The Carbon Trust Polymer Fuel Cells Challenge

Baseline Fuel Cell Systems Cost Analysis:
Methodology and High Level Results

Carbon Trust

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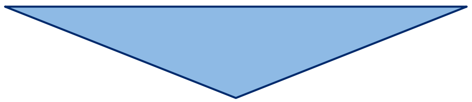
Contents

Background to the Polymer Fuel Cells Challenge (PFCC)

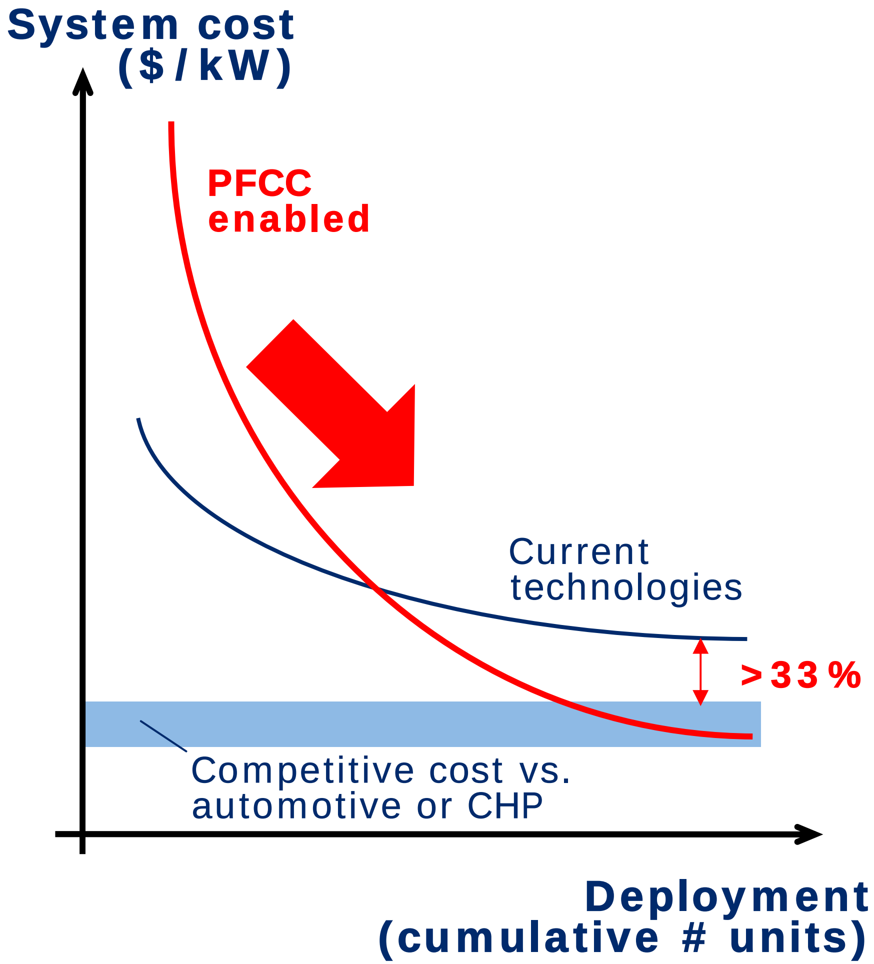
- The Carbon Trust first considered a Directed Research programme on Fuel Cell technology in 2008
  - Led an extensive opportunity review identifying polymer electrolyte fuel cells as a possible intervention area
  - Organised an event in late 2008 to consult the UK polymer fuel cell community and assess both capacity and willingness to take part
- The Polymer Fuel Cells Challenge was designed through 2009
  - Further assessment and interview campaign to design the most relevant programme
  - Design of a **Cost, Market and Carbon** modelling tool
- The model is designed to
  - Assess the impact of breakthrough technologies on polymer fuel cell **system costs**
  - Project the potential **market penetration** achievable with these cost reductions in a range of product applications, and the resulting **carbon savings**

Cost breakthroughs are necessary for mass markets

- Models were needed to help assess costs and their implications
- The models are designed to
  - Assess the **system and lifecycle cost** of representative
    - state of the art systems
    - breakthrough cell technologies
  - Project the potential **market penetration** achievable with these cost reductions in a range of product applications, and the resulting **carbon savings**



- Current technology may not be sufficient to access mass markets
- System level cost reductions of about 1/3 could unlock mass markets (worth up to $180bn worldwide in 2050)
- Breakthrough technologies could deliver these cost reductions



The Polymer Fuel Cells Challenge (PFCC)

- The Carbon Trust launched the **Polymer Fuel Cells Challenge** on 30th September 2009
- The PFCC aims to accelerate the commercialisation of breakthrough polymer fuel cell technologies which enable this step-change in cost of ~1/3 at high volumes
- The PFCC represents a 4-5 year programme in 2 phases with a total investment of up to £8 million from the Carbon Trust and an overall budget of up to £11-12m
- For more information visit www.carbontrust.co.uk/fuelcells

Contents

Methodology

- This presentation introduces the Cost Analysis used in the Carbon Trust's models
- The Cost Analysis tools were developed for the Carbon Trust by Austin Power Engineering with E4tech
- The model is based on a bottom-up approach, tried and tested for modelling undertaken for the US Department of Energy (DoE)
- 3 representative systems were considered in detail for specific product applications:
  - Transport (automotive)
  - Stationary Combined Heat and Power (CHP)
  - Portable / backup power

Cost modelling approach

- **Detailed bottom-up cost modelling has been carried out to illustrate the impact of technology breakthroughs:**

- A bottom-up approach was used for major cost contributors & critical processes:
  - Design system configurations
  - Build up Bill of Materials
  - Develop the manufacturing process flow
  - Assess the costs in all categories, such as material, labour, equipment and tooling, utility, maintenance, capital, etc.

- An 'experience based' methodology was used for less important cost contributors (e.g. sensors, motors etc) or standard off-the-shelf components:
  - Based on "learning curves" and/or comparison with similar products
  - Quotations from vendors
  - Scale high volume prices based on low volume retail or catalogue prices

- Costs were modelled for three production scenarios:
  - Pilot Plant
  - Semi-Scaled
  - Mass production

8

Disclaimers

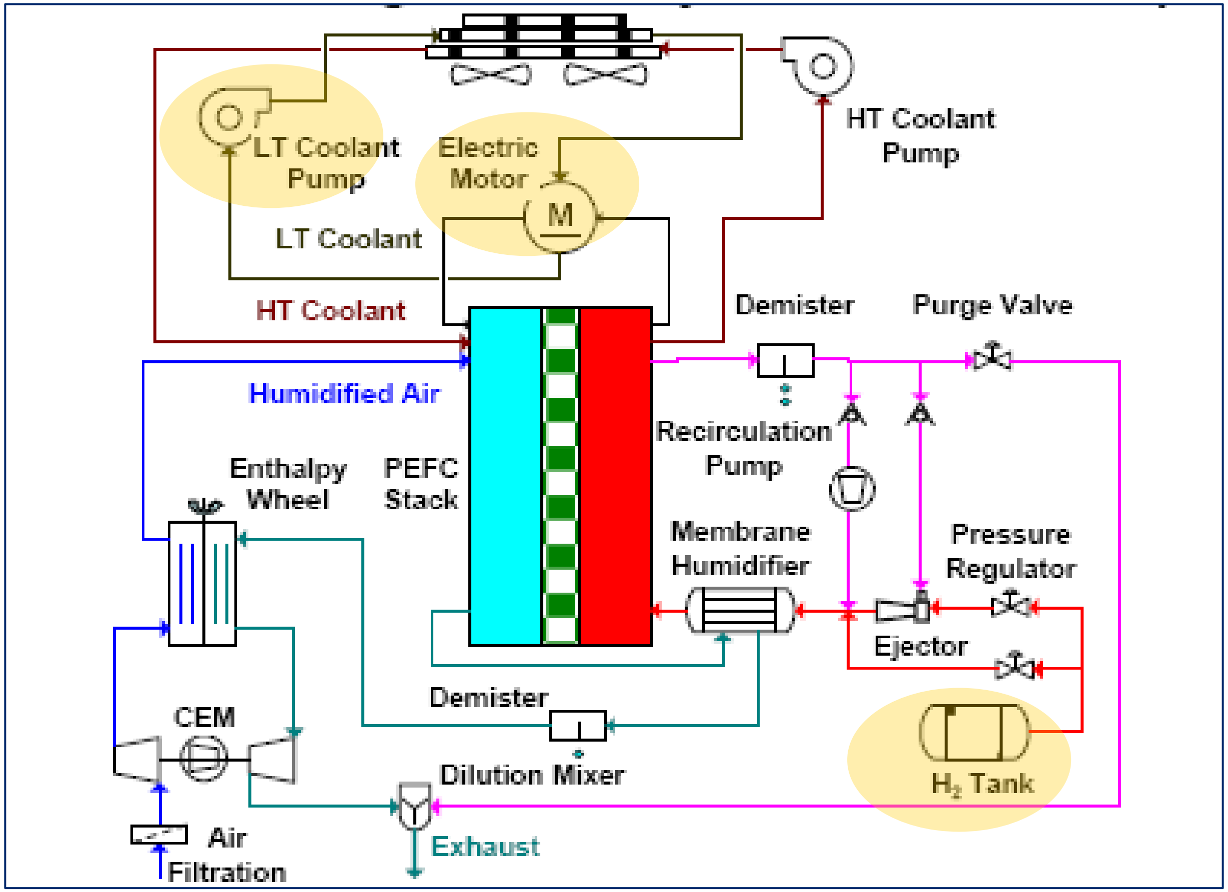
- The models presented here are indicative
  - They are based on assumptions which, to the best of our knowledge, represent credible technology options if current systems were to be manufactured at high volume
  - They do not claim any superiority of the technology choices presented here over other state-of-the-art systems which could be equally valid benchmarks
- The systems chosen are representative
  - With limited time and resources, we narrowed down the study to 3 systems which could be used as platforms to describe related systems (e.g., scaled up or down)
  - These choices do not purport any wider opinion on the future commercial or technical viability or maturity of particular technology options or product applications
- The model is not static and can readily evolve
  - It is flexible to allow the simulation of other systems, and forthcoming breakthroughs
  - It will be improved and refined over time as our understanding develops
- The output costs are not today's street prices
  - The costs calculated at high production volumes are extrapolated beyond current commercially available volumes and therefore do not represent commercial prices

Contents

- Introduction and Rationale
- Cost Modelling Methodology
- System configurations and model results
  - Transport
  - CHP
  - Portable

Transportation: system configuration

- **The baseline system configuration is based on the Argonne National Laboratory (ANL) 2008 PEM fuel cell system for the US Department of Energy (DOE)[1]**



Components not included in the system

[1] Fuel Cell Systems Analysis, R. Ahluwalia, DOE Hydrogen Program Review, Arlington, 2008, http://www.hydrogen.energy.gov/annual_review08_fuelcells.html#analysis

Transportation: key parameters

- The baseline model is an 80 kW_{net} pressurised PEM fuel cell system for transportation[1].

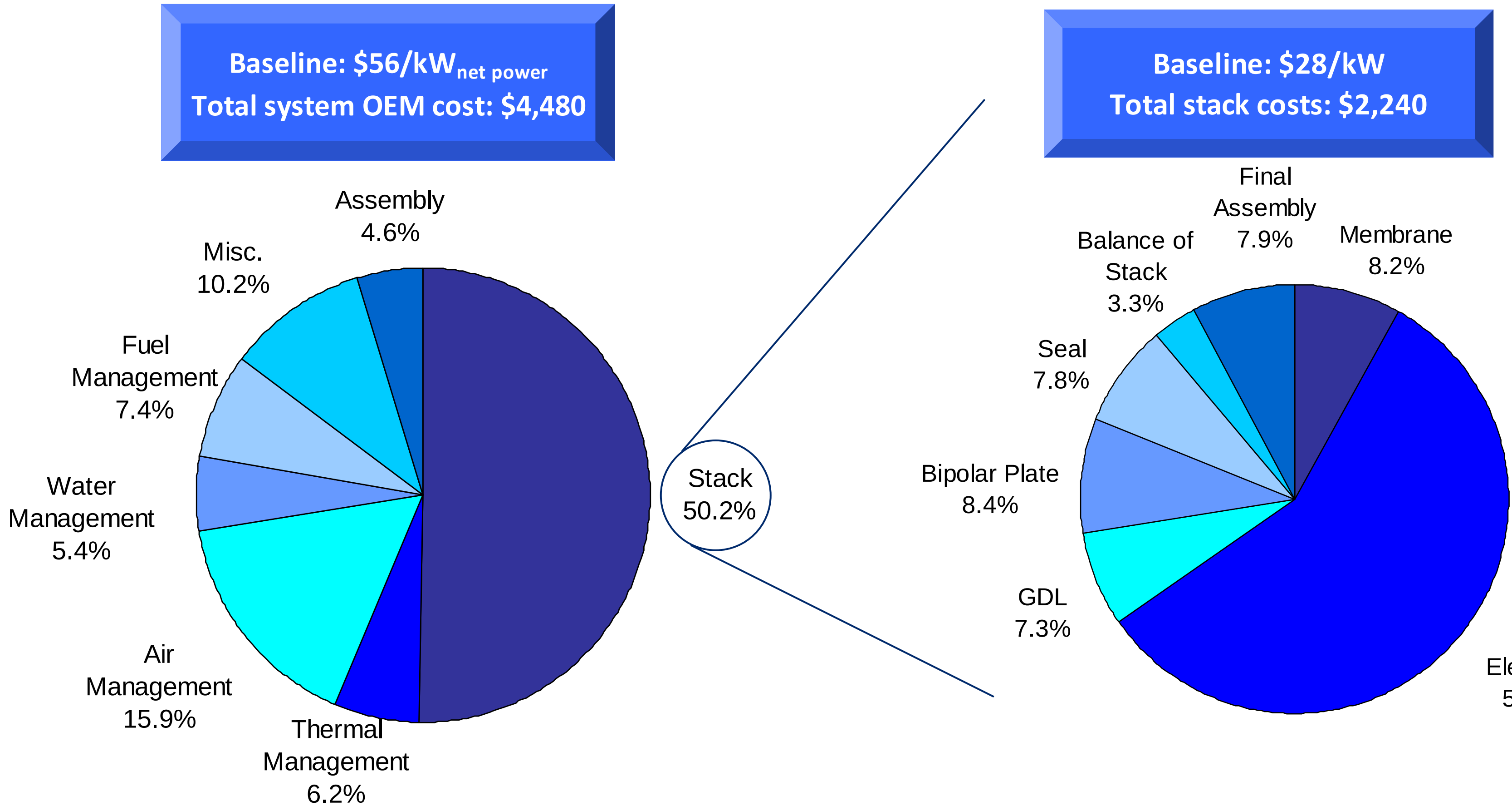
Stack Parameters	Value
System $Power_{net}$	80 kW
System $Power_{gross}$	86.9 kW
System Pressure	2.5 Bar
# of stacks x cells	2 x 219
Power Density	716 mW/cm^2
Cell Voltage	0.685 V
Membrane	PSFA 90 °C, 30 µm
Catalyst	Pt Alloy, Loading: 0.25 mg/cm^2
GDL	275 µm, woven carbon fiber
Bipolar Plate	2 mm expanded graphite, each with cooling channels
Cell Pitch	10 cells/inch

BOP Subsystem	Major Components
Water Management	Enthalpy Wheel Humidifier (air)
	Membrane Humidifier (H_2)
Thermal Management	HT Radiator
	LT Radiator
	Cooling Fan
	Water Pump
Air Management	Compressor Expander Module (CEM)
Fuel Management	H2 Blower
	Ejector

Production Parameters	Value
Pt price ($/tr oz)	1100
# units/year	500,000

[1] Fuel Cell Systems Analysis, R. Ahluwalia, DOE Hydrogen Program Review, Arlington, 2008, http://www.hydrogen.energy.gov/annual_review08_fuelcells.html#analysis

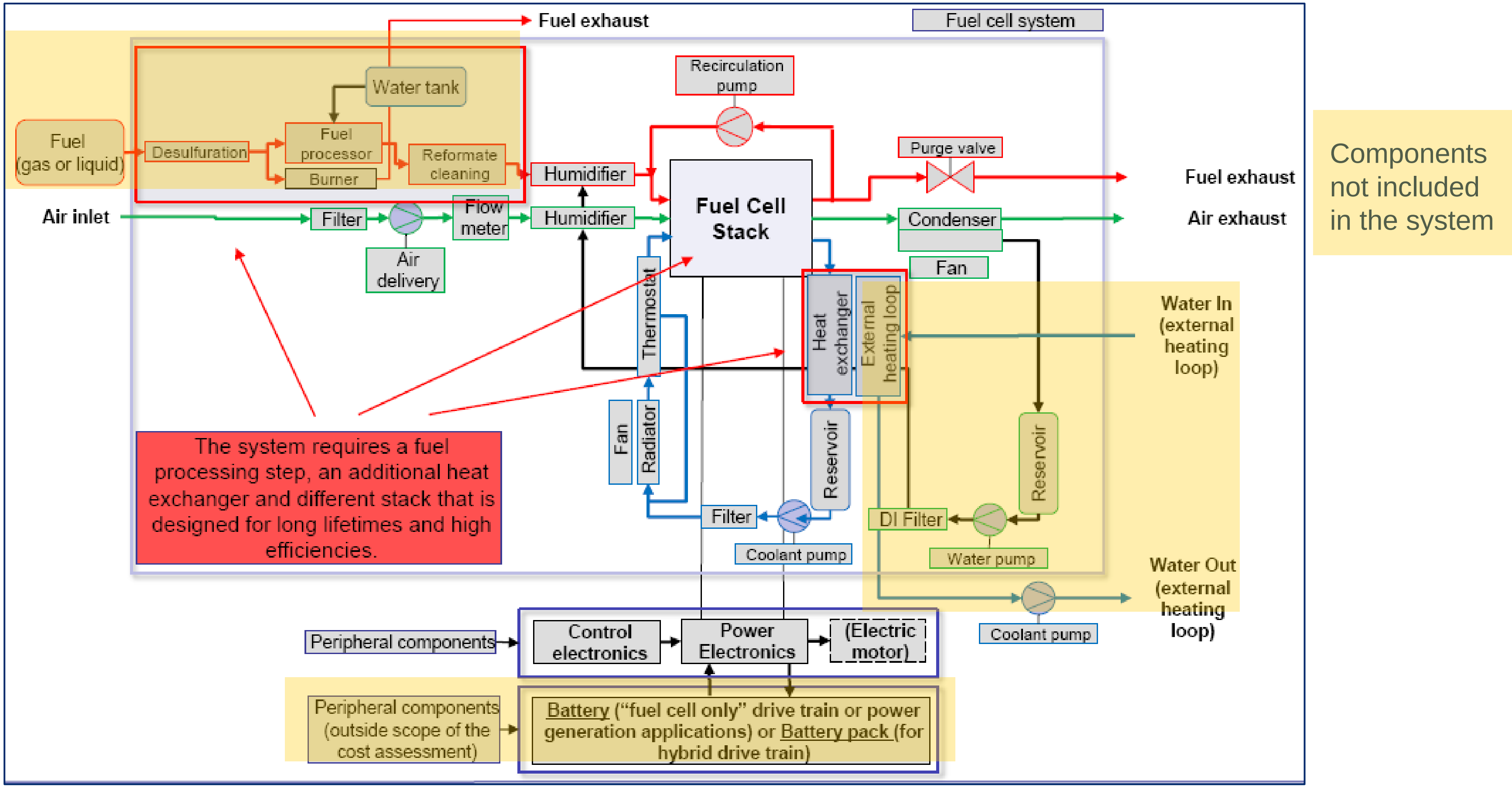
Transportation model results



80 kW_{net} PEM Fuel Cell Stack and System costs (System does not include hydrogen storage)

Stationary CHP: system configuration

- The following baseline system configuration represents a typical reformate-based stationary CHP fuel cell system[1].



[1] E4tech reference

Stationary CHP: key parameters

The baseline model is a 10 kW_{net} pressurised PEM fuel cell system for stationary CHP[1, 2].

Stack Parameters	Value
System $Power_{net}$	10 kW
System $Power_{gross}$	10.5 KW
Durability	40,000 hours
Electrical Energy Efficiency @ Rated Power[3]	35%
CHP Energy Efficiency @ Rated Power[4]	80%
System Pressure	2.5 Bar
# of cells	316
Power Density	210 mW/cm^2
Cell Voltage	0.7 V
Membrane	PSFA 90 ^oC, 30 µm
Catalyst	Pt Alloy, Loading: 0.6 mg/cm^2
GDL	275 µm, woven carbon fiber
Bipolar Plate	2 mm expanded graphite, each with cooling channels
Cell Pitch	10 cells/inch

BOP Subsystem	Major Components
Water Management	Enthalpy Wheel Humidifier (air)
	Membrane Humidifier (H_2)
Thermal Management	HT Radiator
	Cooling Fan
	Water Pump
Air Management	Compressor
Fuel Management	H2 Blower

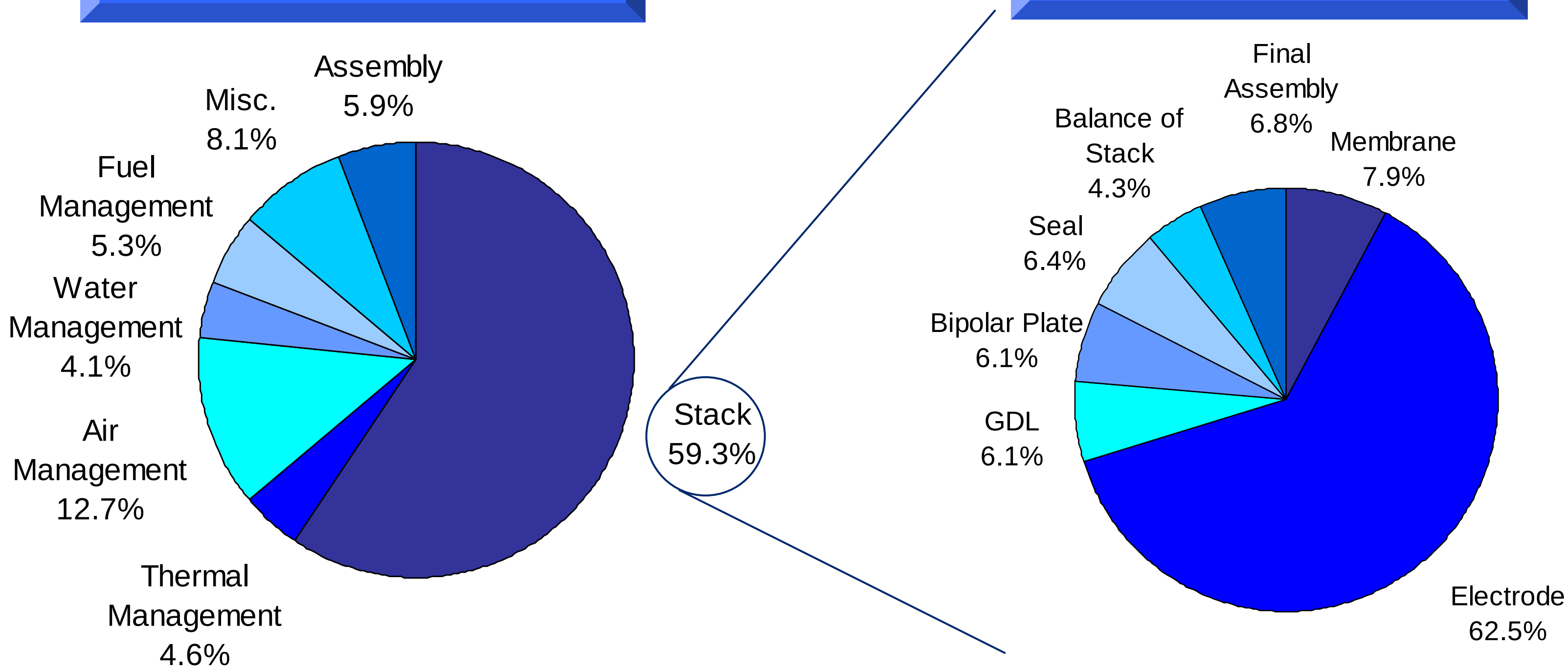
Production Parameters	Value
Pt price ($/tr oz)	1100
# units/year	50,000

[1] Fuel Cell Systems Analysis, R. Ahluwalia, DOE Hydrogen Program Review, Arlington, 2008, http://www.hydrogen.energy.gov/annual_review08_fuelcells.html#analysis
[2] Technical Plan – Fuel cell, DOE, 2007
[3] Ratio of DC output energy to the LHV of the input fuel (natural gas or LPG) average value at rated power over life of power plant.
[4] Ratio of DC output energy plus recovered thermal energy to the LHV of the input fuel (natural gas or LPG) average value at rated power over life of power plant

Stationary CHP model results

Baseline: $325/kW$_{net\ power}$
Total system OEM cost: $3,250

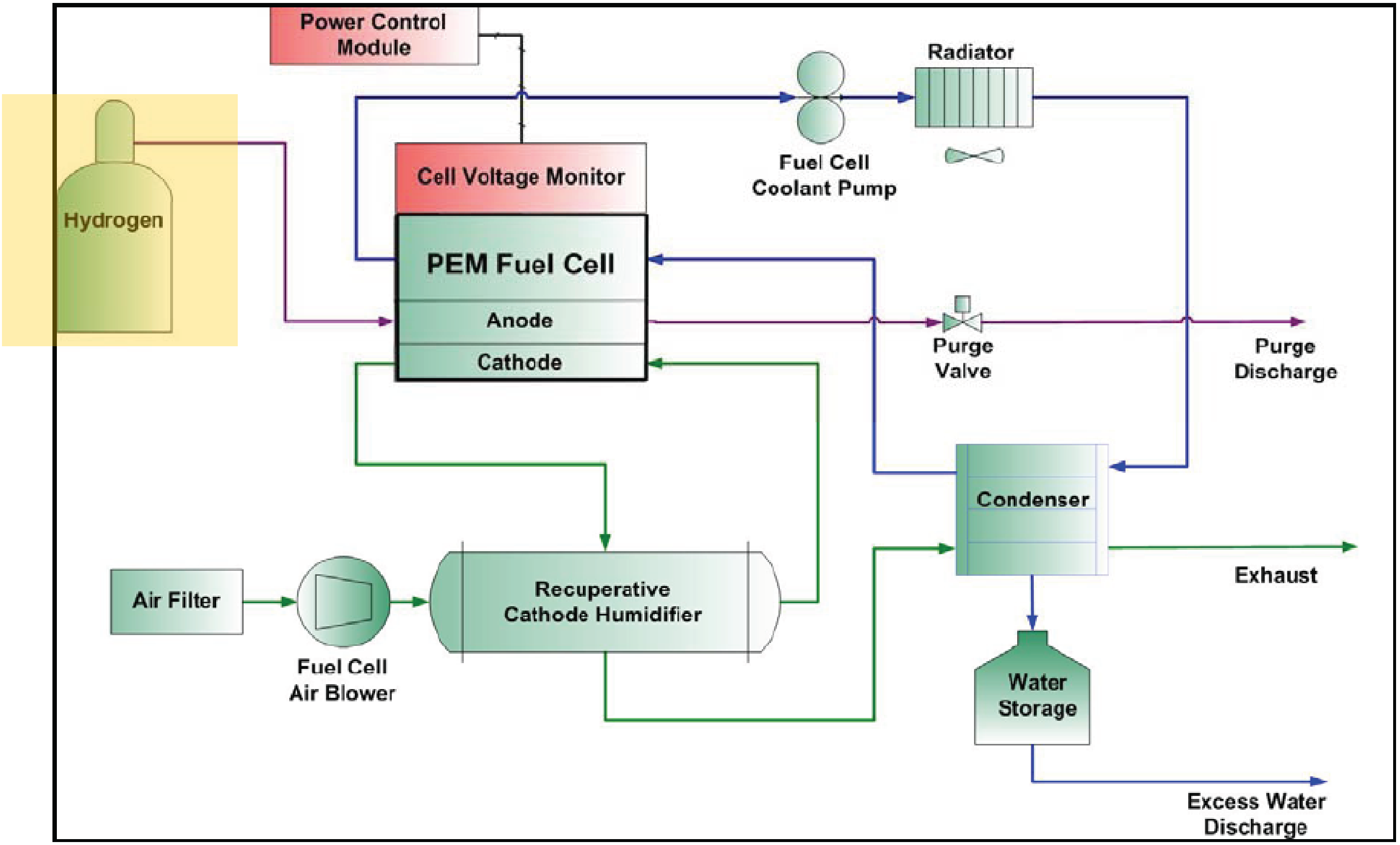
Baseline: $193/kW
Total stack cost: $1,930



10 kW$_{net}$ PEM Fuel Cell Stack and System costs
(System does not include reformer)

Portable power: system configuration

- The baseline system configuration is based on Battelle 2005 stationary PEM fuel cell system for the Department of Energy (DOE)[1].



Components not included in the system

[1] Economic analysis of stationary PEM fuel cell systems, H. Stone, Battelle Memorial Institute, 2005

Portable power: key parameters

The baseline model is a 5 kW_{net} pressurized PEM fuel cell system for portable backup power generator[1, 2].

Stack Components	Technology Basis
System $Power_{net}$	5 kW
System $Power_{gross}$	5.5 kW
System Pressure	Ambient
Designed Life	5000 hours
# of cells	69
Peak Power Density	500 mW/cm^2
Cell Voltage	0.7 V
Membrane	PSFA 90 ^oC, 20 µm
Catalyst	Pt Alloy, Loading: 0.3 mg/cm^2
GDL	275 µm, woven carbon fiber
Bipolar Plate	2 mm expanded graphite, each with cooling channels
Cell Pitch	10 cells/inch

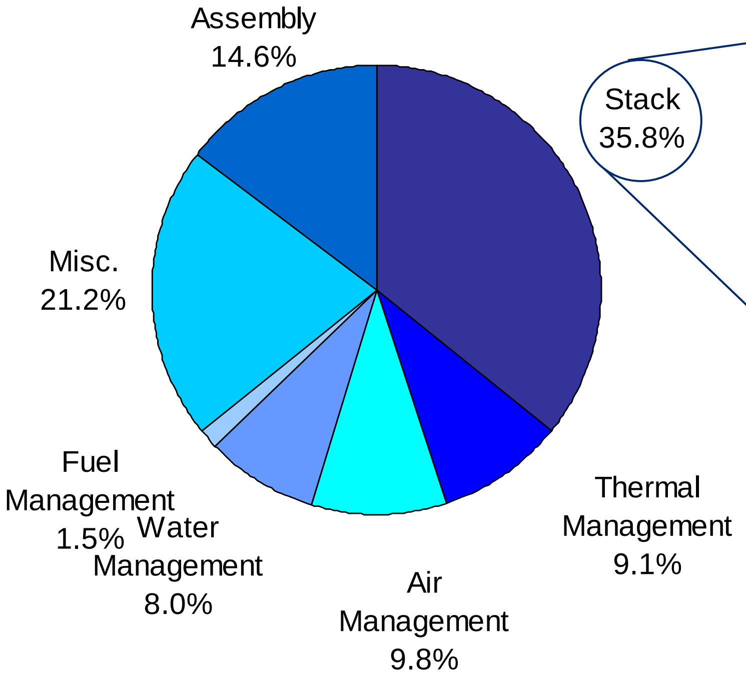
BOP Components	Major Components
Water Management	Enthalpy Wheel Humidifier (air)
Thermal Management	HT Radiator
	Cooling Fan
	Water Pump
Air Management	Compressor
Fuel Management	Anode Gas Dead End, Continuous purge

Production Parameters	Value
Pt price ($/tr oz)	1100
# units/year	50,000

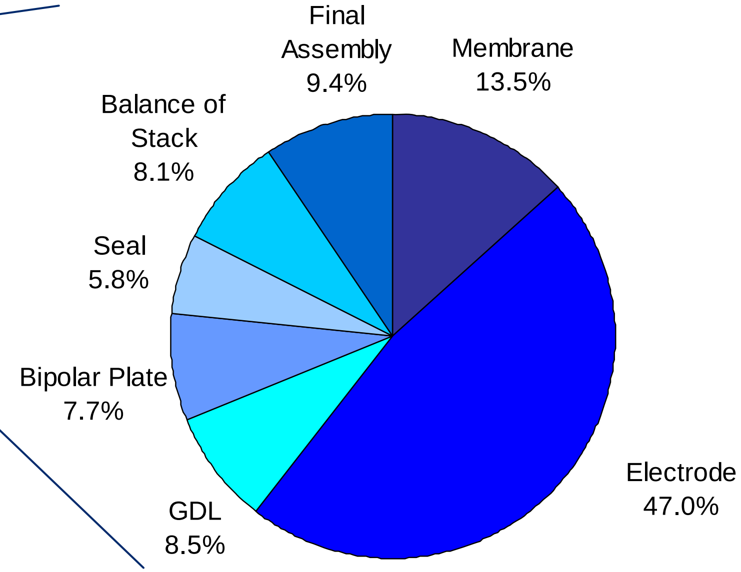
[1] Economic analysis of stationary PEM fuel cell systems, H. Stone, Battelle Memorial Institute, 2005

Portable power model results

Baseline: $264/kW$_{net\ power}$
Total system OEM cost: $1,322



Baseline: $95/kW
Total stack costs: $474



5 kW$_{net}$ PEM Fuel Cell Stack and System costs
(System does not include hydrogen storage)

Important notice to PFCC applicants

- The models used by the Carbon Trust which are presented here may also be used to assess the sensitivity of the output values to varying parameters based on new technologies.
- At Expression of Interest (EoI) stage, it is **not** expected that applicants should provide detailed simulations based on their own system parameters to be benchmarked against the models presented herein! These results are indicative only.
- Applicants may have the opportunity during the selection process (while preparing a Full Proposal) to work with the Carbon Trust on the models with their own set of parameters.
- These will be used to obtain a range of quantitative estimates of the impact that the applicants' breakthrough technologies may have on system costs.
- The applicants will have the option of including these results to strengthen their full proposals.
- However, these simulation results will only be part of a range of criteria considered in the assessment. They will **not** be assessed directly against a single objective for cost improvement (e.g. 33%) and will not constitute a standalone criterion for rejection.
- Instead, they will be considered globally in assessing the technology against a wider set of indicators relevant at system-level.

www.carbontrust.co.uk/fuelcells