Roland Berger | 50 navigating complexity

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

FCH Industrial use cases

FCH

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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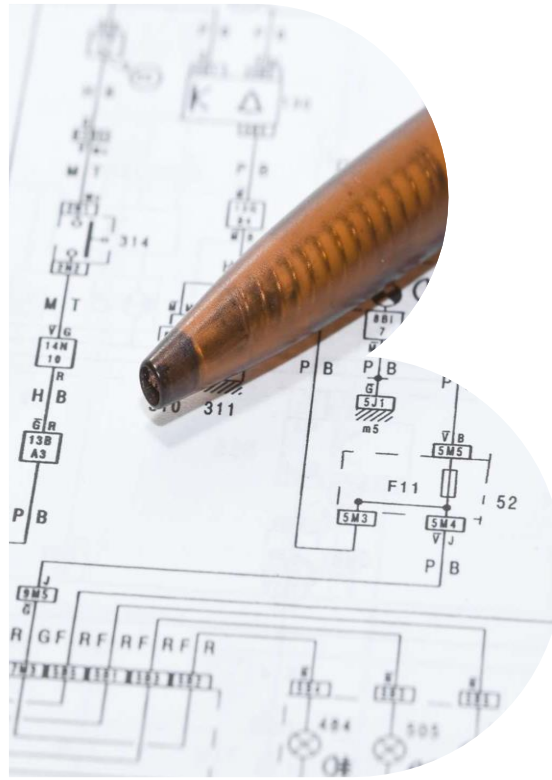


A. Technology Introduction

Large-scale fuel cells in the industrial segment typically service specific use cases with efficient, low-emission distributed energy

Fuel cells in industrial and other large-scale stationary use cases

Brief description: Stationary fuel cell plants in industrial use cases typically generate power or combined heat and power (CHP) at MW-scale by converting natural gas, biogas or compressed hydrogen (from a grid or locally available), e.g. for electricity- (and heat-)intensive industrial production processes

Use cases: Cities and regions can use/promote fuel cells in industrial use cases to reduce CO_2 emissions, pollutant emissions and primary energy consumption. Typical use cases are energy-intensive industries (chemical, pharma, food & beverage), wastewater treatment facilities, data centres

Fuel cells in industrial use cases[1]

Key components	Fuel cell stacks, system module, inverter, heat exchange, storage
Fuel cell technology	AFC, MCFC, SOFC, PAFC, PEM
Fuel	Primarily natural gas, but also biogas and hydrogen (if on site)
Efficiency	~50%$_{el}$, combined >80%
Output	typically > 400 kW$_{el}$, up to multi-MW$_{el}$
Approximate capital cost	dep. on use case and market environment, ca. EUR 4,000-5,000 per kW$_{el}$ (fully installed)
OEMs, system integrators	FuelCell Energy, AFC Energy – (Bloom Energy, Doosan, etc.)
Fuel cell suppliers	Nedstack, FuelCell Energy, AFC Energy (Bloom Energy, Doosan, etc.)
Typical customers	Utilities, ESCOs, energy-intensive industrial manufacturers, wastewater treatment operators, data centre operators, etc.
Competing technologies	Gas boilers + power grid, combustion engines, micro-turbines

1) Focus on European market

Source: Roland Berger

A

Readiness of FC in industrial use cases is increasing in Europe and catching up to North America and East Asia

Fuel cells in industrial and other large-scale stationary use cases

2/4

Overall technological readiness: Mature technological readiness as typical use cases (e.g. power generation, CHP) near commercialisation, growing number of demonstration projects and installations – market even more mature in North America and East Asia (more projects, more OEMs)

TRL* 1 Idea · 2 · 3 Tech. formulation · 4 · 5 · 6 Prototype · 7 · 8 · 9 Fully commercial (marker at 8)

Demonstration projects / deployment examples (selection)

Project	Country	Start	Scope	Project volume
Installation example of large scale fuel cell system at Friatec AG		2015	Deployment of 1.4 MW fuel cell system at production facility of Friatec AG meeting 60% of power need of manufacturing process	n.a.
Installation of SOFC fuel cells in Osaka wholesale market[1]		2015	Installation of 1.2 MW fuel cell system at Osaka Prefectural Central Wholesale Market supplying 50% of buildings energy needs, subsidised by Japan's Ministry of Environment	n.a.
Demonstration of large SOFC system fed with biogas from WWTP (DEMOSOFC)		2015	Large scale (3 x 50 kW_{el}) fuel cell CHP plant demonstration in using biogas from a wastewater treatment facility (no commercial building application as such, but relevant for this power range)	EUR 5.9 m
Demonstration of CHP 2 MW PEM fuel cell (DEMCOPEM)	 	2015	Design, construction and demonstration of 2 MW PEM fuel cell power plant to be integrated into a chlorine production plant, objective is to reach competitive electricity price until 2020	EUR 10.5 m
Demonstration of large scale alkaline fuel cell system (POWER-UP)		2013	Installation of 500 kW alkaline fuel cell system with heat capture to demonstrate automated and scaled up manufacturing capabilities of cost-effective industrial fuel cell components	EUR 11.5 m

1) From a use-case point of view, this could be considered as a commercial building FCH application as well. Listed here due to power output of 1.4 MW

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

Source: Roland Berger

Typically, specific industrial processes and less the power and heat requirements of the site itself create the use case for fuel cells

Fuel cells in industrial and other large-scale stationary use cases

Use case characteristics

Stakeholders involved

> OEMs of FC CHP systems, FC suppliers
> Project developers, plant engineers, installers
> Utilities, ESCOs, power/gas grid operators
> Industrial facility operators, e.g. chemical production or wastewater treatment

Demand and user profile

> Electricity- and/or heat-intensive industrial processes (usually high-temp. heat), relatively constant load
> On-site availability of fuel (e.g. biogas from anaerobic digesters, hydrogen as chemical byproduct) creating opportunity for distributed electricity / CHP generation

Deployment requirements

> Connection to the natural gas grid or on-site supply of biogas or hydrogen
> Sufficient space for distributed energy solution (suitable on-site energy system)

Key other aspects

> Different use cases have different technical requirements for FC systems – the industrial process individually determines the application of a stationary fuel cell

Benefit potential for regions and cities

Environmental

> Low emissions of pollutants and greenhouse gases (esp. CO_2) – significant reduction CO_2, virtual elimination of NO_x and SOx emissions, 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
> Enabler for more renewables in electricity mix with complementary role of distributed CHP to e.g. heat pumps

Economic

> With reduction of product cost and higher electrical efficiencies, TCO-competitiveness with other distributed energy solutions in reach – esp. in markets with high industrial electricity prices / spark spread (difference of gas and electricity prices)

Other

> Reduction of demand for centrally generated electricity
> Higher resilience against interruption of grid electricity supply

Source: Roland Berger

High initial investment cost still primary economic barrier to extensive commercialisation, technical improvements key as well

Fuel cells in industrial and other large-scale stationary use cases

Hot topics / critical issues / key challenges:

> Identification of promising early-stage use cases ("early adopters"), e.g. in advantageous policy and market environments (e.g. CHP support schemes, strict local NO_x emission limits)

> Further reduction of capital cost through economies of scale necessary for widespread adoption

> Further technical performance improvements, e.g. increasing electrical efficiency (possibly up to $60\%_{el}$) increasing the robustness and reliability of fuel cell stacks

> Lack of component standardisation along value chain, further efforts to modularise systems to maximise cost-down potential per kW installed

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

> DEMOSOFC project website

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

Large-scale stationary fuel could also be used to supply district heating grids – First demonstration projects in Asia

Excursus: large-scale stationary fuel cells for district heating

Brief description: Large scale (i.e. multi-MW) stationary fuel cell applications for combined heat and power generation (CHP) can be also used to supply local district heating networks; they are fuelled by natural gas and would typically use high-temp. MCFC or SOFC technology

TRL* 1 2 3 4 5 6 7 8 9 (marker at 7)
Idea, Tech. formulation, Prototype, Fully commercial

Use cases: Cities and regions can deploy or incentivise the deployment of large scale stationary fuel cells for existing or new local district heating networks – especially in urban areas with strict limits for local CO_2 and NO_x / SO_x emissions; they could replace large CHP gas engines or small gas turbines; operators would typically be municipal utilities or energy service companies

Existing deployment projects (selection)

Project/product	Country	Since	Specifications
Noeul Green Energy Plant		2017	A 20-MW MCFC fuel cell plant in Seoul, delivered by FuelCell Energy and POSCO Energy, owned and operated Korea Hydro & Nuclear Power (KHNP), supplying power for ca. 43,000 household to Korea Power Exchange and heat for ca. 9,000 households to Korea District Heating Co
Gyeonggi Green Energy Facility		2014	A 59-MW fuel cell park in Hwasung City, consisting of 21 2.8-MW MCFC stationary fuel cells; supplied by FuelCell Energy, owned and operated by POSCO Energy

For additional information, please contact our Roland Berger team directly

Source: Roland Berger

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

B. Preliminary Business Case

B

In industrial use cases, fuel cells can tap into the annual market for gas-fired on-site generation – several GW in core EU markets

Annually addressable market in four focus countries

Industrial

> **Fuel cell CHPs and prime power** in power ranges from ca. 400 kW_{el} and into the multi-MW range for industrial applications

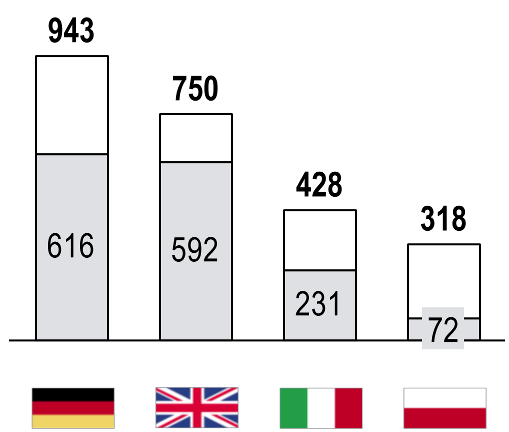
> **Primary markets** include gas-fired distributed generation

> **Conversion markets** comprise non-gas distributed generation

> Forecast based on expected market growth

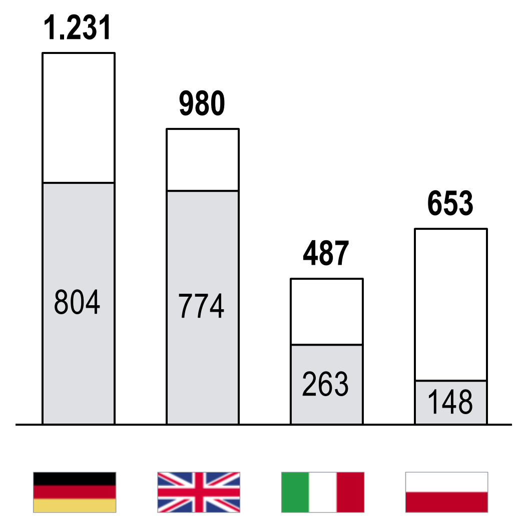
2012 addressable market

[MW]



2030 addressable market

[MW]



Conversion markets [installable capacity] Primary markets [installable capacity]

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

B

We consider three exemplary use cases for large-scale stationary fuel cells in MW-range: combined heat and power and power-only

Examples for industrial use cases (selection) – INDICATIVE

Use cases

- **Data center** with annual power demand of 8,000 MWh (fluctuation of 70-100%) and prime power technology installed, cooling is a major power consumption driver
- Max. necessary power load at ca. 1,000 kW_{el} with typically grid supply and closed, auxiliary power system, based on natural gas
- Connection to natural gas and electricity grid
- Technologies: Grid, FC (power-only or "prime power") with ca. 1.0 MW_{el}

- **Pharmaceutical production facility** with annual base load demand of ca. 11,600 MWh and equivalent heat demand, optimally served by a CHP system
- Max heat load ca. 1,100 kW_{th} and power load at ca. 1,400 kW_{el}
- Typically no relevant power fluctuation with natural gas as main fuel
- Connection to natural gas and electricity grid
- Technologies: Grid + boiler, ICE CHP, microturbine CHP, FC CHP with ca. 1.4 MW_{el}

- **Chemical production facility** with high thermal power demand of ca. 29,000 MWh p.a. and electric demand of ca. 12,000 MWh for industrial processes
- Assumed CHP technology with max. heat load of ca. 1,100 kW_{th} and power load at 1,400 kW_{el} based on natural gas
- Connection to natural gas and electricity grid, potential for on-site biogas supply
- Technologies: Grid + boiler, ICE CHP, microturbine CHP, FC CHP with ca. 1.4 MW_{el}

Typical exogenous assumptions

- **Cost of natural gas**: e.g. betw. 0.020 and 0.040 EUR/kWh
- **Cost of grid electricity**: e.g. betw. 0.055 and 0.145 EUR/kWh (key markets with highest industrial electricity markets are e.g. UK and Italy)
- **CO_2 intensity of natural gas**: 185 g/kWh (potentially decreasing)
- **CO_2 intensity of grid electricity**: e.g. on average ~500-550 g/kWh in many parts of continental Europe with high shares of coal-fired power generation, ~350 g/kWh in the UK (all gradually decreasing over the coming years)
- **CO_2 balancing method for CHP**: 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.)

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

B

Large-scale fuel cells face three main natural gas competitors – large boilers, CHP engines and CHP micro-turbines

Comparison of benchmark applications – INDICATIVE

current / potential	**Fuel Cell CHP** (FC CHP)	**FC Prime Power** (FC PP)	**Electricity grid + gas cond. boiler**	**Gas ICE CHP**	**Gas turbine CHP**
Technical specifications	Combined ca. 1.4 MW_{el} / ca. 1.1 MW_{th} nat. gas FC CHP system (SOFC, MCFC)	1.0 MW_{el}, typically low-temp. polymer electrolyte FC (PEM FC) or solid oxide FCs (SOFC)	State-of-the-art 1.5 MW_{th} gas condens. boiler	State-of-the-art 1.5 MW_{el} comb. engine	State-of-the-art 1.4 MW_{el}
CAPEX[1)]	EUR/kW_{el} ca. 3,200 – 3,400 / *2,900 – 3,100*	EUR/kW_{el} ca. 5,100 – 5,300 / 3,500 - 3,700	EUR/kW_{th} ca. 70-80	EUR/kW_{el} ca. 1,200-1,300	EUR/kW_{el} ca. 1,600-1,700
Heating fuel	Natural gas / biogas	Natural gas / biogas	Natural gas / biogas	Natural gas / biogas	Natural gas / biogas
Efficiency	49%$_{el}$, 31%$_{th}$ / *61%$_{el}$, 31%$_{th}$*	49%$_{el}$ / *61%$_{el}$*	95%$_{th}$	40%$_{el}$, 48%$_{th}$	28%$_{el}$, 50%$_{th}$
Lifetime	16 / *17* years with 3 / *3* fuel cell stack replacements	11 / 14 years with 3 / 3 FC stack replacements	Ca. 15 years	Ca. 15 years	Ca. 15 years
Maintenance	EUR/kW_{el} ca. 50 - 60 / *45 -55* p.a.	EUR/kW_{el} ca. 45 - 55 / 45 -55 p.a.	EUR/kW_{th} ca. 10-15 p.a.	EUR/kW_{el} ca. 90-110	EUR/kW_{el} ca. 65-75 p.a.
Other aspects	Power-driven system with base-load focus and >130°C temp. required for heat	Typically base-load and load-following operation with adaptable power output (through modulation)	n/a	n/a	n/a

1) Incl. installation and stack replacements as re-investments (e.g. Fuel Cell CHP short-term cost to be assumed at cost levels of 100 units per manufacturer, i.e. already significantly lower cost levels than actual current prices: system cost of 2,300 EUR/kW; installation cost 400 EUR/kW; stack replacement cost of 590 EUR/kW)

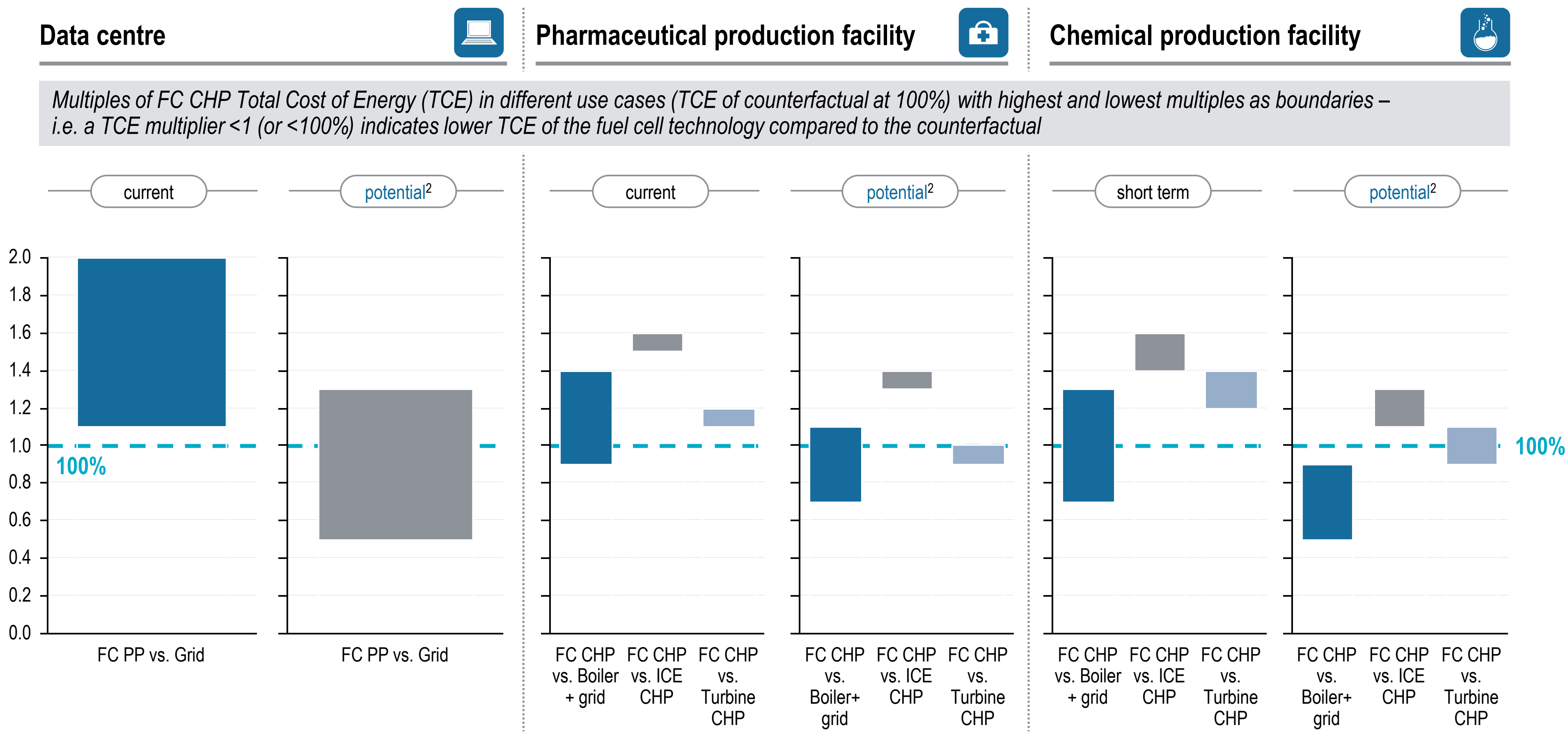
Source: FCH2 JU, Roland Berger

B

With growing production volumes over the long term, large scale FC CHPs can become competitive – much depends on the use case

Business case and performance overview[1] – INDICATIVE

Multiples of FC CHP Total Cost of Energy (TCE) in different use cases (TCE of counterfactual at 100%) with highest and lowest multiples as boundaries – i.e. a TCE multiplier <1 (or <100%) indicates lower TCE of the fuel cell technology compared to the counterfactual



1) Based on 3 use cases across 4 EU markets (DE, IT, PL, UK) as of 2015; ICE = gas-fuelled Internal Combustion Engine
2) Requiring significant volume increases, here up to 50 MW installed capacity per manufacturer
Source: FCH2 JU, Roland Berger

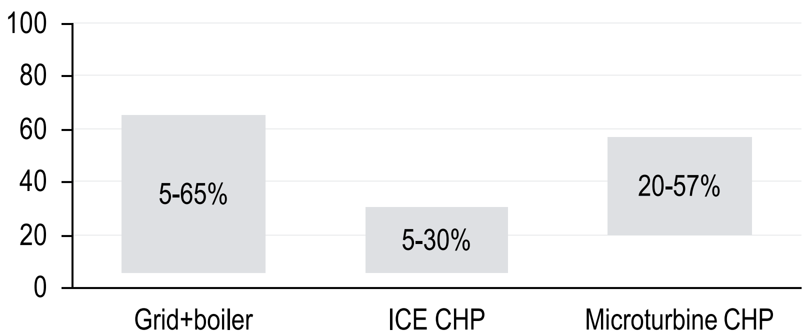
B

CO_2 savings well above 50% are possible thanks to highly efficient distributed generation, NO_x can be reduced significantly as well

Business case and performance overview[1]– INDICATIVE

Environmental

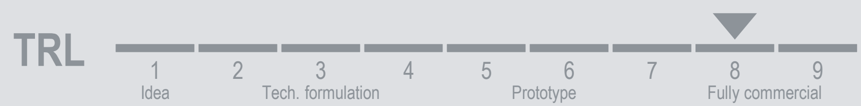
- > **Drastic reduction of local emissions of pollutants NO_x, SO_x, fine dust particles** – potentially significant benefit in urban areas, < 1 mg/Nm^3 for FC vs. < 250 mg/Nm^3 for lean-burn gas ICE (without external NO_x abatement technology)
- > **Significant CO_2 savings**; total attributable CO_2 emissions dep. on CO_2 intensity of electricity mix and gas grid and "accounting method" – CO_2 savings across different industrial use cases [%]:



- > **Outlook**: over the long term, the emissions performance will depend on the decarbonisation of the electricity and gas grids as well as increases in efficiency of FC CHPs

Technical/operational

- > Mature technological readiness as typical use cases (e.g. power generation, CHP) are near commercialisation, **growing number of demonstration projects and pre-commercial installations** – market even more mature in North America and East Asia (more projects, more OEMs)
- > Ready for deployment as industrial FC CHPs would **build on existing natural gas infrastructure or use fuel-supply on site (e.g. biogas, hydrogen)**
- > For FC CHP, **system lifetime are at par** with competing technologies such as ICE or micro-turbine CHPs
- > For any onsite generation, industrial sector primarily concerned with ensuring that its core business is not disrupted – **FC needs to operate seamlessly** with existing infrastructure and cause min. disruption to ongoing productivity



1) Based on 5 use cases across 4 EU markets (DE, IT, PL, UK) as of 2015; ICE = gas-fuelled Internal Combustion Engine
Source: FCH2 JU, Roland Berger

Strong business case (via lower CAPEX), higher efficiencies and innovative financing models (e.g. ESCo) are key success factors

Key performance determinants and success factors

Business case awareness – from CAPEX and TCO/TCE perspective
In industrial use cases, economics are virtually all that matter in the decision making process and decision makers look for payback periods (typically well below 5 years) – (1) creating the potential to sell on a TCO/TCE-based value proposition (i.e. significantly lower OPEX offsetting higher CAPEX) and (2) triggering the need to reduce cost (esp. CAPEX) sufficiently

Electrical efficiency
Potential increases in electrical efficiencies boost electricity production during CHP operations and hence reduce TCE (expected to grow to up 51% in future generation large scale FC CHPs, i.e. significantly more than large-scale ICE CHP at ca. 38-40% or micro gas-turbines at ca. 20-28%)

STRONG REGIONAL DIFFERENCES !

Business and financing models for market penetration
Industrial users are likely more open to alternative business models; CAPEX burdens can be more efficiently distributed. E.g., the ESCo ("Energy Service Company") model is a very relevant (esp. high electricity price) "beachhead" as the end-user is not exposed to any upfront capital cost (particularly advantageous against low payback thresholds). The ESCo model allows the end-user to save money right away – while all operational risks are with the ESCo

Competition from grid electricity supply
Grid parity is below 10 ct/kWh$_{el}$ in many places around Europe; moreover, mature competing distributed generation technologies are available. Esp. CAPEX have to be considerably reduced. High electricity prices and comparatively low gas prices support business case thanks to high electrical efficiency

Source: Delta EE, FCH2 JU, Roland Berger

Use case selection, (NO_x) emission limits and policy support are key commercialisation levers for Regions and Cities

Key considerations for regions and cities

Use cases: exposure to high electricity prices, possibly with on-site fuel supply

To reap benefits of large scale, highly efficient on-site generation with large-scale fuel cells, exposure to high electricity grid prices is a key driver; moreover, need for constant heat demand on-site that is supplied by FC CHP – e.g. in heat-intensive industries; also, on-site availability of (low carbon) fuel – e.g. biogas as byproduct – can render individual use cases even more attractive

Emissions: stricter limits on pollutant emissions (esp. NO_x) as opportunity for fuel cells

In the future, NO_x emission limits are likely to become more stringent, possibly much more so (e.g. European Commission's Medium Combustion Plant Directive (MCPD)) with current proposal of max. 95 mg/Nm^3 (at 15% O_2) will be applied to all new gas engine installations. Resulting need for NO_x abatement, improves the economic case for fuel cells (by improving the marginal capital and operating costs) over gas engines

Policy support: various possibilities for effective support

Given "total business case" or "project economics" logic of many industrial developers for on-site generation, various policy instruments can positively affect the business case – e.g. CHP generation premiums, feed-in tariffs, tax credits, subsidies, soft loans, etc.

Source: Delta EE, FCH2 JU, Roland Berger

Please do not hesitate to get in touch with us

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Source: FCH2 JU, Roland Berger