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

Off-grid power

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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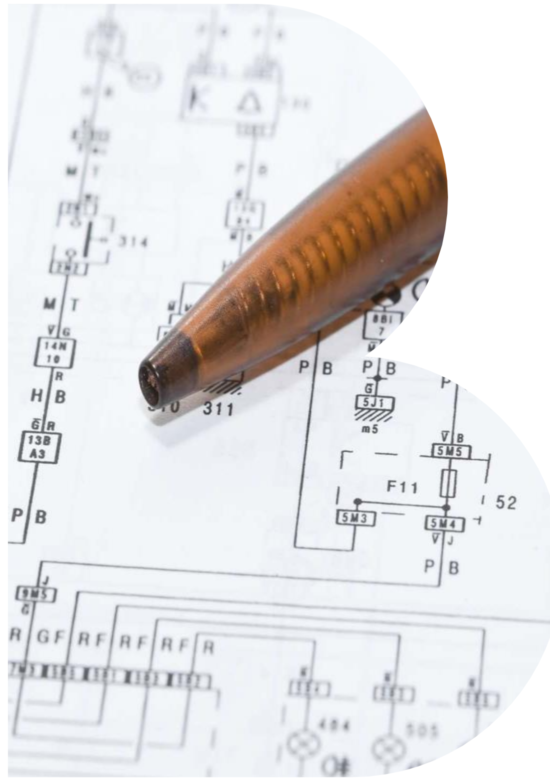
A. Technology Introduction



Fuel cells can act as a reliable, versatile and flexible off-grid power source in various remote areas

Fuel cell off-grid power / isolated microgrids

Brief description: stationary fuel cells for off-grid or isolated microgrids provide base-load (or backup) electricity from hydrogen (or hydrocarbons) via a fuel cel); fuel cells are frequently combined with electrolyzers for power-2-hydrogen from renewables – as integrated end-to-end off-grid solutions

Use cases: Cities and regions can promote stationary fuel cells for off-grid power supply e.g. on islands, alpine villages, otherwise remote settlements currently dep. on on-site generation from fossil fuels – alternative e.g. to diesel generators to reduce emissions and even complement renewable energy sources

Fuel cell powered off-grid power

Key components	Stationary fuel cell: fuel cell stacks, system module, hydrogen or other fuel tank, battery (possibly heat exchanger)
Fuel cell technology	PEM, SOFC, AFC
Fuel	Likely hydrogen (possibly also natural gas, biogas, LPG)
Electrical efficiency (net)	up to 50% (PEM) or even 60% (SOFC)
Output	typically 5 – 250 kW_{el}, (potentially combined to larger systems)
Approximate capital cost	*TBD* – current FCH2 JU objective 4,500 EUR/kW_{el}
OEMs	BOC, Young Brother, Toshiba , EPS, Green Hydrogen, Atawey
Fuel cell suppliers	Ballard, Hydrogenics, EPS, EWII, Proton Motor, Sunfire, ITM
Typical customers	Telecom providers, municipalities in remote areas (e.g. islands, alpine regions), remote industrial facilities
Competing technologies	Fossil-fuel generators with internal combustion engines

Source: Roland Berger

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Various demonstration projects are underway to show the viability of off-grid applications in varying environmental settings

Fuel cell off-grid power / isolated microgrids

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Overall technological readiness: Proven technology for stationary applications outside of Europe (key markets in North America and East Asia), European segment in advanced-prototype/demonstration phase with commercial viability being demonstrated in ongoing projects

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

Demonstration projects / deployment examples (selection)

Project	Country	Start	Scope	Project volume
Demonstration of fuel cell-based energy solutions for off-grid remote areas		2017	Demonstration of technical and economic viability of fuel cell technologies generating electrical energy in off-grid or isolated micro-grid areas	*TBD*
Electrolyzers for operation with off-grid renewable installations (ELY4OFF)		2016	Demonstration of autonomous off-grid fuel cell systems as energy storage or back-up solutions to replace diesel engines (50 kW PEM electrolyser to work along existing renewable electricity, H_2-storage and stationary fuel cell)	EUR 2.3 m
Micro-CHP FC system for off-grid (FLUIDCELL)		2014	Proof of concept and validation of advanced high performance micro-CHP fuel cell system for decentralised off-grid operation	EUR 4.2 m
Integrated Off-Grid Generator Application in remote, extreme-temp environment		n/a	Installation of an off-grid power generator field application of ~4 kW CHP SOFC system by Sunfire for power supply along natural gas pipelines (Ural Mountains)	EUR 4.2 m

Products / systems available (selection)

Name	OEM	Product features	Country	Since	Cost
Hymera	BOC	PEM fuel cell generator capable of delivering 150 W of electrical power, hydrogen is delivered in standard steel cylinders		n.a.	n.a.
H2One	Toshiba	Hydrogen-based autonomous off-grid energy supply system with use cases ranging from power supply to load management		n.a.	n.a.

Source: Roland Berger *) Technology Readiness Level ≤ 5 6-7 8-9

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Besides proving operability under all weather conditions, the modular design allows for flexible scalability of electrical output

Fuel cell off-grid power / isolated microgrids

Use case characteristics

Stakeholders involved

- Municipal authorities and utilities in remote areas such as islands or alpine regions
- Industrial sites with limited access to grid power, telco operators

Demand and user profile

- Base-load power supply
- Backup power supply, especially when combined with on-site hydrogen supply from renewables via electrolyzer

Deployment requirements

- Hydrogen production, delivery and on-site storage – potentially critical for remote areas
- Combination with on-site hydrogen production (e.g. water electrolysis from renewables)

Key other aspects

- Operation under all weather conditions possible for most fuel cells, e.g. incl. self-start in low temperatures

Benefit potential for regions and cities

Environmental

- Zero local emissions of pollutants (esp. NO_x) and greenhouse gases (esp. CO_2)
- Low noise pollution due to almost silent operation

Social

- Reliable power supply in remote areas
- Additional security of power supply for critical industrial processes

Economic

- Low operating cost through long lifetime and minimal need for regular/predictive maintenance visits – long-term potential for TCO below diesel generators
- Potential cost benefit compared to grid connection or grid expansion

Other

- Modular scalability ensures flexible adaptation according to demand

Source: Roland Berger

Overcoming the lack of hydrogen infrastructure/supply in remote areas is potentially the biggest implementation challenge

Fuel cell off-grid power / isolated microgrids

Hot topics / critical issues / key challenges:

> Lack of hydrogen infrastructure/supply in remote areas – hydrogen has to be delivered (e.g. trucked) or produced on site (or other fuels have to be made available on site, e.g. natural gas along pipelines)

> Further reduction of capital cost through economies of scale necessary for large scale implementation of off-grid power systems

> Lack of component standardisation within value chain (similar for a number of stationary fuel cells)

> Limited EU-wide rules and standards for hydrogen storage and transport in order to safeguard quality requirements

Further recommended reading:

> Hydrogen and fuel cells for communities: https://www.ika.rwth-aachen.de/r2h/images/b/b1/HC_HandbookVolA150.pdf

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

Hydrogen fuel cells for off-grid solutions possess numerous advantages compared to conventional Diesel-powered generators

Benefits of FCH off-grid applications

- (Theoretical) possibility of full zero-carbon energy autarky in combination with renewable energy sources, electrolyser and storage system
- Higher operating efficiency (combustion and storage) and extended runtimes, compared to conventional technologies
- High reliability even under extreme climate conditions and seasonal variations
- Environmentally friendly (zero emissions, less regulatory problems or permitting hurdles in environmentally protected areas)
- Low maintenance frequency and thus low maintenance cost
- High flexibility and adaptability to power demand changes

Source: Roland Berger

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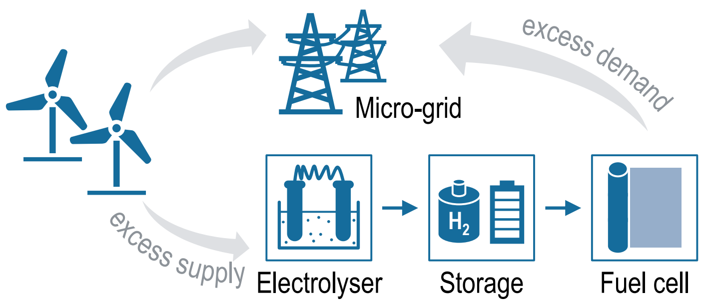
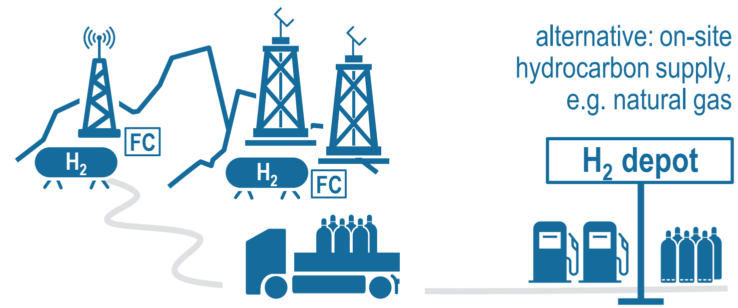
Off-grid applications of stationary fuel cells can be segmented into two broader categories of use cases

Categories of use cases for off-grid fuel cell solutions – SCHEMATIC

	1. End-to-End FCH system	2. FC with external fuel supply
Layout		

	1. End-to-End FCH system	2. FC with external fuel supply
Use cases (examples)	Stand-alone settlements in remote areas such as islands, mountain refuges, industrial sites, mining facilities, telco infrastructure, micro-grids/self-sufficient communities	Telco infrastructure (e.g antennas), television and radio repeaters, natural gas pipeline systems, remote residential areas
Alternatives	Renewable energy sources in combination with fossil-fuel generators and/or batteries	Fossil fuel generators (usually diesel, but also LPG, CNG, gasoline), possibly renewable energy sources in combination with batteries
Requirements/ Operating Model	Power range: several kW – up to multiple MW Fuel cells provide complementary power from green H_2 produced by electrolyser from renewable electricity	Power range: >1-2 kW Typically continuous supply of baseload power, fuelled e.g. with externally supplied H_2
Challenges	Demand and supply fluctuations (renewables), high setup cost, reliability of overall system	Dependency on fuel prices, accessibility / fuel supply routes, high setup cost, reliability of overall system

Source: Roland Berger

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As off-grid solutions, stationary fuel cells typically face the conventional competitor of fossil fuel (Diesel) generators

Comparison of fuel cells and diesel generators (e.g. use case #2) – INDICATIVE

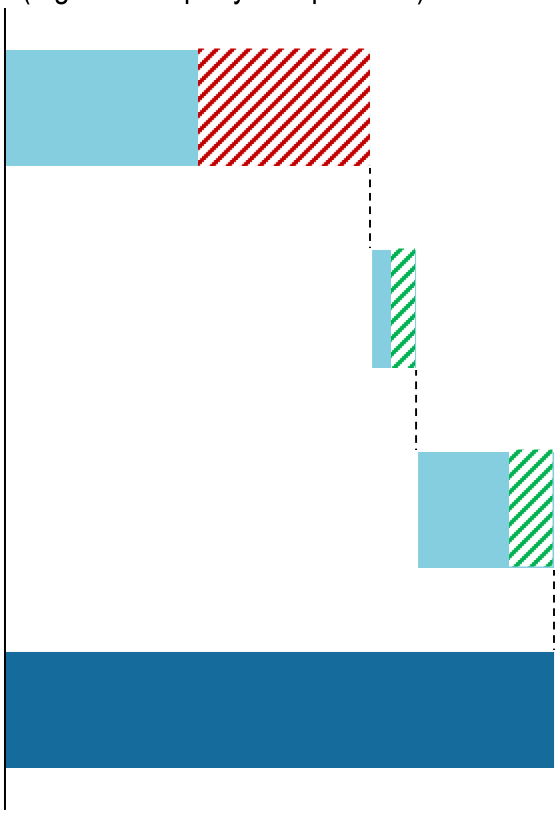
	Stationary fuel cell system (power-only or CHP)	**Diesel generator system** Reference model: CAT C4.4
Technical specifications	Combined ca. 50-100 kW$_{el}$ FC power-only or CHP potentially combined with other added systems like heat storages (if warranted by use case)  	72kW (prime) to 80kW (standby), 4-stroke Diesel engine, 230-480V, 50/60Hz @1,500/1,800 RPM  
CAPEX	Ca. 3,000-4,000 EUR/KW$_{el}$ (fuel cell module)	Ca. 800-1,000 EUR/kW$_{el}$
Fuel	Hydrogen, natural gas, LPG/CNG, biogas, etc.	Diesel fuel (tank capacity e.g. >200 litres)
Efficiency	50-60%$_{el}$, 30-40%$_{th}$	30%$_{el}$
Lifetime	Dep. on use case and target operating model	20-25 years
Maintenance	ca. 40 EUR/kW/a (or even lower)	ca. 40 EUR/kW/a
Other aspects	Several fuel cell technologies generally available (e.g. PEM, SOFC) – dep. on fuel availability, operating model, load profiles and other use case requirements	Mature technology available from a range of suppliers, engine can (in principles) be overloaded (e.g. to 110%)

Source: Shell, CAT, FCH2 JU, Roland Berger

TCO for both technologies have common drivers but heavily depend on the individual use cases – Fuel cells can compete in the long run

Schematic outline of technology-specific TCO for use case #2 – SIMPLIFIED

Total Cost of Ownership (TCO)
(e.g. in EUR per year / per kWh)



	Stationary fuel cell system	**Diesel generator system**
Capital cost	> Higher cost per kW installed > Higher development and permitting cost	> Lower cost per kW installed > Maturity level reached, low development cost
Op's & Maint.	> Less frequent maintenance routine > Lower overall maintenance cost	> Higher maintenance frequency, more need for spare parts > Higher overall maintenance cost
Fuel cost	> Higher efficiency, possibly more expensive fuel prices (external delivery), high delivery cost of H_2 > Likely lower overall fuel cost	> Lower efficiency, potentially lower fuel prices, high delivery cost > Likely higher overall fuel cost

Take-away Currently, the high capital costs make fuel cells the more expensive alternative. However, further performance improvements and cost reductions can lead to a better cost position than conventional fossil fuel generators in the future

Source: Roland Berger, Shell

Additional **cost** for fuel cell

Additional **savings** through fuel cell

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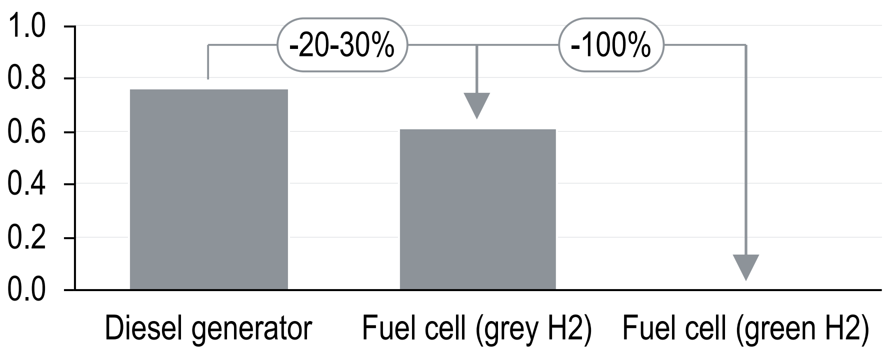
Large CO_2 savings are possible for FCs with low-carbon fuel; commercial readiness is relatively advanced

Business case and performance overview – INDICATIVE

Environmental

> **Drastic reduction of local emissions of pollutants NO_x, SO_x, fine dust particles** – potentially significant benefit in remote areas that may be under conservation

> **Significant CO_2 savings**; total attributable CO_2 emissions dep. on CO_2 intensity of supplied hydrogen (grey vs. green):



> **Outlook**: over the long term, the emissions performance will depend on the share of green hydrogen used and the amount of CO_2 emitted by delivery logistics to the site

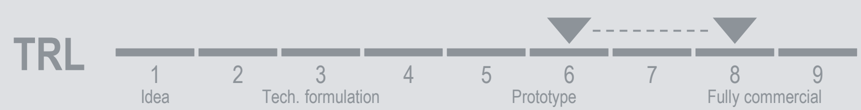
Technical/operational

> **Proven technology** for stationary applications outside of Europe (key markets in North America and East Asia), European segment in advanced-prototype/demonstration phase with **commercial viability** being demonstrated in **ongoing projects**

> Ready for deployment as fuel cells provide necessary **reliability for off-grid applications**, require infrequent maintenance and **fuel supply** can be assured in multiple conceivable scenarios

> For FC CHP, **system lifetime** is **slightly below** lifetime of Diesel generators

> Modular scalability ensures flexible adaptation according to demand



Source: FCH2 JU, Roland Berger

Please do not hesitate to get in touch with us

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Source: FCH2 JU, Roland Berger