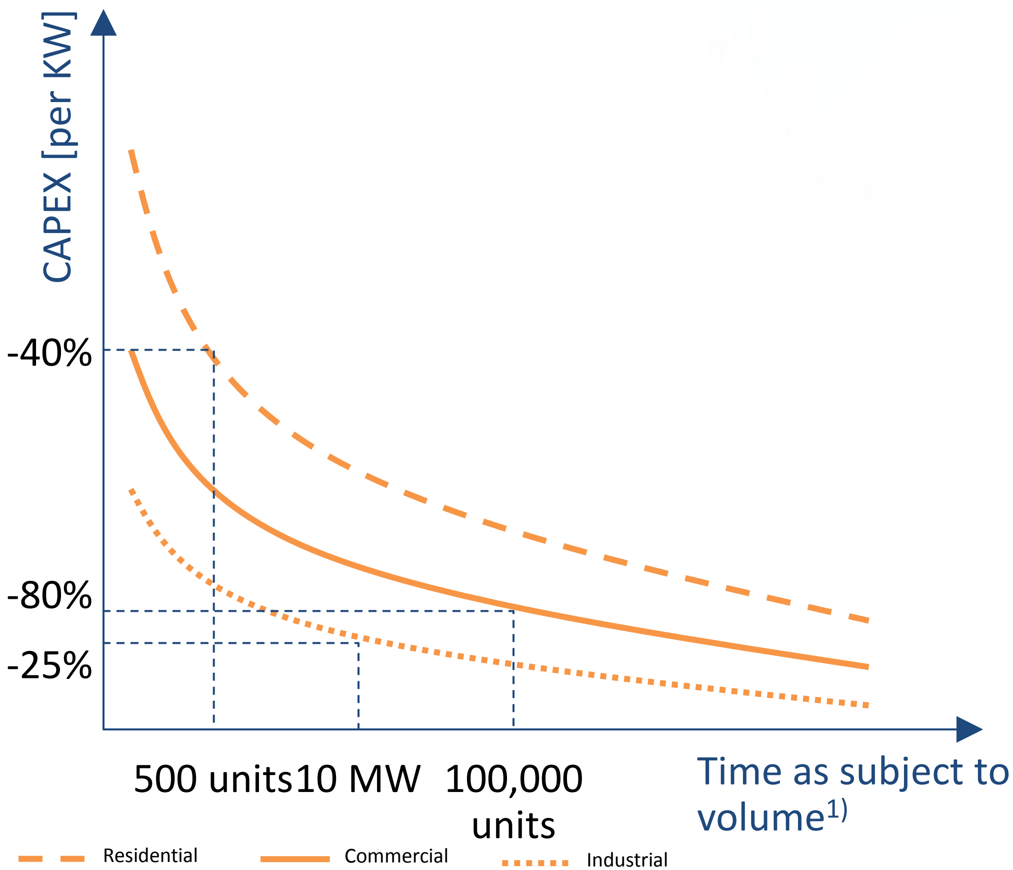
3 **Policy framework must allow to explore FC benefits** (e.g. funding to support initial commercialisation)

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

1 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

Source: FCH JU Coalition, Roland Berger

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

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**

Fuel cell durability [yrs][1)]

- 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

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

Source: FCH JU Coalition, Roland Berger

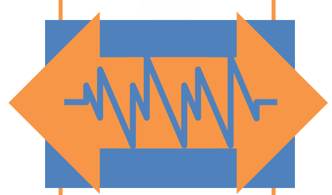
To enable conducive policy framework, industry must take the lead – Policy commitment subject to specific targets that need to be met

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...

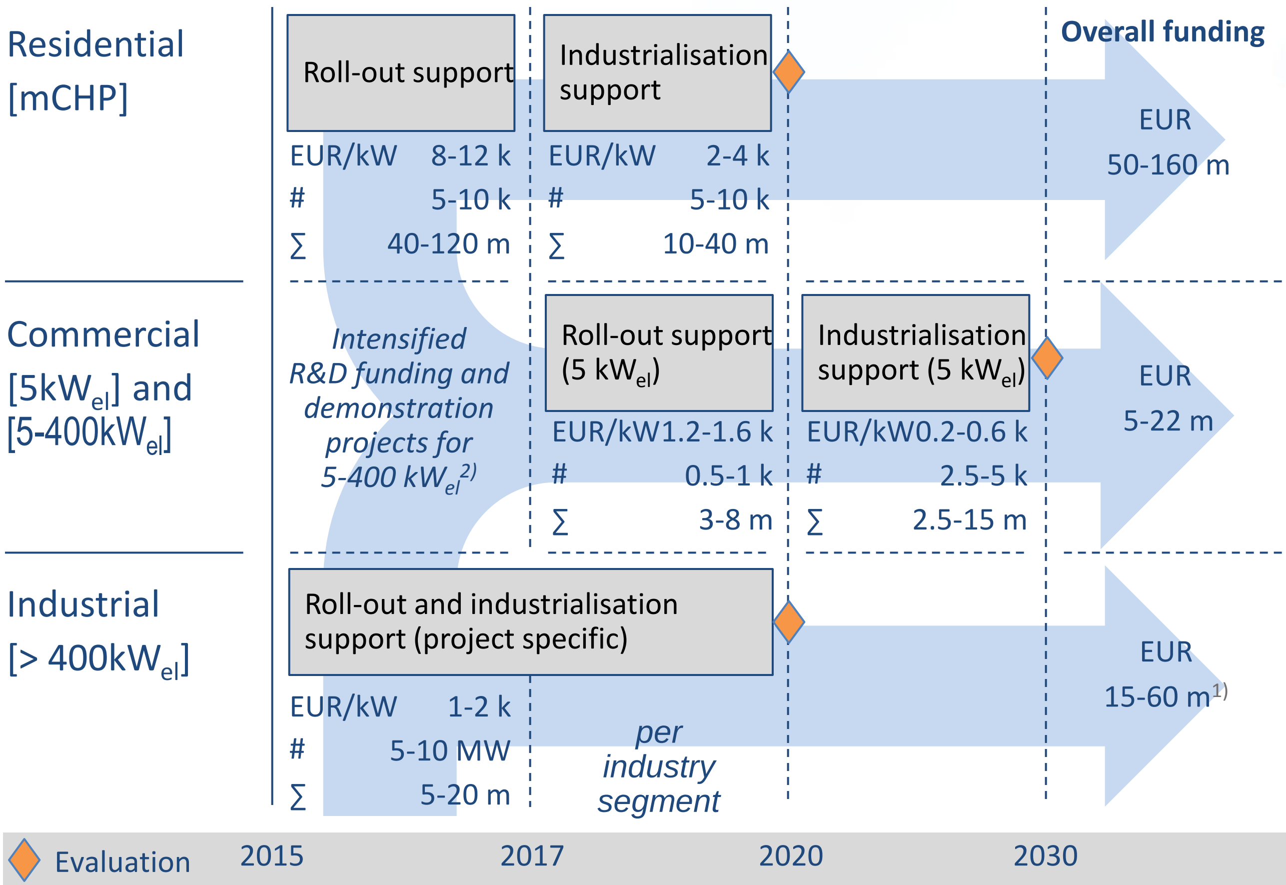
... to enable industry actions

- > **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

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

Proposed <u>minimum</u> funding framework for initial commercialisation in the focus markets



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

Source: FCH JU Coalition, Roland Berger

<u>**Rationale**</u>

- > 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**

European mCHP players anticipate different volume-driven levers for cost reduction along three main phases of the learning curve

Selected levers of volume-driven cost reduction for fuel cell module – Focus on mCHP[1)]

1 Standardisation (<500 units cum. per company)

- **Increasing batch sizes** to reduce set-up time, direct labour costs and energy use
- **Improving process capability** in cleaning, spraying and firing to reduce scrap rate;
- Adopting **basic automation of manually-intensive processes**
- Achieving **higher utilisation for equipment and material;**
- Implementing simple lean organisation of **work flows**
- Increasing **sourcing of specific BoP-components**
- Developing **low-volume tooling**
- Simplifying **quality control**

2 Industrialisation (<10,000 units cum. per company)

- **Part automation of stack production** and assembly process (e.g. automatic loading cartridges);
- More competitive **sourcing of stack materials** (e.g. steel, ceramics)
- **Shorter TAKT time with faster lines**
- **Larger batch sizes** – esp. for energy-intensive processes like firing
- **Automation and serial tooling for manufacturing bespoke items** (e.g. heat exchanger, hot-box metal work)
- Transition from special to **standard specification parts** (e.g. for pumps and sensors)
- Competitive **sourcing of (semi-) standard components**
- **Semi-automated end-of-line testing**

3 Mass market production (>10,000 units cum. per company)

- Move to **completely automatic manufacturing** with removal of nearly all bar essential manual handling
- **Single-piece process flows** to increase Overall Equipment Effectiveness and reduce set-ups
- Improved **production methods** (e.g. high-speed steel forming)
- **Automated manufacturing and tooling for added-system**
- Full transition to **tiered supply chain**
- Implementation of **low-cost BoP designs for high-volume production**
- **All-out competitive sourcing**, even outsourcing to low-cost countries
- **Fully automated end-of-line testing**

1) Particular focus on European stack producers and system developers (esp. SOFC-based)

Source: FCH JU Coalition, Roland Berger

Given different maturities of FC segments, policy support should be tailored – Focus on investment support and demo projects

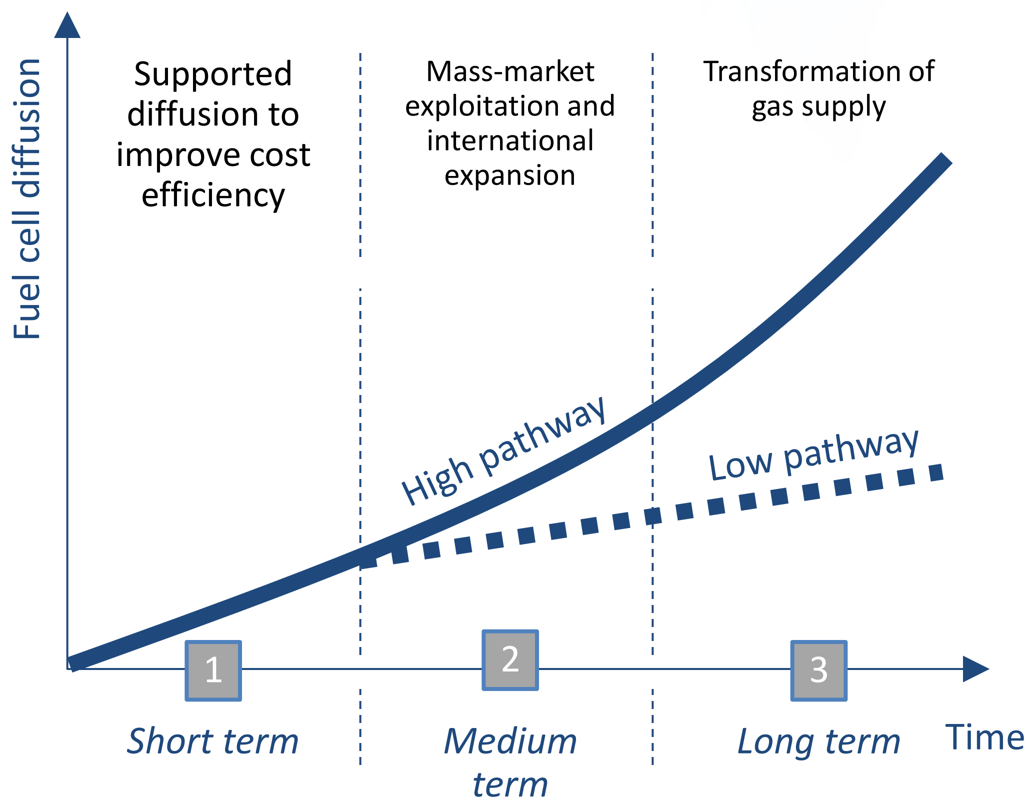
Segment-specific recommendations for implementation of policy measures

Segment	Recommendations
Residential segment	> Put in place **temporary mCHP subsidy scheme to enable learning and thus cost degression**; **eligibility for EU mCHPs**; binding cost targets as condition for continuation > Establish a **framework that allows power feed-in** > Commit **limited further funding to R&D on manufacturing methods, improving stack durability and robustness** > **Reform eco-labelling** to ensure a level-playing field in terms of comparing different heating solutions and thereby assure equal treatment of FC mCHPs
Commercial segment	> Commit **funding to development and demonstration projects** for FC CHPs (5-400kW) > Support **research and development for medium-range CHPs to enable technical readiness, esp. increasing electrical efficiency, improving fuel cell robustness, reducing stack degradation and raising durability**, developing complete heating solutions beyond FC as well as hybrid systems > Initiate **roundtables of value chain and Go-2-market players** to shape alliances for commercialisation > Put in place **temporary subsidy for CHPs in 5 kW_{el} niche** (upon successful completion of ene.field)
Industrial segment	> Put in place **a EU project-based support scheme targeting emissions savings in specific industrial use** cases (e.g. data centres, chemical, pharma); **eligibility for EU manufacturers**; binding emission targets and cost targets conditions for continuation; focus on cost reduction > Commit **further funding to research and development with particular focus on: cost reduction via scaling up production; improving stack durability and robustness**; genuine cost reduction by replacing precious metals > Keep **CHP production premiums and align with other regulation** (e.g. EEG reform in DE)

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

Next steps for transition to mass-market (after 2020)

Follow-up Study:
"Business Models for Fuel Cell Micro-CHP In the European Market"

Innovation in business models, including financing and leasing approaches

- Fuel cell systems will always be at a premium to already established technologies, such as condensing boilers, and thus novel financing models as used in other industries are essential for reaching the desired levels of market penetration

- Contributions from utilities, banks / leasing companies, service and installation contractors, regulators, fuel cell and system manufacturers and possibly smart grid players

Open Questions

What could be the help necessary at EU level ?

What can FCH JU offer through a coalition rather than individual company own choices ?

- Business models are normally tailored to the technology; which one(s) could work for micro-CHP fuel cells ?

- How well technology and policy risk can be managed, the strength of the partners selected, and how well the proposition is made to the customer ? (who is taking the technical risk if the product is not performing ? only replicate in regions with similar policy support? value in the business for all partners; give customers choice)

- Products with longer payback mean longer contracts needed with the customer – does that limit the market ? What about "bundling-renting" (and tailor marketing messages per countries and segments)?

- Would the model be only a "race-to-volumes" or also increase awareness and support to the existing channels or looking for environmental/social benefits? etc