Review of Fuel Cell Commercial Potential for DTI and The Carbon Trust

Final Report

London

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E4tech

Carbon Trust / DTI Disclaimer

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E4tech Disclaimer

Please note that this report represents the best available information at the time of preparation (October-December 2002), though commercially confidential information has not been divulged. The authors would like to thank all of the individuals and companies who provided inputs to this review.

In providing this report the authors do not intend to devise specific policies or advise individual companies on precise courses of action, since these may require analysis of factors beyond the scope of this report.

Contents and index

The DTI and the Carbon Trust set out jointly to understand the commercial opportunity for fuel cells in the UK

DTI fuel cell activities

- R&D programme since 1992
  - 156 projects supported
  - DTI Expenditure of £14.2 m
  - Total Expenditure of £92.5 m
- Helped develop UK industrial capability
- Approach based on technology route maps and calls for proposals
- Assessment by Independent Advisory Panel (FCAP)

Carbon Trust fuel cell activities

- Low Carbon Technology Assessment highlighted the relevance of fuel cells
- Under the Low Carbon Innovation Programme the Carbon Trust will continue to actively develop fuel cell related projects under the R&D, Demonstration, Carbon Finance and Market Diffusion headings

Rationale for the study

- High interest in fuel cells
- Significant UK and global activity
- Limited UK resources that need focusing
- Historic technology push approach
- Need to understand the basis for market pull
- Desire to build partnerships between government and industry

The aim was to develop a common understanding of fuel cells as a basis for complementary, targeted action

Issues addressed

- What will drive fuel cell uptake in main applications?
- Which fuel cell technologies will dominate these applications and what is the route to commercialisation?
- How strong is the UK as a potential market for fuel cells?
- What are the UK's strengths & weaknesses as a supply base for fuel cells?
- What opportunity areas might be worth exploring based on these findings?
- What levers should the DTI and Carbon Trust consider pulling in order to develop these opportunities?
- How can the public and private sectors work together effectively in fuel cells?

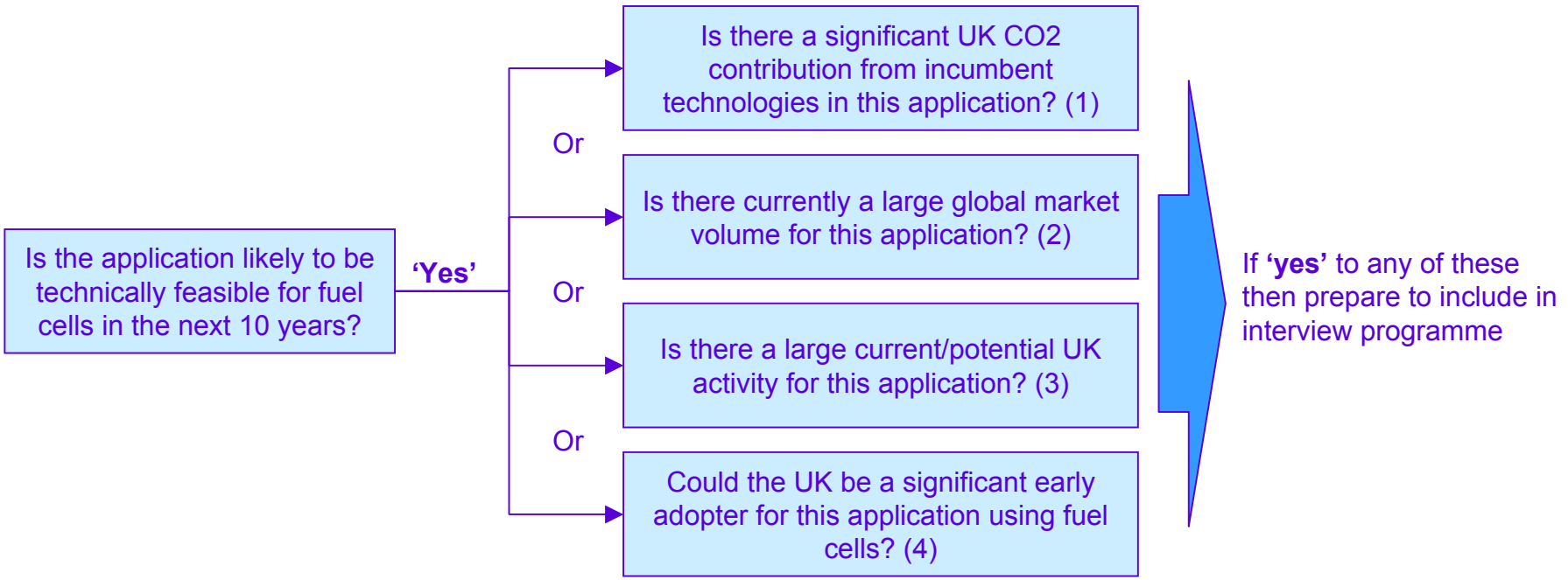
Issues not addressed

- Analysis of the benefits of fuel cells
- Review of every potential application
- Detailed market forecasts
- Detailed technology assessments
- Selection of UK opportunities
- Decisions over resource allocation to opportunities
- Setting of policy

A highly consultative structured approach was followed

	Identify potential fuel cell applications	Select most significant applications and identify stakeholders	Conduct interviews with stakeholders to determine commercial prospect for fuel cells	Synthesise views as input to workshop	Conduct validation workshop and invite feedback	Summarise all findings in draft report	Issue final report
Goals:	• Identify and classify all reasonable fuel cell applications in transport, stationary and portable power sectors	• Screen applications to produce working shortlist of 'significant' apps • Identify UK and international stakeholders for interview programme	• Demand side view of fuel cell capabilities and prospects compared with competing technologies • Supply side view of capabilities and prospects relative to demand side requirements	• Identify where fuel cells can realistically challenge competing technologies • Identify which fuel cell technologies have strongest prospects	• Review commercial prospects with informed audience • Discuss UK opportunities and policy options • Invite email feedback	• Summary of commercial prospects, UK opportunities and policy options	• Discuss DTI/CT comments in January
Approach:	• Use existing databases & insights • E4tech brainstorm	• Assessment of key factors associated with applications • CT/DTI/E4tech contacts	• Face to face and telephone interviews	• Team expertise and outputs from previous stages to cross-reference technology and requirements	• One day event with day and evening audience • Email feedback	• Submit 20 December for review	• Submit end January

A screening process was applied to focus the interview process on the most significant potential applications



Indicative metrics for screens:

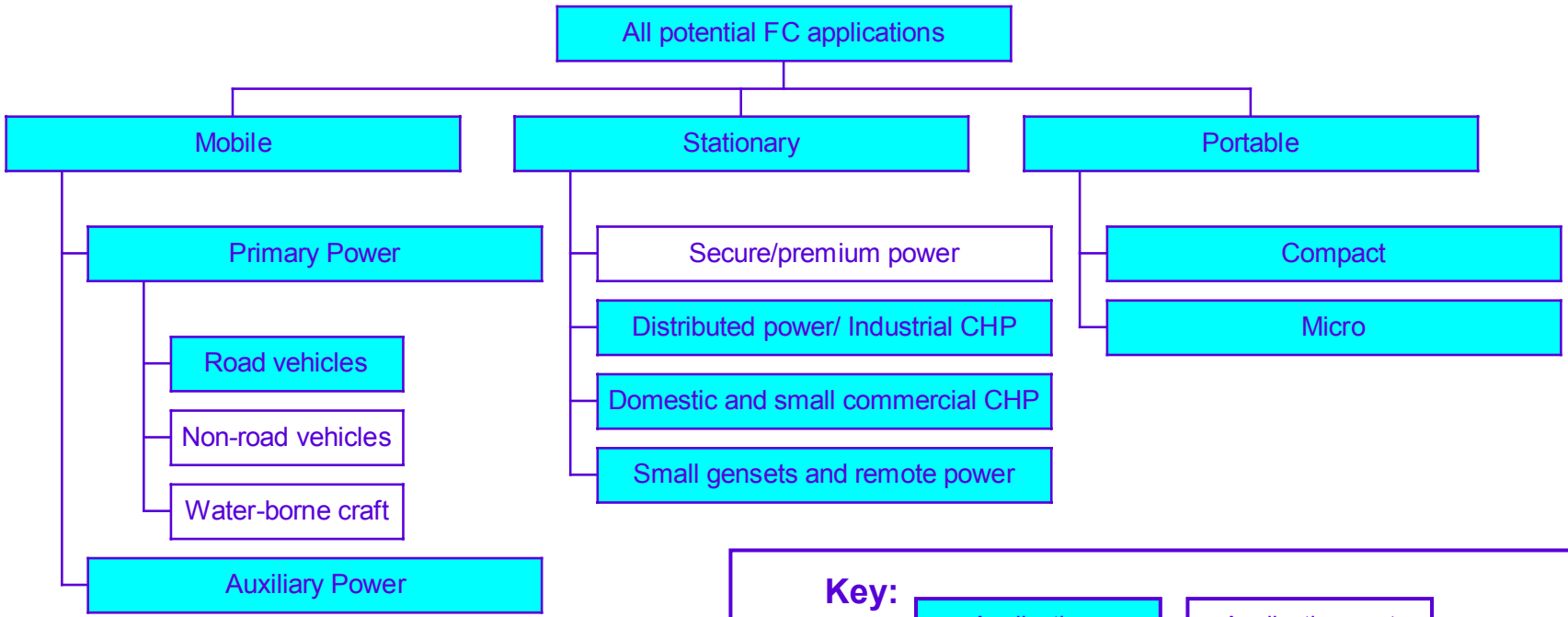
(1) Does the sector as a whole contribute >1 M t CO2 in the year and is the application more than 10% of this?

(2) Does the application represent >1% of the global market for the sector as a whole?

(3) Is the UK >10% of the global market? Is the UK well positioned to be active in R&D or manufacture in this area?

(4) Could fuel cells penetrate 5% of this market within 3 years?

Overview of market segmentation used in the study



Key:

Applications selected for further consideration, after pre-screening

Applications not selected for further consideration, after pre-screening

Portable: Fuel cells that power devices which are carried in their normal mode of operation (e.g. laptops, phones and charging holsters, not generators that can be moved)

Mobile market segments considered in the study

		Applications/Markets	Current technologies
Primary Power	**Road vehicles**	• Scooters	• Gasoline ICE (2 or 4 stroke)
		• Passenger cars • Minivans • Light gen.duty com. vans (<2T)	• Petrol / diesel ICE • Hybrid
		• Custom taxis • Light urban duty vans (<2T)	• Petrol / diesel ICE
		• Medium / heavy urban duty trucks • Urban buses • Municipal vehicles	• Diesel ICE
Auxiliary Power		• Luxury Car	• High voltage Battery
		• Truck	• Diesel, petrol or LPG ICE generator

Stationary market segments considered in the study

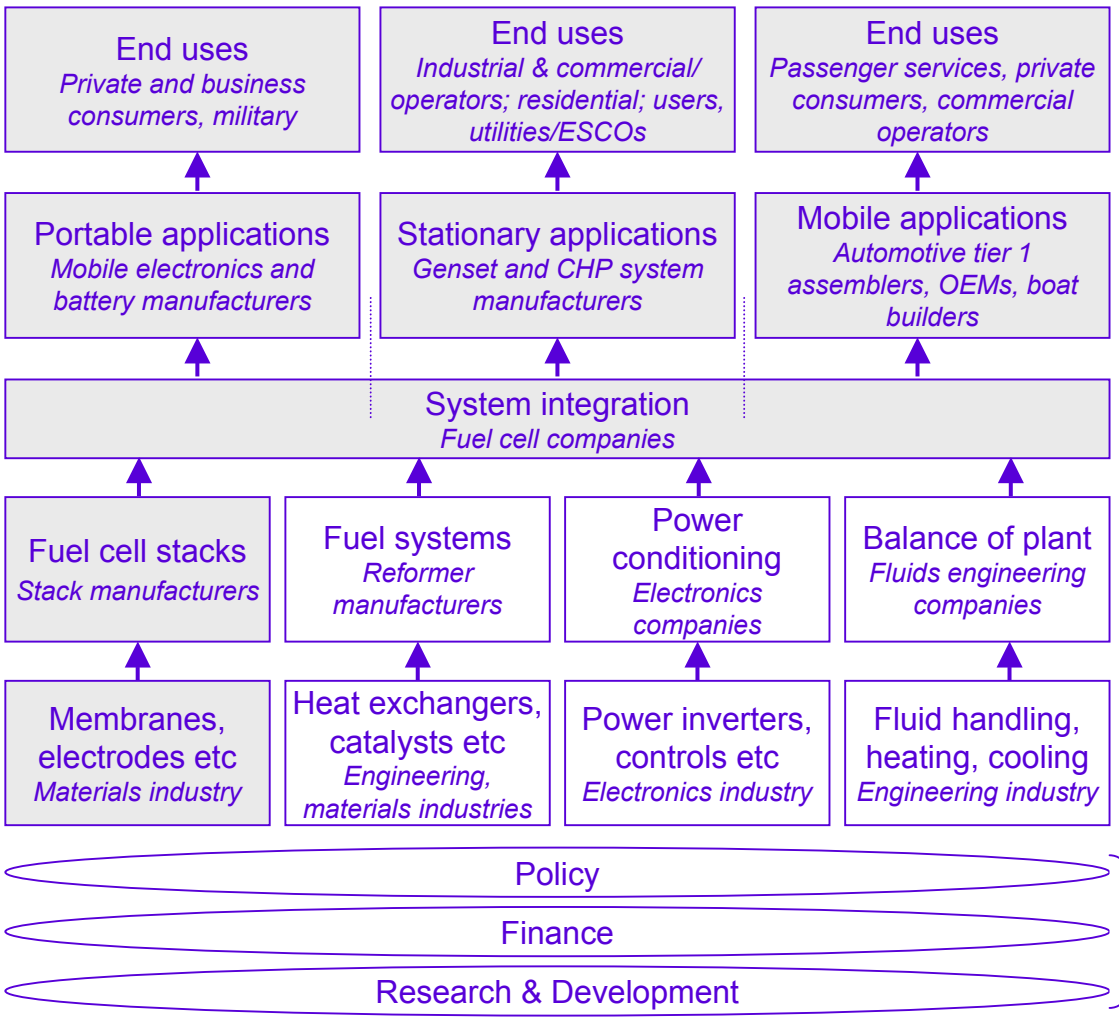
	Applications	Markets/ examples	Current technologies
Distributed power/ CHP	Micro-grids	• Housing developments/Off-grid residential • Islands • Developing countries	• Mains grid extension • Renewables • ICE generator
	T&D grid reinforcement	• Utilities • Grid operators	• Increase grid capacity for centralised generation
	Peak shaving or base load	• Industrial sites • Buildings	• Gas turbine generator • ICE generator
	CHP	• Industrial sites • Buildings	• Boiler plus mains supply • Diesel or fuel oil ICE plus mains supply
Domestic & small commercial CHP	Residential and other small buildings	• Boiler replacement • Small district heating / micro-grid power	• Individual or District boiler plus mains supply • LPG or diesel ICE plus water jacket
Small gensets & remote power	Off-grid buildings	• Developing countries • Holiday homes • Temporary buildings	• ICE portable generators • Simple combustion: e.g.biomass, kerosene • Renewables
	Communications infrastructure/ Low power packaged services	• Transmitters • Network nodes • Road traffic systems • Remote monitoring	• Batteries • ICE generators • Mains supply • Solar
	On-location power	• Construction sites/ Emergency services • Aircraft ground power	• Diesel ICE generator (vehicle, barge, trailer or trolley mounted)
	Low noise on-location power	• Outdoor events • On location recording	• Diesel ICE generator • Batteries
	Battlefield power	• Military battery chargers	• Diesel ICE generator • Batteries

Portable power segments considered in the study

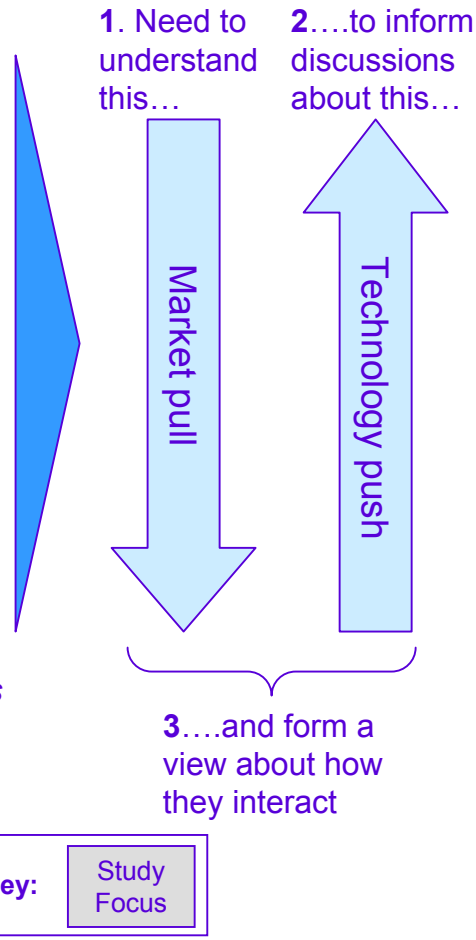
	Application/ examples	Current technologies
Compact	• Chargers for power tools • Drills • Strimmers • Lawnmowers • Lights	• Mains grid • Portable diesel or petrol genset
	•Wheelchairs	• Rechargeable battery
	•Wearable military power packs	• Rechargeable or disposable battery
	•Professional electronics e.g. video cameras	• Rechargeable or disposable battery
Micro	•Laptops	• Rechargeable battery
	•PDAs / convergent devices	• Rechargeable battery

The interview programme was designed to be market-led

Simplified Structure of the Fuel Cell Industry (layers & *entities*)



Implications for Programme



Contents

The UK has the potential to build upon significant areas of strength

Summary	Section
• **Fuel cells have significant commercial potential worldwide, but challenges remain in all applications**	Commercial potential of fuel cells
• **The Government needs to stimulate both the market and supply side in the near term to maximise long term benefits for the UK**	Government intervention
• **The UK has the opportunity to benefit by becoming a significant fuel cell market, mainly in stationary applications**	Market side opportunities
• **The UK's fuel cell industry, though modest, has pockets of acknowledged expertise. The main opportunities appear to lie in focusing on high value applications and specialising in IP-led areas of the supply chain**	Supply side opportunities

Each of these arguments is broken down in the referenced sections, with a summary of each set of supporting arguments shown at the beginning of each section and sub-section. All pages are indexed in the top left hand corner.

Contents

Fuel cells have significant commercial potential worldwide, but challenges remain in all applications

	Application area	Features/Examples*	Key fuel cell drivers	Fuel cell potential	Fuel cell challenges
Mobile	Propulsion	Road vehicles (buses, cars, scooters)	• Prospect of future regulation	• Huge volumes globally • Not before ~2010	• Cost • Lifetime • Performance • Fuel infrastructure
	Auxiliary Power Units	Luxury cars Trucks	• Desire for greater onboard power • Cheaper lifetime cost (trucks)	• Large global market • Could start in ~3 years	• Technology path • Fuelling (potentially)
Stationary	Distributed generation / CHP	Industrial, municipal, micro-grids 100kWe-1MWe	• Niches where low emissions and/or total ownership cost valued	• Some early niches/demonstrations • Mostly after 2010	• System cost too high • Must be proven over long periods • Conservative market
	Domestic & small commercial CHP	Houses, hotels, offices 0.5-10kWe	• Potentially attractive value proposition for consumers & utilities	• Some early demonstrations • If proven then from ~2010	• Unproven market and technology • Other micro CHP technologies emerging
	Small gensets and remote power	Communications, UPS, village power 1-25kWe	• Niches which require e.g. low emissions/noise, minimal maintenance and can withstand high cost	• Wide range of niches already open • Opportunity rises as cost decreases	• Reliability must be proved • Maintenance • Fuel supply
Portable	Compact and micro devices	Power tools, portable electronics, chargers	• Rising power demands • Battery disposal problems	• Wide range of devices worldwide • Compact now emerging, micro in ~3 years	• Micro technology very difficult • Fuel supply and handling

*See Appendix C

Contents

The prospect of future regulation is the main reason that fuel cell propulsion is being considered

- The drivers for fuel cells are focused on societal benefits but vary by market
- There is a divergence of views about whether compelling customer benefits exist
- Current agreements for CO2 reduction do not require fuel cell vehicles, but future regulation may necessitate them

The drivers for fuel cells are focused on societal benefits but vary by market

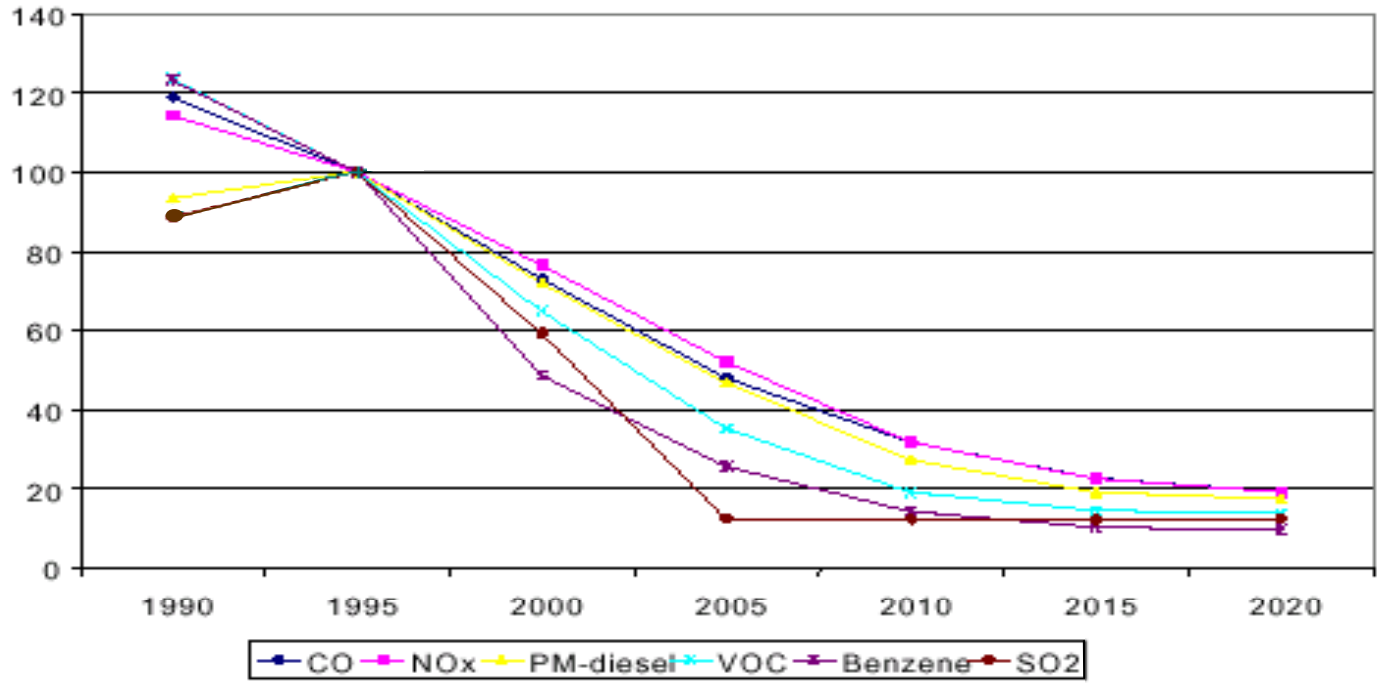
Driver	USA	EU	Japan	Notes
Urban air quality improvement	■	◪	■	• Primarily a societal benefit • Also strong in other key cities e.g. Taipei, Beijing • Strongest driver for urban buses especially particulate matter
CO2 reduction	◪	■	◪	• Primarily a societal benefit
Energy security	■	◨	■	• Primarily a societal benefit • Depends upon level of domestic resources
Long term auto industry competitiveness	■	■	■	• Supply side driver based on image value of eliminating/ reducing environmental criticism • Also strong in South Korea

Key (horizontal comparisons only)

◪ = Small factor ◨ = Medium factor ◪ = Large factor ■ = Very large factor □ = Not a factor at all

European air quality projections are very promising except in urban hotspots

EU projected total mass of road transport emissions
Index, 1995=100



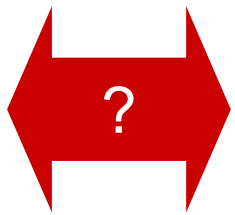
- Reduction in *mass* of particulate matter may not indicate similar reduction in human health effects
- Most hotspots are in areas of high population density

Source: Auto Oil II Programme, 1999/2000

There is a divergence of views about whether compelling customer benefits exist

Potential customer benefits

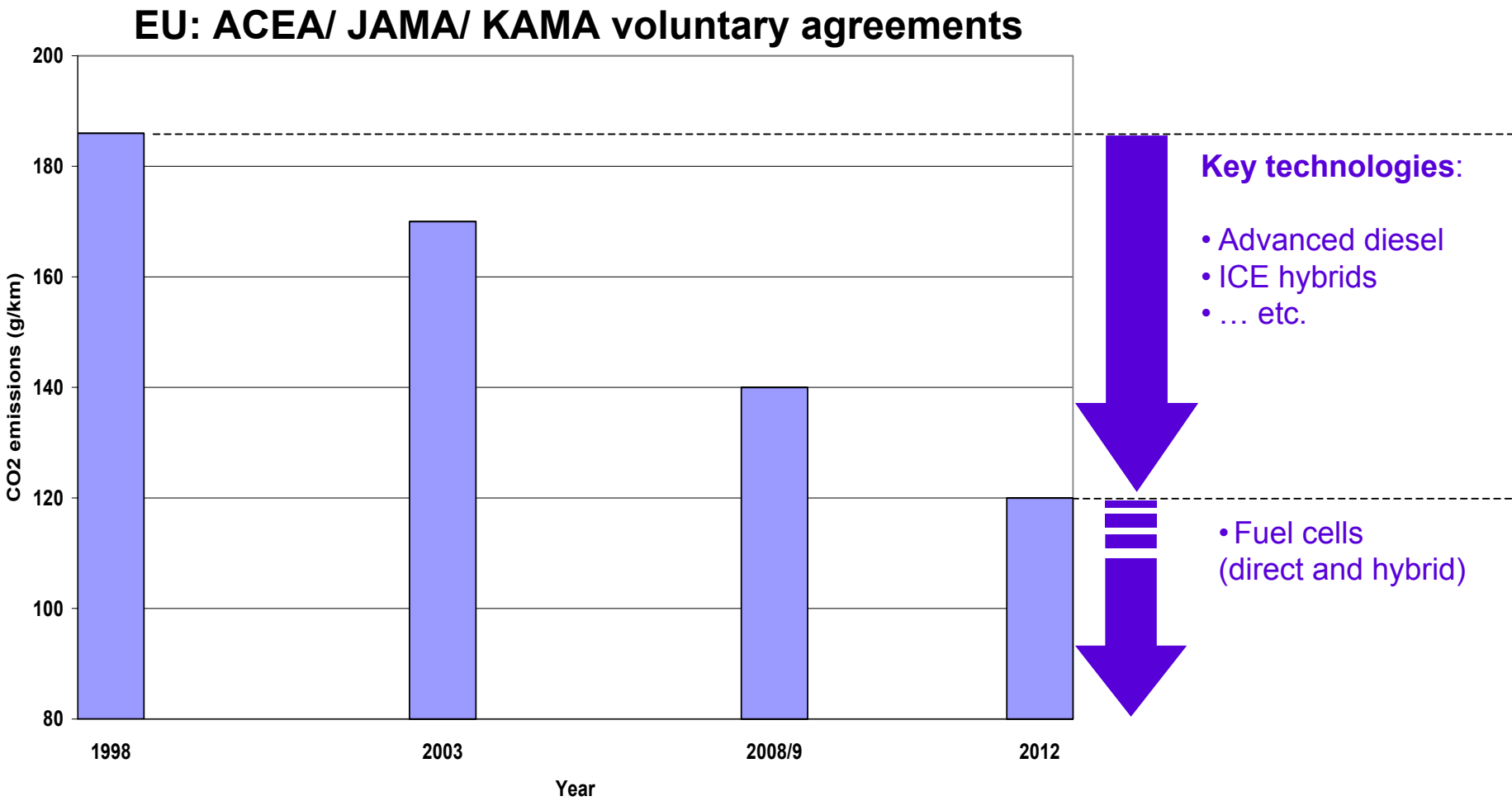
- Lower lifetime costs
- Lower noise
- Increased potential for on board electric power
- Vehicle packaging flexibility (e.g. GM HyWire concept)
- Improved power delivery characteristics



Divergent views

- Supply side (e.g. fuel cell manufacturers): anticipate clear customer benefits
- Demand side (e.g. auto makers): sceptical that customer genuinely values these benefits

Current agreements for CO_2 reduction do not require fuel cell vehicles, but future regulation may necessitate them



Source: EU

There is huge fuel cell potential but big obstacles remain

- Fuel cells compete against a number of technologies (and societal behavioural changes) that *could* satisfy medium term requirements for very low CO_2 and pollutant emissions in most regions
- PEMFC appears to be the primary technology choice but a number of technology challenges remain
- Hydrogen is the current fuel focus, despite the fact that infrastructure and storage problems remain to be solved
- If the hurdles are overcome, the mainstream propulsion market is expected to open up after 2010

Fuel cells compete against a number of *very low* CO2 and pollutant emission technologies

Configuration	Tank to wheels efficiency	Cost compared with conventional ICE	Range	Technical uncertainty
Hydrogen + fuel cell	System ~35-40%	Currently very high, realisation of cost reduction is uncertain	Currently poor depends on storage	High
Hydrogen + internal combustion engine	System ~28%	Acceptable	Currently very poor depends on storage	Low
Battery	N/a	High	Poor	High

Behavioural changes such as increased reliance on travel by foot and public transport are other routes to meeting the CO_2 and emissions reduction requirements

There are a number of PEMFC technology challenges remaining

Cost

e.g. for passenger cars $50/kWe

+

Lifetime

e.g.

5,000 hours operation with transients/ cycling

+

Performance

e.g.

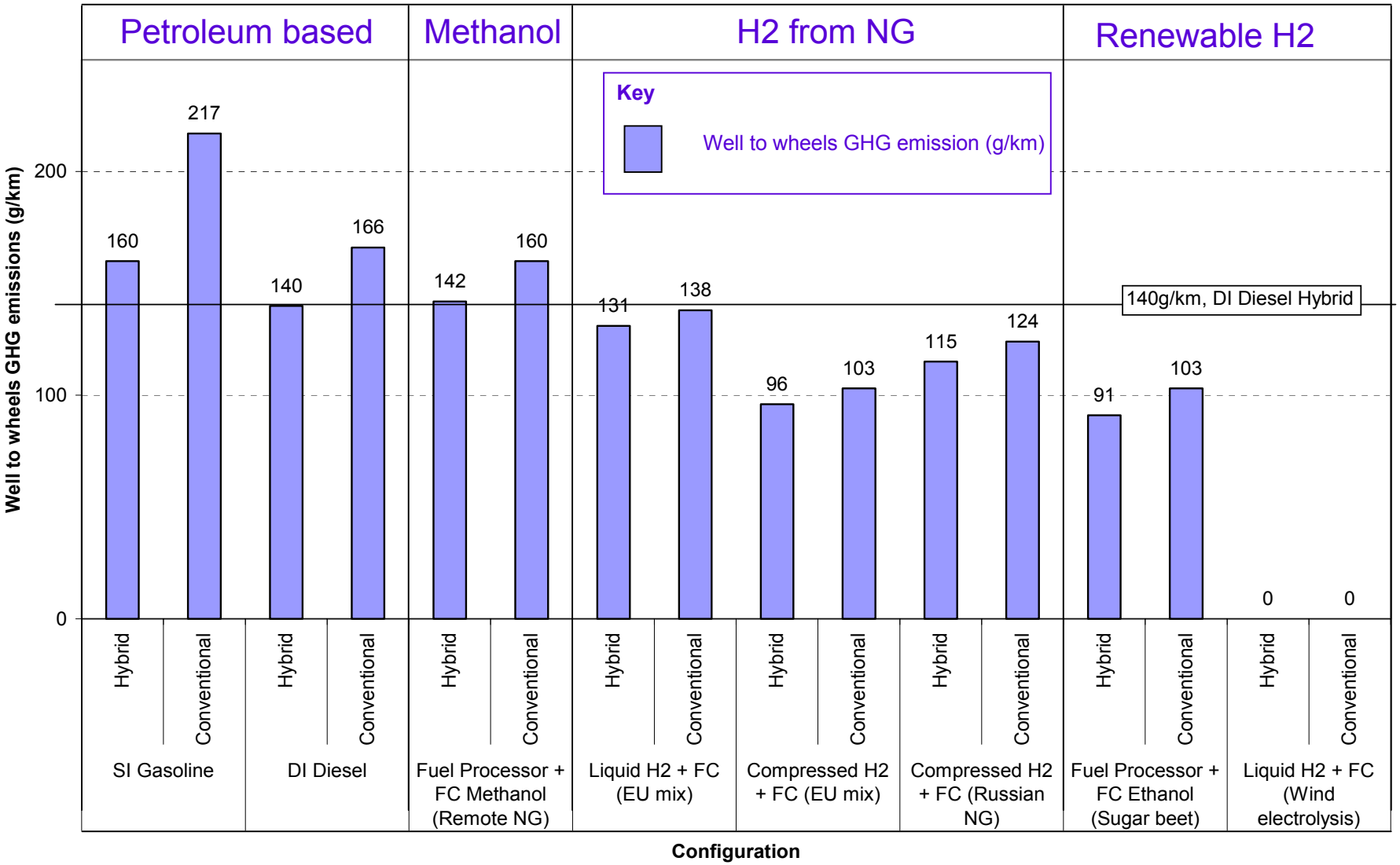
operability in hot, arid environments

Solving multiple technical issues with an integrated solution remains a challenge

Hydrogen is the current fuel focus for propulsion, despite the fact that infrastructure and storage problems are unresolved

- Hydrogen provides a route to zero ‘well to wheels’ emissions
- Other fuels have lower environmental advantages and will only have marginal penetration
  - Methanol has toxicity issues and only represents a transitional fuel, exacerbating the infrastructure issues
  - For other liquids, reformer technology is currently bulky and unreliable
- The path to a hydrogen infrastructure remains unclear due to supply/ demand risk
- Hydrogen storage and therefore vehicle range is currently inadequate with conventional vehicle designs

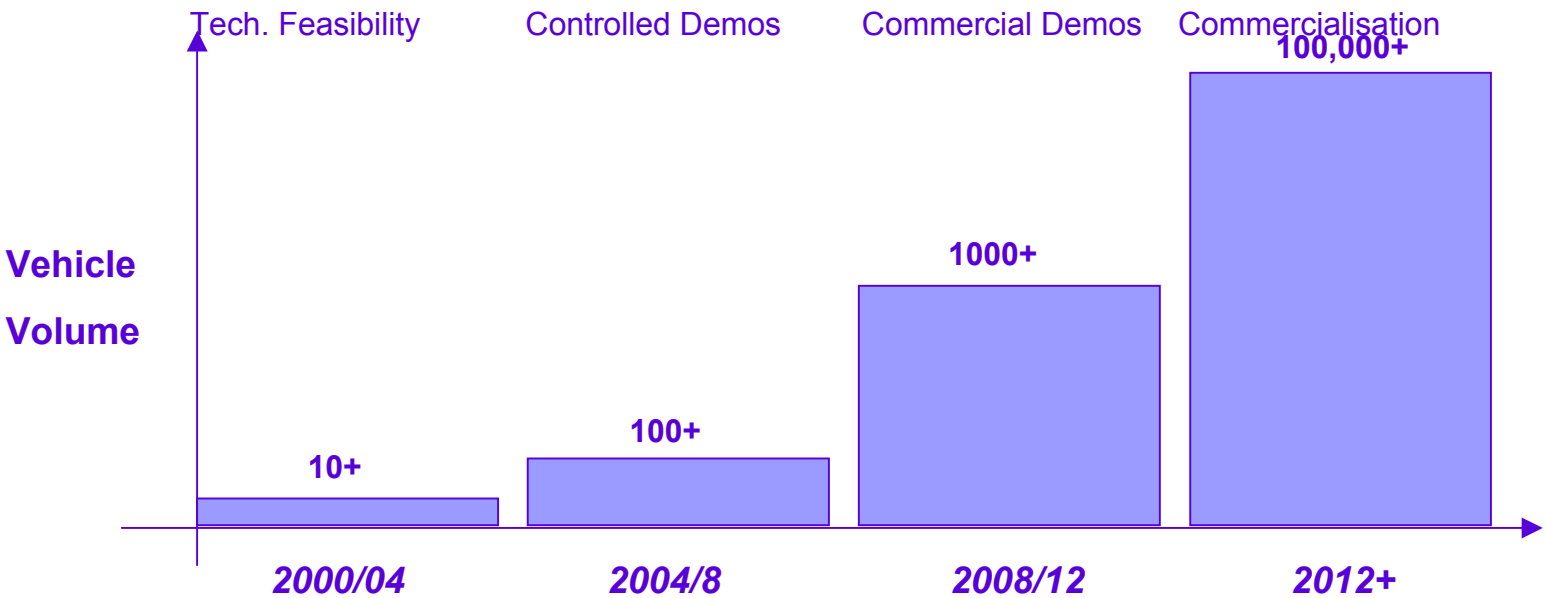
Hydrogen provides a route to zero well-to-wheels emissions



Source: GM/LBST WTW Study

If the hurdles are overcome, the mainstream propulsion market is expected to open up after 2010

US Freedom Car fuel cell vehicle targets



Source: Freedom Car

- Ultimately, all cars, scooters and urban buses could be fuel cell vehicles (currently, worldwide, 40m new cars are produced each year)
- Commercialisation of depot-based fleets will take place first, followed by cars and scooters which are likely to be ahead of urban buses

Note: Japan's METI is aiming for 50,000 FCVs by 2010; 5m by 2020

Contents

The drivers for fuel cell Auxiliary Power Units are direct customer benefits

- Auxiliary Power Units (APUs) are likely to be found in both luxury cars and trucks:
  - **Luxury cars:** driver for fuel cell use is the increasing onboard electrical power requirements
  - **Trucks:** drivers for fuel cell use are cost of fuel, and engine wear & tear at idle
- Both luxury car and truck applications are less price sensitive and require less stringent performance characteristics than propulsion units

Long term market for APUs could be relatively substantial with commercialisation potentially ahead of propulsion

Application	Configuration	Technology options	Long term market potential
Luxury cars	Standalone APU	• Gasoline + simple reformer + SOFC	3.2 million units $14bn per year
		• H2 + SOFC or PEMFC (once H2 widely available)	
	Integrated APU with additional functionality*	• Gasoline + simple reformer + SOFC or • Gasoline + reformer + PEMFC	
Trucks	Fuel used is same as propulsion ICE	• LPG + simple reformer + SOFC • (LPG + reformer + PEMFC also possible)	4 million units $27bn per year
		• H2 + PEMFC or SOFC	
	Fuel used is different from propulsion ICE	• Gasoline + simple reformer + SOFC	
		• H2 + SOFC or PEMFC (once H2 widely available)	

APUs based on gasoline and SOFC technology may achieve commercialisation relatively quickly because they do not rely on development of a H2 infrastructure. If launched as a retrofit item this could be as soon as 2-3 years time.

* e.g. assistance with emission control, cold start. Retrofit would not be applicable

Contents

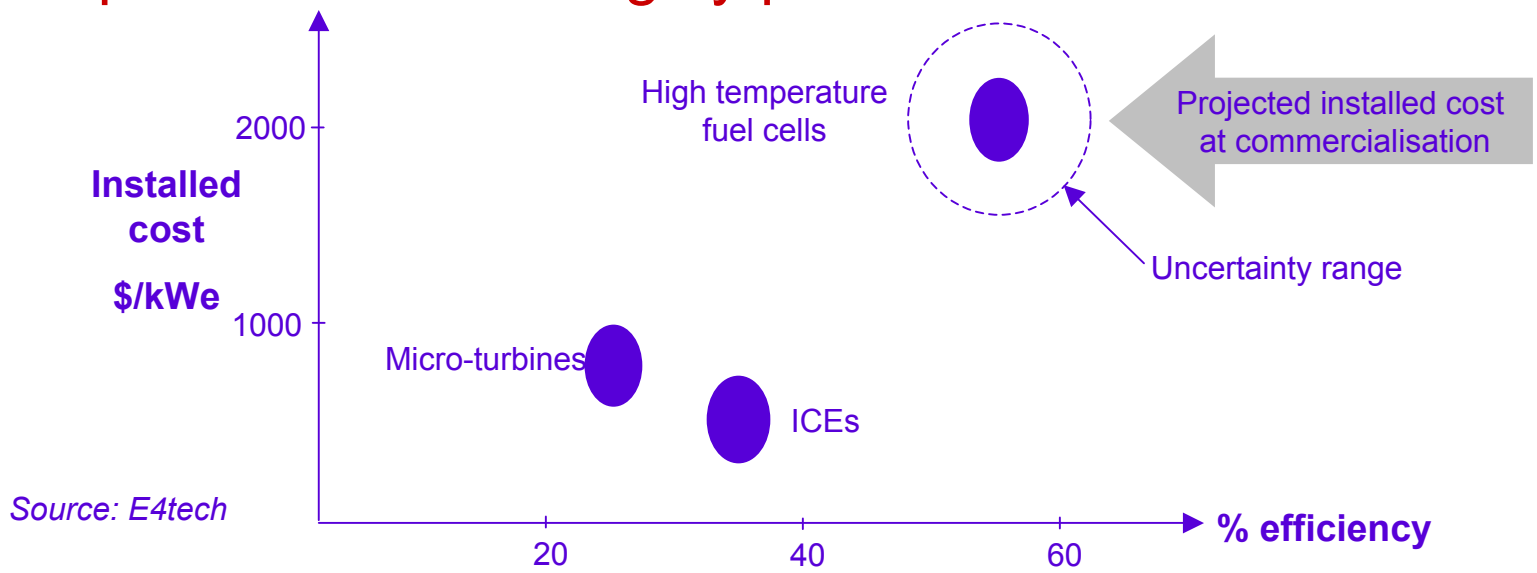
In large scale distributed power and CHP, fuel cell use will be in applications where cost is not the sole driver

- In the main distributed power/CHP market, there are currently no drivers that are specifically advantageous to fuel cells
- Fuel cells face tough challenges due to the need to be cost competitive and thoroughly proven
- High temperature fuel cells are likely to be adopted for this application, but PEMFC show potential in specific areas

For distributed power/CHP markets, there are currently no drivers that are specifically advantageous to fuel cells

- Economics are the primary driver:
  - Some buyers consider lifetime cost, but the majority select systems primarily on initial and installed cost
  - Financial benefits of distributed generation are not yet available
- Buyers are typically conservative:
  - Unwilling to accept technologies that are unproven
  - Buyer instinct is to use redundancy rather than new technology to deliver reliability
- Emissions are not (yet) a major driver:
  - "The 'downtown premium' for fuel cells in urban locations is not yet available"

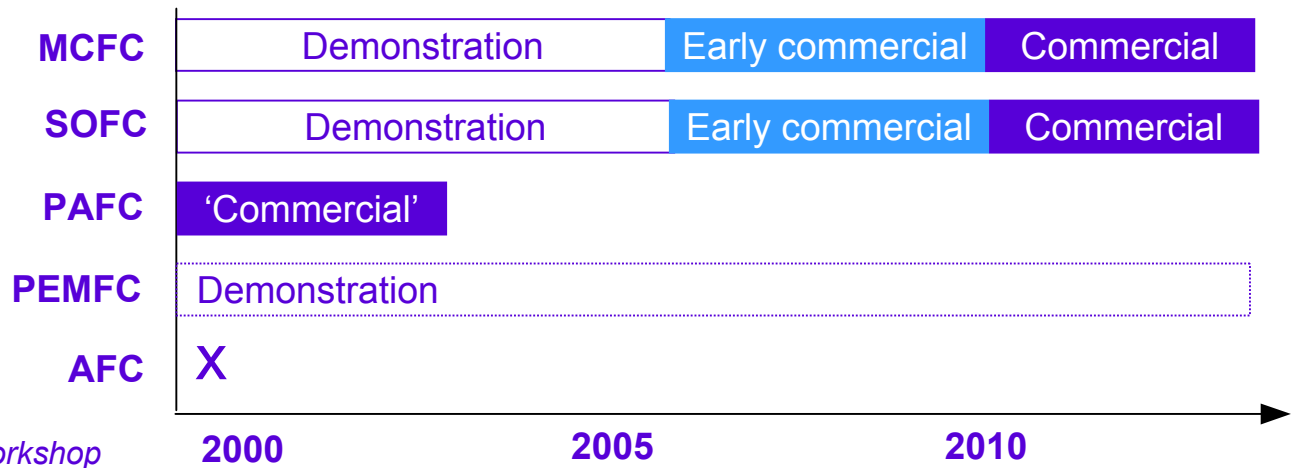
Fuel cells face tough challenges due to the need to be cost competitive and thoroughly proven



- Adoption will not be widespread before cost decreases and reliability is proven
  - Manufacturing will need to yield cost reductions
  - Demonstration programmes essential
- May be early commercial applications in niches from ~2005
  - Municipal buildings - less cost sensitive than private buildings and industry
  - Environmentally sensitive areas – some premium for low emissions
  - Critical power – a premium may be available for significantly improved reliability
- Wider commercialisation likely to be closer to 2010

High temperature fuel cells are likely to be adopted for this application, but PEMFC show potential in specific areas

- SOFC is considered to be the most promising technology for these applications
- MCFC is further advanced than SOFC for large scale applications, but still remains to be proved in long term operation, particularly in view of potential materials challenges
- PAFC has limited potential for further cost reduction
- PEMFC is in demonstration at this scale, but its low temperature will restrict use to specific markets e.g. where hydrogen is available
- AFC is not being developed at this scale and may be limited by system dimensions
- Turbine integration can significantly increase system efficiency for MCFC and SOFC systems, but the first generation of fuel cells for this application will probably not have this feature
- Early systems may also be power-only with CHP systems coming later



Source: E4tech, workshop

Contents

Domestic and small commercial CHP are potentially attractive for consumers, utilities and Government

Consumers could benefit if utilities can provide a value proposition that is more attractive than separate gas and electricity purchase

Gas and electricity **utilities** could benefit from:

- Organic growth into new regions
- Longer term customer commitment than for supply only
- Avoidance of electricity transmission costs
- Opportunity for remote load management and distributed grid services
- Compliance with obligations under the Energy Efficiency Commitment

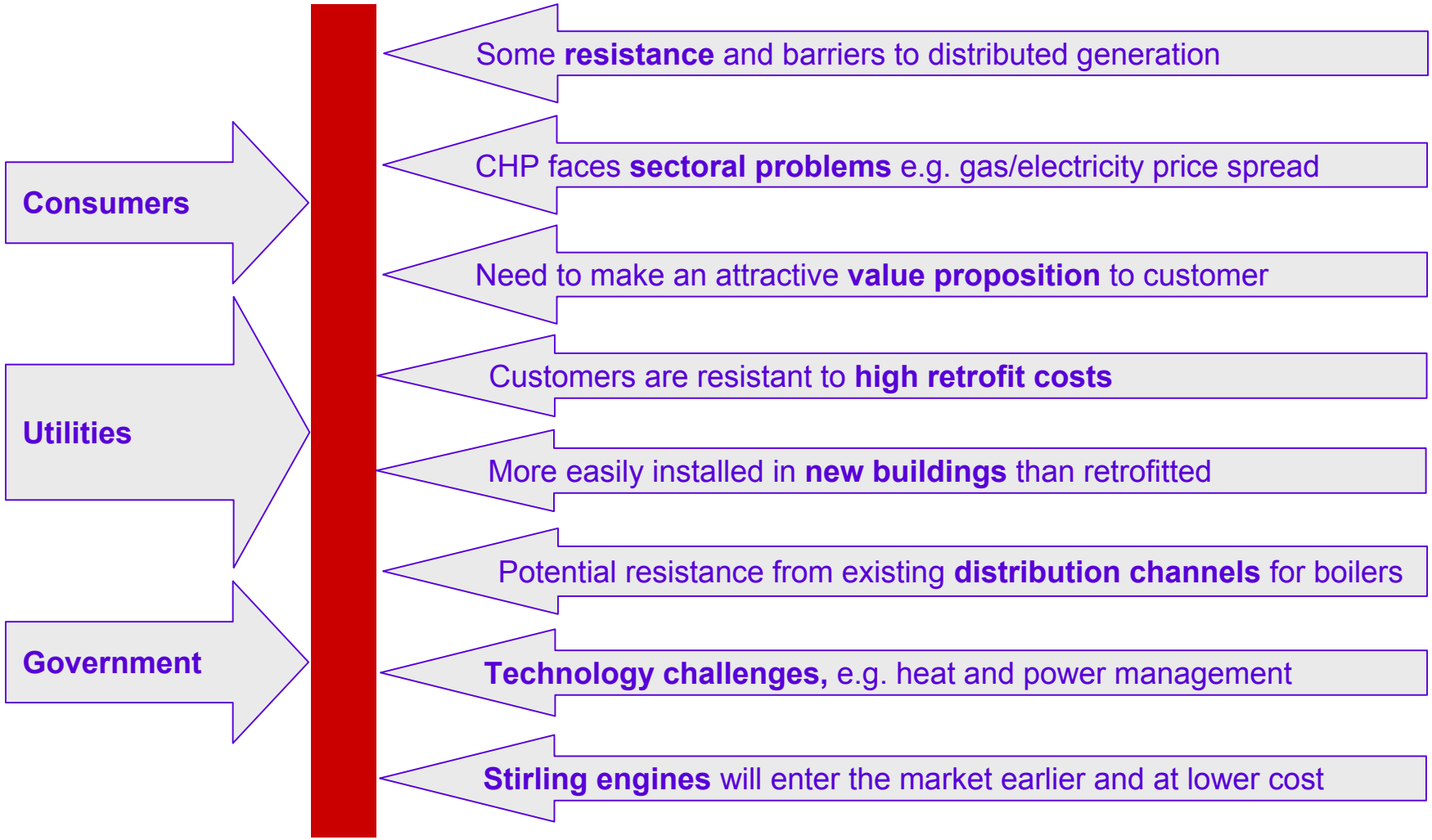
Could contribute to **Government** objectives:

- Good quality CHP promotion
- Reduction of residential sector CO2

There is strong medium term potential for fuel cells in domestic and small commercial CHP, if proven

- Domestic and small commercial CHP are potentially attractive for consumers, utilities and Government
- Domestic CHP still presents tough challenges for all technologies, particularly fuel cells
- In the medium term, PEMFC and SOFC could play a role in domestic CHP systems if successfully proven

However, small scale CHP still presents tough challenges for all technologies, particularly fuel cells



In the medium term, PEMFC and SOFC could play a role in small scale CHP systems if successfully proven

Commercialisation depends upon successful demonstration

- UK demonstration projects of domestic Stirling engine CHP are underway. These will provide key learnings to utilities and integrators, some of whom favour fuel cells due to their lower heat:power ratio (hence less wasted energy in summer)
- Fuel cell trials of fuel cell devices are expected in 2-3 years, at approximately 5kW$_e$ scale
- Successful demonstration of fuel cells could then lead to commercialisation from ~2010, through utilities

Technology selection remains unclear

- SOFC is a promising technology for this application, but lifetime issues have to be overcome
- PEMFC technology is suitable with small reformers (under development at the scale considered) or where hydrogen is available
- An additional burner may be required for hot water in early generation SOFC and, potentially, all PEMFC systems.

Contents

Fuel cells will find niches within small gensets and remote power, depending on the requirements of each application

- Genset and remote power applications have a range of requirements, and cost is often not the main consideration
- Fuel cells will find niches in many of these application areas, based on their performance characteristics
- PEMFC is the most promising technology as its capabilities already match the required performance characteristics of niches

Genset and remote power applications have a range of requirements, and cost is often not the main consideration

Purchase drivers for example applications

	Example applications				
	Phone Mast UPS (5kWe)	**Emergency standby (10kWe)**	**Military battery charger (5kWe)**	**Remote monitoring (50We)**	**Rental genset (25kWe)**
Current technology / **Main purchase drivers**	Mains with battery UPS	Genset	Diesel genset	Battery	Petrol genset
Cost					
Reliability					
Noise					
Emissions					
Refuelling frequency					
Portability					

Key (horizontal comparisons only)

 = Small factor  = Medium factor  = Large factor  = Very large factor  = Not a factor at all

Fuel cells will find niches in many of these application areas, based on their performance characteristics

Fuel cell prospects for example applications

Example	Phone Mast UPS	Emergency standby	Military battery charger	Remote monitoring	Rental genset
Rationale	Need to compete with battery based systems ideally with longer autonomy	Must prove reliability compared with gensets	Performance and robustness must be better than silenced gensets	Must work longer and more reliably than battery	Need to be cheaper and more robust than petrol gensets
Implications for fuel cells	Autonomy better than batteries, but reliability not yet proven	Power electronics should be able to deliver reliability, but not yet proven	Robustness is challenging, but fuel cells adequate for some uses	Simple fuel cells can perform well in these applications, using hydrogen	Fuel cells are unlikely to meet cost targets
Market	Large market for low power systems if proven	Wide range of potential applications if proven	Strong potential early market, but small volumes	Early market for small proven systems	Not an early market

PEMFC is the most promising technology as its capabilities already match required performance characteristics of niches

- PEMFCs are currently suitable in terms of
  - Availability at the right scale (0.1 - 5 kW)
  - Availability at a suitable cost for niches ($4000-6000 /kW)
- Small SOFCs are potentially applicable in this market, but require further development

Contents

Portable fuel cells are unique in that there are strong customer requirements for the benefits they may be able to provide

- Drivers include strong customer needs
  - Power and energy demands are rising in many portable applications
  - Need to recharge reduces the utility of a device
  - Concern by integrators that cadmium (used in Nickel Cadmium batteries) may become difficult to dispose of under EU legislation

- Portable fuel cells potentially outperform the competing technology
  - Longer duration between recharging than batteries, for no penalty in weight or volume
  - Refuelling is instant, compared to recharging
  - Battery performance appears to be approaching its limits, whilst fuel cells are still improving
  - Fuel cells have no toxic waste disposal problems

In practice, micro fuel cells remain technically challenging and so initial portable applications will not be in very small devices

COMPACT

Increasingly challenging

MICRO

Application	Rationale for fuel cells	Technology issues
Chargers for power tools	• Independence from mains • Smaller scale and lighter than gensets	DMFC or PEMFC possible. Note: direct power very hard due to peak loads
Wheelchairs	• Longer time between refuelling than recharging • Consumers are used to cost of annual battery change	PEMFC being developed for this area
Wearable military power packs	• Lower weight/ longer lifetime than batteries or gensets • Low noise • Market less cost sensitive	Mostly DMFC, some DEFC, PEMFC being deployed
Professional electronics e.g. video cameras	• High power compact systems • Market less sensitive to cost, weight and volume than consumer products	DMFC or PEMFC, potentially in separate pack
Laptops	• Higher power to volume ratio than existing Li- ion batteries, longer time between recharging	DMFC, or PEMFC with methanol reformer. Compactness is challenging
PDAs / multifunction devices	• High power demands from new devices which are too difficult for current technology batteries. • N.B. phones very challenging due to size	Methanol systems leading. Holster chargers possible first step due to size

DMFC: Direct Methanol Fuel Cell DEFC: Direct Ethanol Fuel Cell

Contents

The Government needs to stimulate both the market and supply side in the near term to maximise long term benefits

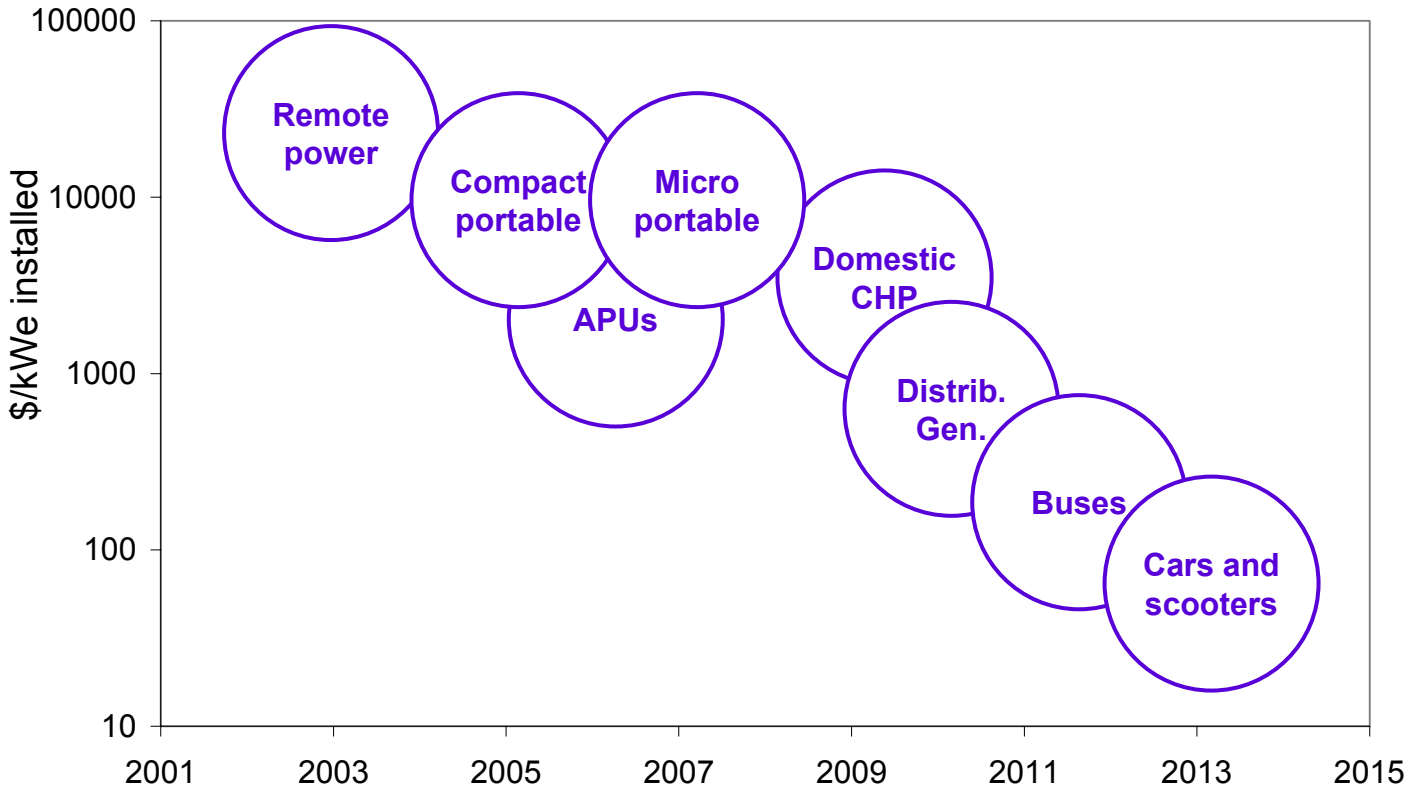
- Many fuel cell applications provide clearest benefits to society rather than meeting strong customer or supply side needs
- Early, smaller fuel cell applications are critical to provide stepping stones to cost reduction and wider commercialisation
- A strong Government role is therefore needed to yield maximum long term benefits for society and the fuel cell industry
- UK Government support for fuel cells is small in comparison to the support available to several industry-leading geographies
- If an increased UK Government role is possible, then combined market *and* supply side stimulation offers most benefits

Many fuel cell applications provide clearest benefits to society rather than meeting strong customer or supply side needs

Application	User benefits	Societal benefits	Supply side benefits	
Vehicle propulsion	• Improved power delivery (e.g. max torque at start) • Potential for lower cabin noise • Potential for more on-board electrical devices	• Lower CO2 across fuel chain • Much lower/zero air pollutant emissions • Lower noise	• Improved packaging flexibility • Enables higher on-board electrical loads • (Provides access to legislation-driven markets)	Society is main beneficiary
Auxiliary Power Units • Trucks • Luxury cars	• More efficient than IC engine, lower fuel usage • Use of APU at idle rather than reducing life of IC engine • Potential for more on-board electrical devices which can be used at any time of day	• Lower CO2 across fuel chain • Much lower/zero air pollutant emissions • Lower noise	• Enables higher on-board electrical loads • (Provides access to legislation-driven markets)	Meets user and supply side needs
Stationary • Distributed power/ CHP • Domestic & small commercial CHP • Small gensets & remote power	• Potentially more efficient and reliable than conventional technologies, so lower total cost of energy • Potential for high power quality • Potential for very low noise • Potential for indoor operation	• Lower CO2 across fuel chain • Much lower/zero air pollutant emissions • Lower noise	• Solid state power electronics allows multiple outputs to be offered • (Provides access to legislation-driven markets)	Society is main beneficiary
Portable • Compact • Micro	• Independence from mains for longer periods than with batteries • Potentially lighter than batteries	• Avoids toxic battery waste (e.g. cadmium)	• Increased power density (e.g. for convergent devices)	Meets user and supply side needs
	Many benefits remain to be proved, or do not meet strong customer needs	Clearest benefits in most applications	Few compelling cases for fuel cells	

Early, smaller fuel cell applications are critical to provide stepping stones to cost reduction and wider commercialisation

Commercial introduction points* for fuel cell applications



Note: Bubble size not significant

*The point at which fuel cell applications are purchased in significant numbers without subsidy

Sources: E4tech, Methanex, Workshop attendees

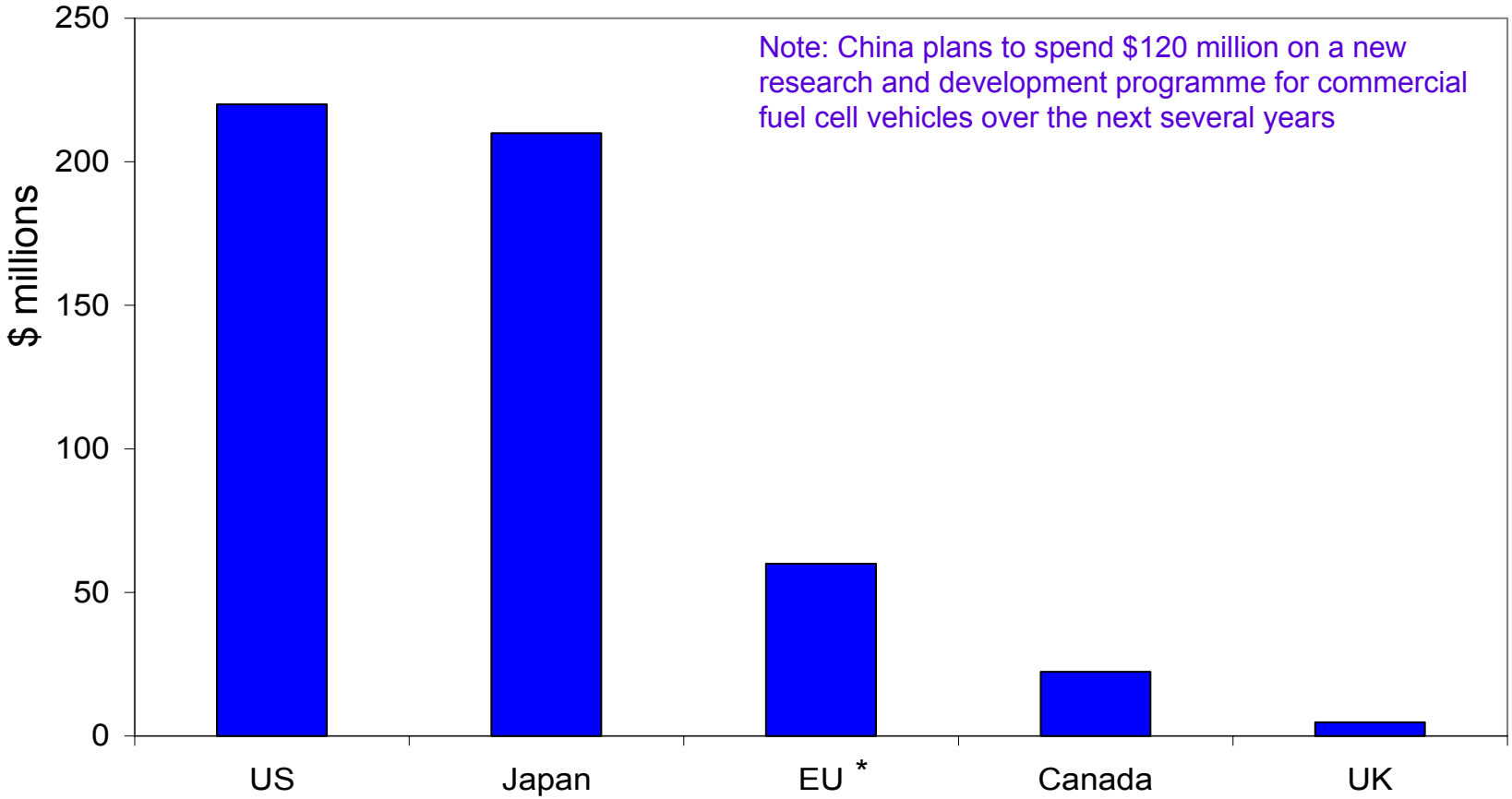
A strong Government role is needed to yield maximum long term benefits for society and the fuel cell industry

Divergent benefits and timing	• Early applications are expected to be those which offer benefits mainly to users rather than society (e.g. communications UPS) • Mainstream applications (e.g. vehicle propulsion and distributed power) offer benefits that are mainly societal • A very significant cost reduction is required in order to move from early applications to mainstream applications
Implications for Government	• Government should enable the development of markets for early applications which may lead to cost reduction in mainstream applications (e.g. lower cost PEMFC) • Government should also assist in the development of technologies for mainstream applications and prepare to enable markets for them (e.g. PEMFC components and stacks)

Desired outcome	• Early applications are sold in greater volumes:
	  • Yields faster improvements in cost and performance.
	  • Increases supply side employment and capability
	• These improvements are of direct benefit to mainstream applications:
	  • Applications become commercial at an earlier stage hence societal benefits are brought forward
	  • Additional employment and capability benefits are provided

UK Government support for fuel cells is small in comparison to the support available to several industry-leading geographies

Estimated government expenditure on fuel cell RD&D in 2002



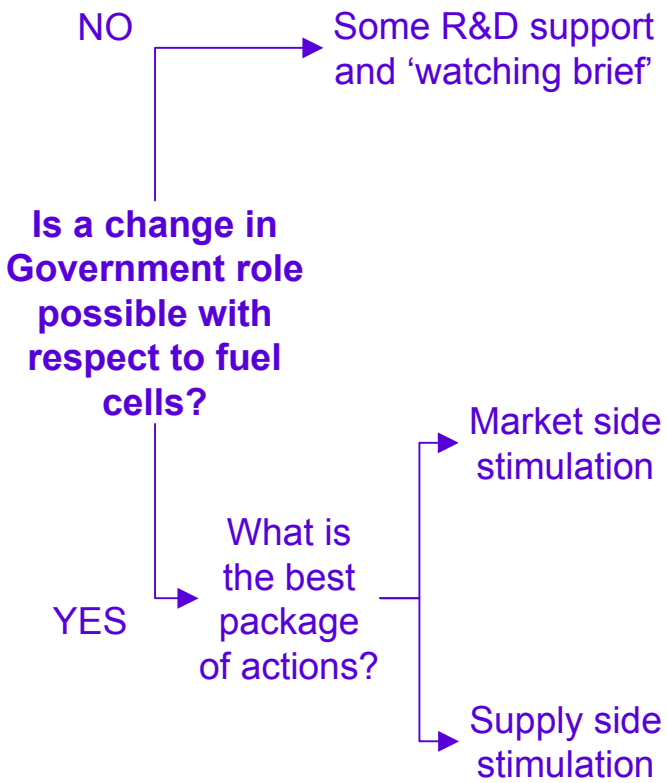
Regional development expenditure has not been included

* Average annual expenditure over the past three years.

Sources: World Fuel Cell Council, DTI

See Appendix D

If an increased UK Government role is possible, then combined market *and* supply side stimulation offers most benefits



Beneficiaries	Potential results	Implications
Only UK-based organisations	• Possible growth in jobs/ export capability • Delayed emission reductions • Not market-based	Loss of option value for UK in fuel cells, but low downside risk
UK and international organisations	• Develop UK support and fuel infrastructure • Attract inward investment • Provide UK emissions reductions • May not benefit UK fuel cell suppliers	More benefits of a combined program, but higher down-side risk
Only UK-based organisations	• Growth in UK jobs / export capability • Risk of backing the wrong horse	

Contents

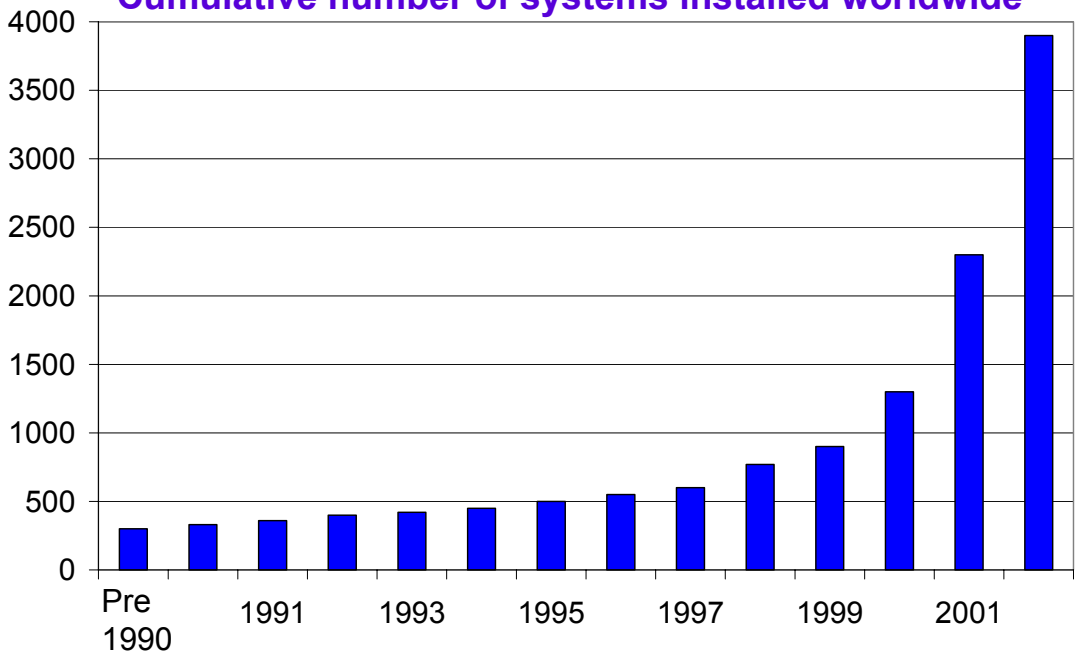
The UK has the opportunity to benefit by becoming a significant fuel cell market, mainly in stationary applications

- As fuel cell markets worldwide are at an embryonic stage, the UK has not been left behind
- The UK is well placed to benefit from the stimulation of stationary fuel cell markets
- There would be fewer benefits from stimulation of fuel cell vehicle markets in the UK
- Stimulation of the portable device market would provide limited benefits to the UK

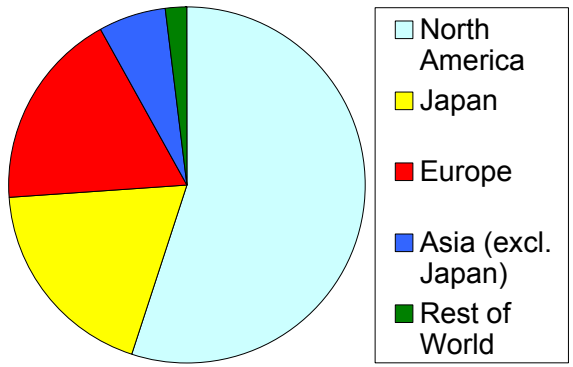
As fuel cell markets worldwide are at an embryonic stage, the UK has not been left behind

- Only 4,000 systems have been installed to date
- Approximately 57% of installations are in stationary applications, 28% in portable and 15% in transportation
- The UK currently has only one fuel cell in regular commercial operation

Cumulative number of systems installed worldwide



Regional split, by number of systems



Source: Fuel Cell Today Survey of Worldwide Activity 2002

The UK has several market advantages in stationary power, mainly in distributed power and CHP

Distributed power / CHP	Domestic and small commercial CHP	Small gensets and remote power
✓ Deregulated electricity industry ✓ Extensive natural gas network ✓ Potential for integration with intermittent renewables ✗ Not an early adopter market ✗ Barriers to distributed generation – although some being addressed	✓ Extensive natural gas network ✗ Good electricity grid network coverage and quality ✗ High levels of domestic boiler ownership ✗ Low differential between electricity and gas prices ✗ Not an early adopter market	✓ In general the EU market often does not require gensets to be as heavily engineered as in the US

Key
✓ = Positive factor
✗ = Negative factor

The UK could benefit from stimulating the market for stationary fuel cells

Market stimulation

- Localised emissions restrictions
- Support for high quality CHP
- Energy efficiency standards
- Increased fuel costs through taxation/levies
- Support for renewably sourced hydrogen fuel

Benefits

- Potential for high UK content stationary fuel cells (see section 7)
- May create indirect supply side opportunities:
  - Experience could be used by UK supply side for mainstream stationary and mobile application development
  - Service and fuel infrastructure would need to be local, creating UK capabilities which may be exportable
  - International integrators may need local base to serve local demand
- Could contribute to CO_2 reduction, regardless of who supplies the fuel cells

The UK market for fuel cell vehicles is not exceptional, though there are encouraging features

- "The UK market is nothing exceptional – one of several potential markets for FCVs, but probably not one of the first" (Major fuel cell company)

BUT

- Existing High vehicle and fuel prices/tax may help
- Urban congestion and congestion charging could favour FCV efficiency
- Public sector awareness is reasonably high e.g. demand for clean ZEV urban buses
- No particular consumer demand for other vehicle types
- Government seen as taking a proactive role
- Other advantages include the significant UK wind resource and the fact that it is an island, potentially making new fuel infrastructure investment simpler

The UK could seek to benefit through stimulating the market for fuel cell vehicles, though there are important drawbacks

Market stimulation

- UK can influence the debate on EU regulations for passenger cars
- The UK can stimulate the market for low carbon passenger cars e.g.
  - Further reform of vehicle and fuel taxation to provide incentives to minimise CO2 emissions
  - Relief from congestion charges
- UK can lead in the creation of niche vehicle classes and fleets
- Government could facilitate infrastructure development

Benefits

- Earlier environmental improvements than under status quo
- Sensitise consumers to low carbon products and services
- Spin-off supply side effects, such as stimulating entrepreneurial activity and attracting inward investment

Drawbacks

- Fuel cell vehicle demonstrations are very expensive*
- The vehicles available in the short/medium term have low UK content (see section 7)

* Indicative lease costs for FCVs: Toyota FCV car ~£80,000p.a.; CUTE bus 2 years ~£800,000

The UK portable device market is not distinctive and market stimulation would provide limited benefits to the UK

Market features

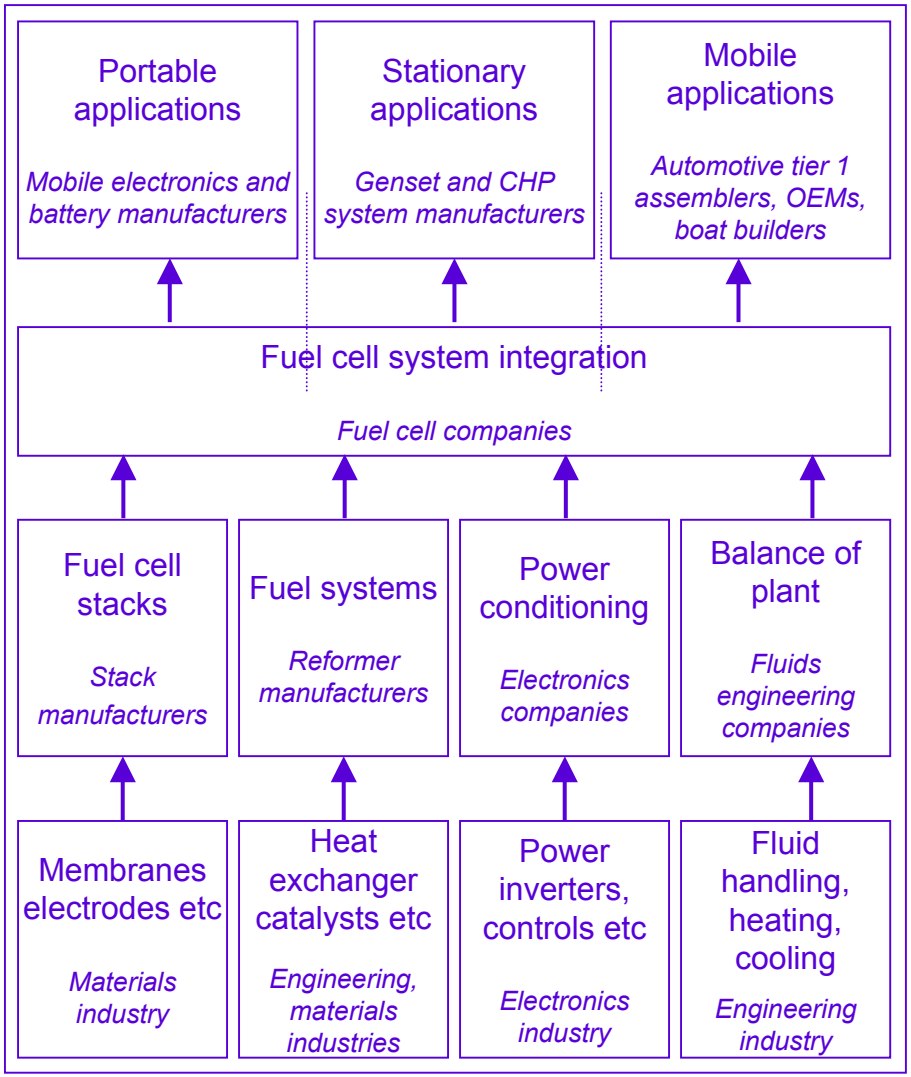
- Not an early adopter market for novel technologies, though a high margin market
- Military tries to avoid sourcing 'specials' but has some specific fuel cell interests in narrow niches

Implications of market stimulation

- Japanese consumer electronics brands have very strong image and therefore are more likely to benefit than UK manufacturers
- Very limited CO_2 or other emissions benefits from battery replacement
- Portable fuel cell technology has limited applicability in mainstream applications where societal benefits are greater

Contents

UK is currently a modest player on the supply side of the fuel cell industry, but has pockets of acknowledged expertise



Areas of Strength

- Established supply base in stationary power system integration, with some interest in offering fuel cell systems
- Integration strengths in niche applications for portable fuel cells, but little base for consumer electronics markets
- Some world class R&D & components developers in PEM fuel cells, but few system and stack-level players
- Strong SOFC technology base and a few early stage companies
- Relevant skills and one world class company in other component areas

See Appendix E

There is an established supply base in stationary power system integration and some interest in offering fuel cell systems

- Established companies in domestic water heating (~10) and large power systems (<5)
- Few major players but many specialists in volume markets e.g. small gensets
- Some utilities would like to offer CHP systems to their customers
- Established power equipment company developing fuel cell system for stationary power sector

Integration strengths in niche applications for portable fuel cells, but little base for consumer electronics markets

- Little if any corporate base in consumer electronics (compared with Japan and US)
- Integrators of power tools, wheelchairs and battlefield power devices
- No micro fuel cell stack companies (dominated by Asian & US consumer electronics companies)
- Two compact PEM developers, some development in compact SOFC
- Novel IP that could be employed in different types of fuel cell, including micro and compact fuel cells

Few system and stack-level players in PEM fuel cells, but some world class R&D and components

Sector	Strengths	Weaknesses
Fuel cell systems	One company with claimed distinctiveness versus more established players, currently focusing on the stationary market	At fairly early stage compared with competitors
Stack subsystems	One company with several years of R&D track record	Very early stage compared with competitors
Membrane electrode assemblies	One company described as 'world class'; strong university research especially in catalysts; two novel early stage enabling technology companies	Limited breadth of supply
Bipolar plates	Four companies with different capabilities serving international markets, one of these includes technology for portable micro fuel cells; strong science base	
Other low temp fuel cell stack components	Good base of specialist materials and components companies; good university research	Very limited local market; many UK companies would be tempted to set up alongside major customers in North America

Strong SOFC technology base, but companies are at an early stage

Sector	Strengths	Weaknesses
Fuel cell systems	One company with claimed distinctiveness compared to more established players	At fairly early stage compared with competitors
Stack subsystems	Two companies, each with several years of R&D track record	Very early stage compared with competitors
High temp fuel cell stack components	Small but strong base of specialist materials and components companies; strong university research	Not a wide range of suppliers; steel industry waning; materials manufacturing mostly not in UK

Despite the general decline in engineering, the UK has relevant skills and one world class company in other component areas

Sector	Strengths	Weaknesses
Fuel processors	Historically strong in research and early development, especially in catalysts and ceramics; one player still described as 'leading'	UK capabilities and activity have declined
Power conditioning systems	Large scale power engineering	Lacking relevant solid state power electronics companies
Mechanical balance of plant	Turbochargers and compressors historically strong	Most areas have declined in line with automotive sector; very few tier one suppliers;
H2 production and storage	UK historically strong in fuels, growing interests in hydrogen energy. Some R&D in production and storage	No UK companies directly involved in production or on-board storage

Contents

Main opportunities appear to lie in high value fuel cell applications and specialising in IP-led areas of the supply chain

- Application integration offers a few opportunities for the UK
  - There are opportunities for stationary power system integration through established UK companies
  - Portable fuel cell integration opportunities lie in specialist compact rather than high volume micro devices
  - In fuel cell powertrain integration APU opportunities are more promising than propulsion
- Low temperature fuel cell components offer a strong UK opportunity, whilst stack companies are positioned for high value non-automotive applications
  - Low temperature IP-based fuel cell components are an area of strength, but support will be needed to retain activity in the UK
  - At present, stationary and portable stack development appears to be more feasible than vehicle stacks
- High temperature fuel cell systems & materials are areas of technology strength, but UK needs to catch up with competition
- The UK could benefit through targeting specific IP-led areas within balance of plant

There are opportunities for stationary power system integration through established UK companies

- **Large scale distributed power** provides integration opportunities for the UK.
  - Successful companies will require well established brands, global reach and the ability to invest heavily for the long term. The UK has a small number of such companies.
  - Fuel cell systems used by these integrators will not necessarily be developed internally or sourced locally. A need for close technology co-development may mean that these integrators would move activity elsewhere if a significant proportion of the fuel cell technology is not UK-derived.

- At least one UK company is planning to integrate fuel cell **domestic CHP systems:**
  - Other companies have the potential to participate since they have the necessary channels to market.
  - UK integrators are likely to source subsystems globally, so UK fuel cell and component companies may not be at an advantage unless they provide distinctive cost, performance or other benefits.

- **Gensets and remote power systems** are developed by integrators with a focus ranging from specialist to mass market, depending on application.
  - The UK has several specialists but few mass market players and the former are often less aware of the potential benefits of fuel cells.
  - Specialist applications may provide a good opportunity for UK fuel cell and component companies to work in partnership with integrators in order to develop near term commercial products.

Portable fuel cell integration opportunities lie in specialist compact rather than high volume micro devices

- The UK has very limited presence at integrator level for mass market applications such as portable electronic devices. These applications are dominated by Japanese and US companies with their own **micro** fuel cell development programmes which the UK is unlikely to be able to match.
- At slightly larger technology scale the UK has integration activity in portable / quasi-portable applications such as wheelchairs, military and DIY battery chargers. The UK also has at least two **compact** fuel cell companies with relevant technologies for this area.

In fuel cell power-train integration, APU opportunities are more promising than propulsion

- Fuel cell vehicle development is currently dominated by US, Japanese and German vehicle manufacturers operating from technical centres within their own countries and with strong alliances to leading fuel cell companies.

- The UK has no major vehicle technical centres, though it has limited presence in vehicle development engineering activities, with emphasis on premium niches rather than mass markets. These niches, particularly luxury cars, are promising applications for APUs, but much less so for fuel cell propulsion.

- As fuel cell vehicle volumes increase it is likely that integration of fuel cell powertrains will migrate to fuel cell assembly plants, whilst retaining strong links to development engineering centres. These assembly plants will probably replace engine assembly plants in the vehicle supply chain.

- The UK has in the past been a favourable location for vehicle and engine assembly, based upon labour flexibility and historic skills in the sector, but this is threatened by exchange rates and the decline of UK car manufacturers. The lack of development engineering centres places the UK at a further disadvantage as a volume assembly base for fuel cell powertrains.

- There may still be opportunities for the UK to play a role in assembly of fuel cell APUs. This activity is likely to centre upon tier 1 components players which have a diminishing presence in the UK, though the presence of luxury car manufacturers may attract assembly operations.

Low temperature fuel cell components are an area of strength, but support will be needed to retain activity in the UK

- UK has a leading position in MEA technology and also a strong base of companies in bipolar plates and other low temperature fuel cell components. There are also some novel and potentially valuable enabling technologies under development. Several of these components and technologies are complementary whilst the application focus is broad.
- A very small proportion of the business of these companies is UK-derived. As the fuel cell market develops internationally, several of these companies are likely to be put under pressure to move to manufacturing centres outside the UK unless their home market develops in tandem.
- Continued support of these companies and technologies will draw upon other areas of the UK supply chain and help to build a critical mass. It may also be possible to develop automotive fuel cell components through a well-organised collaborative programme with automotive companies.
  - A UK fuel cell components industry technical centre (real or virtual) could be used to provide a focus for development efforts, with particular focus upon critical industry challenges such as next-generation membranes.
  - New entrants to the supply chain could be encouraged where UK skills are available but the fuel cell opportunity is not recognised.

At present, vehicle stack development appears to be beyond reach so other options may need to be considered

- The UK stack industry is small, potentially distinctive but not focused on very high volume markets
  - The UK has a small number of stack developers at varying stages of development, though none are at the scale of the industry leaders in North America. However, some UK players claim strong technical differentiation.
  - Although the market for stationary fuel cell stacks is set to grow significantly, in the long term the largest volume opportunity will be automotive fuel cell stacks
- Continued fuel cell commercialisation will require considerable funding for all applications, implying that careful focus is needed
  - Fuel cell propulsion development funding requirements for volume vehicles appear prohibitive for UK companies and so stationary and portable applications are the likely targets.
  - Higher value applications which match the distinctiveness of UK technologies are the logical choice. This may also keep the option of vehicle applications open for the long term.
- If UK companies are not successful there is a range of opportunities for the UK to maintain involvement in fuel cells
  - Selling IP or companies in their current state would probably not deliver significant added value, though licensing may provide R&D payback for companies that cannot gain funding.
  - An international fuel cell developer may be persuaded to set up a centre in the UK if conditions were seen to be very favourable for fuel cell applications. The UK supply chain and research base would benefit, though UK stack companies may be threatened.
  - A manufacturing centre for fuel cell stacks could be attracted to the UK in order to maintain a place in the fuel cell business, if it were felt that organic growth of UK companies would not lead to this.

High temperature fuel cell systems & materials are areas of technology strength, but UK needs to catch up with competition

- UK has a strong technology base in SOFC materials and subsystems. These technologies are complementary and cover a range of potential applications from small to large scale
- SOFC systems are typically developed as a whole, rather than assembled from subsystems supplied by components companies:
  - Barriers to entry may hence be higher than for low temperature systems
  - The main input for the stack/system developer is materials
- UK technology development is at the short stack and subsystem level, while international competitors have full systems under trial. Competing systems may not be optimally designed, so opportunities still exist for UK players. Support for continued commercialisation of UK stack technology would assist these opportunities to be exploited.
  - Support for R&D in specific materials would maintain the strong research base in a key section of the supply chain. New entrants to the supply chain could be encouraged where UK skills are available but the fuel cell opportunity is not recognised.
  - A UK fuel cell technology centre (real or virtual) could be used to provide a focus for diverse UK skills and development efforts by linking universities and companies to strengthen the UK industry.
- Without continued support other opportunities could be considered
  - Overseas exploitation of IP developed in the UK could provide a short-term return on R&D investment, but will not maximise the potential opportunity if done in isolation
  - A manufacturing centre might be attracted to the UK to support the supply chain, but might also compete directly with the existing industry

The UK could benefit through support for specific IP-led areas within balance of plant

- The UK has skills in specific areas of balance of plant, rather than across the range.
- Some fuel processor expertise exists, but competition in this area is significant. Support for exploitation of UK strengths in catalysis – in partnership with fuel processor developers – would enable UK companies to access global opportunities in reformer components.
- Cost-effective, small-scale power conditioning systems (PCS) suitable for fuel cells currently have limited availability in the market. Developing expertise around existing UK skills in large-scale PCS equipment could allow exploitation of a niche, and potentially allow access to other markets.
- Some UK companies are well placed to produce other balance of plant equipment (pumps, compressors, etc) but this area is as yet undeveloped. Encouraging links between these companies and those already in the fuel cell supply chain could enable new opportunities to be exploited and provide critical enablers for fuel cell companies.

Appendices

A. Interview and workshop participants

B. Summaries of findings in each sector

C. Main features of application areas

D. Worldwide government support for fuel cells

E. UK companies with capabilities relevant to fuel cells

F. Opportunity discussion data

Discussions were held with over 60 organisations

Demand side			Supply side	
Mobile	**Stationary**	**Portable**		
• Aprilia • BA • BMW • BP • Boots • Cardiff Uni. • Daimler Chrysler • Delphi • DTI • ENEA • Evobus • Ford • GM • Leyland/Daf • Ricardo • Sussex Uni. • Shell • Toyota	• Baxi Potterton • British Sugar • Dalkia Services • FG Wilson • Hawker Battery/ Enersys • Innogy • Invensys • Methanex • National Grid • Orange • Perkins • Scottish & Southern • TXU-Powergen	• Black & Decker • DuPont • Gillette • Motorola • Sunrise Medical • University of Duisburg	• Accentus • Adelan • Advantica Technologies • Alstom • Ballard • Ceres Power • Conduit Ventures • European Fuel Cell • Fuel Cell Today • Heatric • Ineos Chlor • Intelligent Energy • ITM Power • Johnson Matthey	• LIFE-IC • Microponents • Nuvera • Porvair • QinetiQ • Regenesys Technologies • RegenTech • Rolls-Royce • Scientific Generics • UTC Fuel Cells • Victrex • Vepro • World Fuel Cell Council/ Fuel Cell Europe

Workshop day attendees

Company	Name
Adelan	Michaela Kendall
Alstom (fuel cells)	John Loughhead
Ballard Automotive	Mark-Uwe Osswald
Baxi Potterton / European Fuel Cell GmbH	Guido Gummert
BMW	John Hollis
BP	Angelo Amorelli
Ceres Power Ltd	Nigel Brandon
Ineos Chlor	Dave Hodgson
Intelligent Energy	Dennis Hayter
Johnson Matthey	Jack Frost
Morgan Fuel Cell	Laurence Bryce
Porvair	Ian Stirling

Company	Name
QinetiQ	Ken Cowey Steve Farmer
Ricardo	Nick Owen
Rolls Royce	Alan Spangler
Scientific Generics	Peter Bance
Scottish and Southern Energy	Garth Graham
Shell Hydrogen	Chris de Koning
Toyota	Bert de Colvenaer
TXU Energy	John Curran
UTC Fuel Cells	Darcy Nicolle
World Fuel Cell Council/ Fuel Cell Europe	Patrick Trezona

	Company	Name
Workshop facilitation and hosts:	Department of Trade and Industry	Iain Todd, Barbara Hammond, Ray Eaton, Roy Williamson
	Carbon Trust	Tom Delay, Peter Shortt, Garry Staunton, Jonathan Bryers
	E4tech (UK) Ltd. and Associates	Adam Chase, Ausilio Bauen, David Hart, Rebecca Hailes, Jo Howes, Paul Arwas

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Summary of mobile sector findings

Application	Incumbent technology	Drivers for fuel cells	Commercial potential of FCs in applications			Fuel cell technology variant and strength	UK supply capabilities
			Probability	Timing	Prize		
Mobile propulsion • **All vehicle types**	ICE	• No market pull • Concern about future regulation • Automotive company desire to move away from environmental 'bad guy' image	• Substantial technical hurdles • Probable	• Demos 2002-4 leading to urban fleet demos 2004-2008+. Car and scooter commercialisation in 2010+, followed by buses, depending on fuel and other factors	Stacks: ~$3 bn in 2011 ~$135 bn (long term)	• PEMFC, likely fuel: H2 compressed or liquid • Volume, weight • Cost reduction potential, mass manufacturing potential	• OEMs – luxury cars • Bus assembly • Limited car assembly • Engineering services and electric drive skills • Suitable BoP but undeveloped market • PEM stacks and small scale emerging SOFC stacks • MEAs for PEM • Bipolar plates for PEM • Materials science expertise esp. catalysts, ceramics and metals prototyping • Academic and R&D base
Mobile Auxiliary Power Units • **Luxury cars**	Battery	• Performance/ Cost relative to batteries coupled with rising power requirements	• Fuel related • Probable	• Fuel related, up to 5 years	Stacks: ~$0.3bn in 2011 ~$3.2 bn (long term)	With same fuel as propulsion: • SOFC or PEMFC with gasoline reformer • SOFC or PEMFC with H2	
Mobile Auxiliary Power Units • **Trucks**	Separate and additional onboard genset	• Cost of fuel and wear and tear at idling	• Fuel related • Probable	• Fuel related, up to 5 years	Stacks: ~$0.6bn in 2011 ~$6.5 bn (long term)	If same fuel as propulsion: • Diesel reforming unlikely • SOFC or PEMFC with LPG reformer • SOFC or PEMFC with H2 Carrying separate fuel: • SOFC with gasoline reformer • SOFC or PEMFC with H2	

Summary of stationary sector findings

Application	Incumbent technology	Drivers	Commercial potential of fuel cells in this application			FC technology variant and it's strengths	UK supply capabilities
			Probability	Timing	Prize		
Distributed power/CHP	• Gas turbine • CHP	• Economics: lifetime cost of system with greater efficiency, gas/electricity price difference • Some environmentally sensitive niches	Requires significant development, cost reduction. Early niches – environmentally sensitive areas or where resource available	• Niches possible for demonstration from 2005 • Wider commercialisation and CHP integration from 2010	~$6 bn in 2011	• SOFC most commonly discussed • SOFC/PAFC needed in UK for process heat • PEMFC. Will get cost reduction from automotive use	• Integrators: some current experience. Large corporates with trusted brand could develop integration engineering skills • SOFC stacks: several early stage companies, position potentially competitive • SOFC stack components: are within stack companies, but specialist material companies and research have potential • Power conditioning: good large scale expertise • Mechanical BoP: no specific strengths
Domestic and small commercial CHP	• Gas boiler • Mains electricity	• Product/service offering for utilities • CO2 reduction	Likely through utilities if regulation supportive	• Demos in 2-3 years • Utility commercialisation from 2010	~$3 bn in 2011	• SOFC – direct use of gas, high T heat produced • PEMFC where H2 is available or with small reformer	• Integrators:likely to be existing companies e.g. in boilers • PEM stacks/systems: 2 early stage cos. • MEAs: leading technology & research base • Bipolar plates:good base-4 UK companies and good research • Fuel processors:some niche technology • Power conditioning: low at this scale
Small gensets and remote power	• Petrol/ diesel genset • Batteries	• Vary with application: reliability, refuelling frequency, cost, noise, emissions, portability	• Strong in military and other niches • Possible in most markets • Unlikely in very cost sensitive markets	• Imminent in niches • In next 5 years for wider markets	~$2.5 bn in 2011	• PEMFCs match requirements now • SOFCs possible but further away	• Integrators: many co.s could act as fuel cell integrators as low investment, technical difficulty to buy in stacks • PEMFCs as above • Power conditioning: low at this scale

Summary of portable sector findings

Application	Incumbent technology	Drivers	Commercial potential of fuel cells in this application			fuel cell technology variant and it's strengths	UK supply capabilities
			Probability	Timing	Prize		
Portable	• Batteries • Mains power • Gensets	• Longer recharge times, higher power to volume ratios than batteries. • More portable, quieter than gensets	• High in niches e.g. military, • Medium in many • Low in very small devices e.g. phones	• Very early niches for compact applications • Micro applications within 5 years	~$11bn in 2011	• DMFC or PEMFC plus reformer– high energy density and potential availability of methanol • PEMFC + hydrogen – no liquid involved	• Integrators: not good for micro in consumer products – US and Japan better but some in compact applications • Stacks – 2 compact PEM developers, nothing in micro • MEAs – expertise in one company and in research but not specifically compact/micro • Bipolar plates – 4 companies but not specifically compact/micro • Other – novel enabling technologies for micro?

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The mobile fuel cell market is considered as two separate areas: propulsion and auxiliary power units

Propulsion	Auxiliary Power Units
• Includes a wide variety of road vehicles • Typically: scooters 5kW+, cars 50kW+, buses 150kW+ • Fuel cells in hybrid or sole driver mode • Can be used to power some onboard electrical devices when stationary	• Two main application areas: luxury cars and trucks • Partially or fully replace battery, 5kW++ • Able to provide power independent of rest of power-train (which may be internal combustion engine)

The stationary fuel cell market is considered as three main application areas

Distributed power / CHP	Domestic and small commercial CHP	Small gensets and remote power
• Typically 100 kW_e –1 MW_e+ • Power or heat led • For power, heating and cooling • Examples: industrial auto generation, CHP in hospitals, microgrids, critical power • Global current addressable market approx $52bn p.a.	• Typically 0.5 – 10 kW_e • Heat led • For power and heating • Examples: single and multi-dwelling houses, small hotels, restaurants, offices • Current global hot water boiler market estimated at $17bn p.a.	• Typically 1-25 kW_e • Power only • Examples: mobile phone masts, critical facility back-up power, temporary power gensets, battery charger, remote power, energy storage using hydrogen • Global current addressable market estimate $12bn p.a.

N.B. This list is not exhaustive. Other applications mentioned in interviews include:

- Integration with renewables
- Load management e.g. peak shaving

Sources: Based on CSFB, US EIA, E4tech

Appendices

A. Interview and workshop participants

B. Summaries of findings in each sector

C. Main features of application areas

D. Worldwide government support for fuel cells

E. UK companies with capabilities relevant to fuel cells

F. Opportunity discussion data

Support programmes for fuel cells (1)

	Nature of support	Status of industry
US	• Hydrogen and fuel cell research funding exceeded $220m in 2002 • Providing $258m over 10 yrs for fuel cell cost reduction and commercialisation • Tax incentives for purchase or conversion of vehicles to fuel cells • Freedom CAR: government/industry support for fuel cell research • Californian LEV legislation, coupled with incentives for renewable energy and fuel cells, similar schemes in 24 states • State/local incentives to encourage fuel cell manufacturers to locate in their area e.g 3 yr $103m Ohio fuel cell Initiative for fuel cell R&D, Pittsburgh attracted Siemens Westinghouse with $8.2m incentives and nearly $4m low interest loans	• 23 fuel cell producers • California fuel cell partnership refuelling stations and fuel cell vehicle testing • Stationary fuel cell demonstrations
Canada	• $95 m investment in the last 20 years from government • Funding projects including fuel cell bus trials and has established Fuel Cells Canada and Canadian Transportation Fuel Cell Alliance • National Research Council Innovation Centre to spend $13 million over the next 5 years on R&D and commercialisation • Funding is for alternative technologies, not fuel cells specifically	• 7 fuel cell stack companies and many component suppliers • Bus demonstration projects • Stationary fuel cell demonstrations
Japan	• Significant funding for a number of years: $210m in 2002 • World Energy Network (WE-NET) –national hydrogen program, over 28 years with $2bn funding. 3 phase: R&D, demo projects (to 2005), commercialisation (2006-20) • Federal and local incentives including targets for fuel cell cars and cash and tax incentives for stationary and automotive fuel cell use • Japan Fuel Cell and Hydrogen project supports FCV demonstrations and early H2 infrastructure	• 10 fuel cell producers • 4 refuelling stations, with plans for 5 more stations fuelling first ‘commercial’ Toyota and Honda FCVs in 2003 • Stationary fuel cell demonstrations

Support programmes for fuel cells (2)

	Nature of support	Results to date
Germany	• Had second largest funding program, but direct investment has declined, with resources now directed to projects with shared costs, and to acquiring fuel cell power units, buses and infrastructure • Now focused on encouraging implementation. • CHP legislation is facilitating fuel cell entry into stationary power market • $18m budget for fuel cell R&D announced in 2001	• 6 fuel cell producers • Refuelling projects in Hamburg and at Munich Airport • Clean Energy Partnership Berlin - public refuelling station in 2003 • Stationary fuel cell demonstrations
Other	• EU: Clean Urban Transport for Europe (CUTE) project demonstrating fuel cell buses. European Integrated Hydrogen Project for development of vehicles and refuelling stations. Up to $70m funding per year for fuel cell and hydrogen RD&D • Also FP6 has $2bn allocated for R&D, but not all for fuel cells • Iceland: Ecological City Transport System (ECTOS) using fuel cell buses • Singapore: SINERGY programme for energy technology includes cooperation with Daimler Chrysler for FCV demonstration and with BP for hydrogen infrastructure for FCVs • China: R&D investment for the last 20 years, and plans for $114m for commercialisation.	• EU (excluding Germany) has ~15 fuel cell producers • More than 10 refuelling stations with a total of 33 buses to be in operation in EU cities in 2003 • Stationary fuel cell demonstrations

Sources: 'Fuel Cells: The Opportunity for Canada' June 2002 by PriceWaterhouseCoopers for Fuel Cells Canada, 'Fuel cells and hydrogen: the path forward' September by Breakthrough Technologies Institute, World Fuel Cell Council, DTI

The Canadian success story…

Canada's competitive position

- 13 Canadian companies primarily focused on fuel cell production and/or system integration
- Strengths in fuel cells for stationary, portable and transportation applications
- International strategic alliances between Canadian companies and industries that will be fuel cell users e.g. Hydrogenics with GM
- 28 other suppliers, service providers (consultancy, R&D, VCs) and fuelling infrastructure developers
- Knowledge-based clusters of fuel cell companies, suppliers and service providers in Vancouver, Toronto, Montreal and Calgary
- Financial support for clusters from federal and provincial government
- Clusters create strong linkages, promote knowledge transfer, provide self-sufficiency, pool of skills
- Each cluster has its own partnerships and technology strengths e.g. PEM in Vancouver

Current economic benefits to Canada

- Fuel cell producers employ around 1640 people
- Employment multiplier estimated at 2.5, giving 4,100 jobs in fuel cell companies, supplier industry and as a result of spending
- $91 m annual capital and operating expenditure by fuel cell companies on Canadian goods and services
- Spin-off benefits from technology crossover in composites, power electronics, control systems, electric drive train technologies, catalysts and heat transfer technology
- $91 m R&D investment from fuel cell companies, and increased number of Canadian patent filings in fuel cell manufacture

Source: 'Fuel Cells: The Opportunity for Canada' June 2002 by PriceWaterhouseCoopers for Fuel Cells Canada

…the way forward for Canada

Further proposed support

- Sustained funding for R&D and commercialisation
- Partnership with fuel cell companies and clusters to create a positive business environment
- Incentive packages from governments to attract location of plants for stationary fuel cells
- Promotion of demonstration projects and early adoption in the public and private sectors
- Education and training for skilled resources
- Development of codes and standards

Further development

- Attract stationary fuel cell manufacturing
- Develop small pilot plants for transportation fuel cells, followed by scale up to full capacity located close to centres of automotive manufacturing
- Export possibilities including:
  - Sale of proprietary knowledge to other fuel cell producers
  - Securing a share of portable fuel cell production
  - Material and component manufacture for sale to other fuel cell producers
  - Sale of fuel and fuelling infrastructure to other countries

Future economic benefits to Canada

- Creation of 43,000 jobs in stationary fuel cell production and 13,200 in transportation fuel cell production, with generation of a total of 141,000 direct, indirect and induced jobs in North America by 2011. The proportion of these jobs in Canada will depend on their ability to attract and keep producers
- Operating expenditures (excluding payroll) of $6.5 billion in North America
- Capital expenditure, both from initial expenditure and from enhancement of facilities likely to be large. Ballard have previously estimated that a full scale (300,000 unit) facility would cost $250-300 m.
- Value-added production in industries using fuel cells such as Canada's automotive industry
- Reduced costs of healthcare and environmental protection as a result of lower use of incumbent technologies

Source: 'Fuel Cells: The Opportunity for Canada' June 2002 by PriceWaterhouseCoopers for Fuel Cells Canada

US Freedom CAR Partnership Plan

- A research initiative of the US Department of Energy (DOE) and the United States Council for Automotive Research (USCAR)—Daimler Chrysler, Ford and GM, announced in January 2002
- focused on collaborative, pre-competitive, high-risk research to develop component technologies for cars and light trucks, primarily hydrogen-fuelled fuel cell vehicles
- Partners will conduct strategic planning, determine technical requirements, identify resources needed
- Will fund R&D at national laboratories, automotive suppliers, universities, small businesses, and other research institutions. Direct funding to automobile companies will be limited. Projects will be selected competitively, with industry and government developing the scope, priorities, and project measures.
- Technical milestones set for 2010 include:
  - Electric Propulsion System with a 15-year life capable of delivering at least 55kW for 18 seconds, and 30kW continuous at a system cost of $12/kW peak.
  - 60% peak energy-efficient, durable fuel cell power system (including hydrogen storage) that achieves a 325 W/kg power density and 220 W/L operating on hydrogen. Cost targets are at $45/kW by 2010 ($30/kW by 2015)
  - Fuel cell systems, including a fuel reformer, having a peak brake engine efficiency of 45%, and that meet or exceed emissions standards with a cost target of $45/kW by 2010 and $30/kW in 2015
  - Demonstrated hydrogen refuelling with developed commercial codes and standards and diverse renewable and non-renewable energy sources. Targets: 70% energy efficiency well-to-pump; cost of energy from hydrogen equivalent to gasoline at market price, assumed to be $1.50 per gallon (2001 dollars).
  - Hydrogen storage systems demonstrating an available capacity of 6 wt% hydrogen, specific energy of 2000 W-h/kg, and an energy density of 1100 W-h/litre at a cost of $5/kW-h.5
  - Material and manufacturing technologies for high volume production vehicles that enable 50% reduction in the weight of vehicle structure and subsystems, affordability, and increased use of recyclable/renewable materials.

Appendices

A. Interview and workshop participants

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UK companies with capabilities relevant to fuel cells

Stacks

- Adelan
- Ceres Power Ltd
- Intelligent Energy
- Rolls-Royce
- QinetiQ

Integration

- Alstom
- Alternative Fuel Systems Ltd
- Baxi Potterton
- DSTL
- Ecocats Ltd.
- FG Wilson
- LDV
- Leyland Product Developments Ltd
- MIRA
- Regenesys Technologies Ltd
- ReGenTech
- TXU Europe
- VEPRO
- Vickers
- Voller Energy

Fuel

- Air Products
- BP
- BOC
- Linde Gas (UK) Ltd.
- Messer UK Ltd.
- Shell

Components & Materials

- ABB Alstom Power
- Accentus
- Advance Galatrek
- Advanced Ceramics Ltd
- Advantica Technologies
- Air Products Europe
- ATT
- Avesta Sheffield
- Beeston Heating Ltd.
- Bitrode Ltd.
- Bowman Power Systems Ltd.
- Brevini (UK) Ltd.
- Brush Electrical
- Cannon Technologies
- CERAM Research
- Ceramtec
- Chart Heat Exchangers
- City Technology Ltd.
- Crompton Instruments
- Cummins Power Generation
- Driver Technology Ltd
- EA Technology
- Electrospeed
- Energy Matters
- Fuel Cell Control Ltd.
- Frank W Murphy Ltd.
- FR-HiTemp Ltd.
- Gasforce
- The Generics Group
- GDS Instruments Ltd.
- Heatric
- Holset
- Ineos Chlor
- ITM Power
- Johnson Matthey
- Jordan Hydrogen Systems
- Lake Interconnection systems
- Lancaster Fibre Technology
- Levelstate Systems Ltd.
- Marconi Caswell Ltd
- Mast Carbon
- Megacon Controls Ltd.
- Mel Chemicals
- Microponents Limited
- Microtherm International Ltd
- Morgan Fuel Cell
- Papst plc.
- Peter Brotherhood Ltd.
- Porvair
- Proman Energy Ltd
- Schneider Electric Ltd.
- SMC components
- Solartron Analytical
- Special Metals Wiggin Ltd
- Taylor Fuel Control
- Technical Fibre Products Ltd.
- TEI Mechanical Services
- Thermacore Europe Ltd.
- Tioxide Specialities
- Victrex plc
- Wellman Defence
- Wellman Robey Ltd.

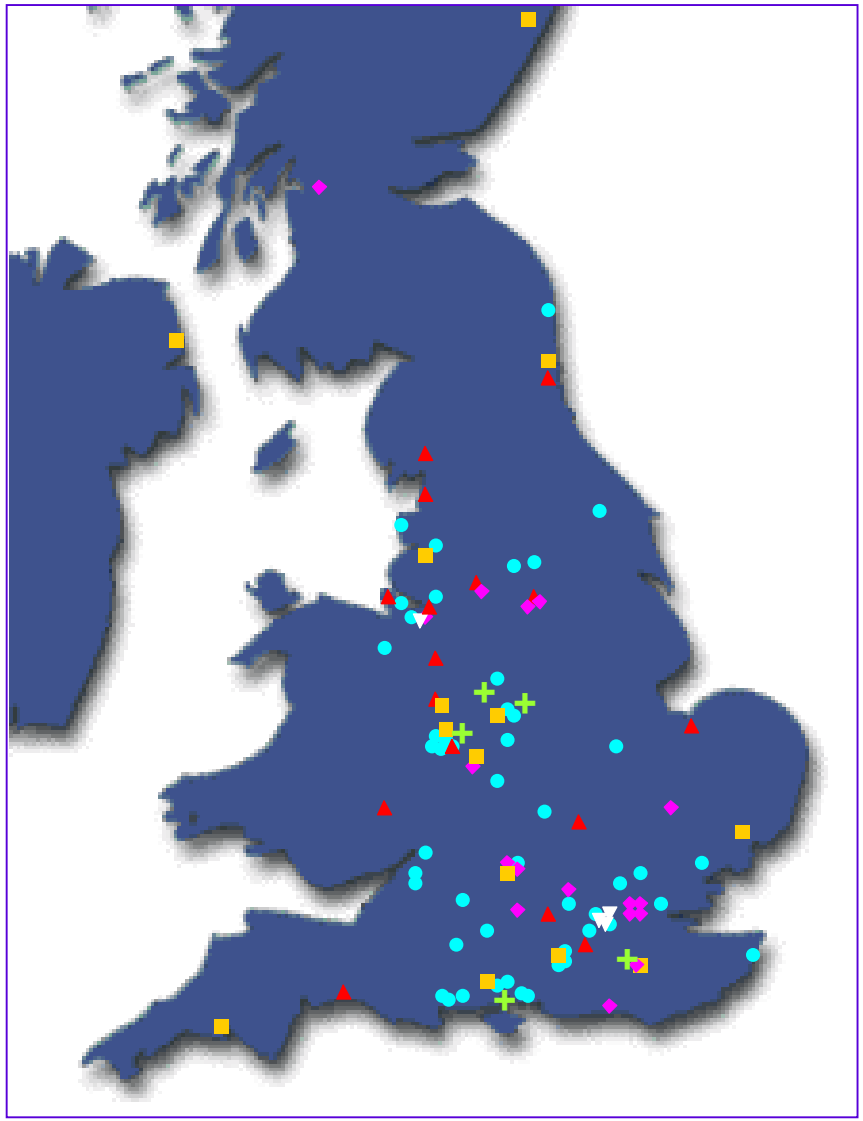
Consultancy, information & finance

- CEL International Ltd.
- Close Brothers Corporate Finance
- Conduit Ventures Ltd.
- Core Technology Ventures
- E4tech UK Ltd.
- EA Technology
- Escovale Consultancy Services
- Fluent Europe Ltd.
- Fuel Cell Network
- Fuel Cell Today
- Future Energy Solutions
- H2NET network
- HEAUKI
- HIL Tech Developments Ltd.
- Interact Consultancy (UK) Ltd
- International Innovation Services
- Renewable Energy Management
- Ricardo Consulting Engineers Ltd.
- Scottish Fuel cell consortium
- The Generics Group

Based on ETSU report 'Prospects for UK Fuel Cell Component Suppliers' F/03/00251/00/REP

E4tech

Distribution of UK companies by type



Appendices

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UK automotive integration sector has areas of strength but does not provide a strong magnet for fuel cells

- Both technology centres and OEM manufacturing for luxury cars are located in the UK
- UK has a major engine technology centre but limited passenger car assembly
- ICE manufacturing is relatively strong (4m units per annum vs. 1m vehicles), but threatened by strength of pound
- The UK motor sport industry is thriving
- Engineering services and electric drive skills are well represented
- Some bus assembly but powertrain manufacturing is carried out elsewhere

Opportunity discussion: stationary fuel cell integration

Opportunity area	Investment required		Fuel cell market potential ***	UK capabilities	UK challenges / opportunities?	Strategic rationale	Comments
	$/yr*	Time**					
Integration of large scale distributed power fuel cell systems	~$50m	5-10 years	~$6 bn in 2011	• Small number of established integrators • One fuel cell company active in this area	• Integrate systems based on UK and/or imported stacks & components	• Provides fuel cell supply chain 'pull'	• Major branded players will dominate, as integrator must be reliable / established, to (a) assure client trust, (b) provide integration engineering skillset • Stacks will be sourced on performance (and some supplier affinity)
Integration of domestic fuel cell CHP systems	~$5m	5-10 years	~$3 bn in 2011	• Small number of established integrators • Two or more fuel cell companies with relevant capabilities	• Integrate systems based on UK and/or imported stacks & components	• Local integrators will be needed for local markets • Provides fuel cell supply chain 'pull'	• Integrators will be existing companies but may be small/niche • Stacks sourced on performance
Integration of fuel cell genset and remote power systems	~$1-3m	2-5 years	~$2.5 bn in 2011	• Some integrators in specialist markets • Two or more fuel cell companies with relevant capabilities	• Integrate systems based on UK stacks & components	• Possible higher value entry point for FCs, sourced on performance • Provides fuel cell supply chain 'pull'	• Existing UPS integrators could easily include fuel cells in product range • Likely that only existing genset manufacturers will develop fuel cell gensets

* Estimated typical R&D spend for a single company wishing to pursue this opportunity area *(Source: Conduit Ventures)*

** Estimated duration of spend in order to establish a business with strong prospects of success *(Source: Conduit Ventures)*

*** Estimated global fuel cell market accessible under the spending conditions above*(Source: Industry surveys cited in PwC, Fuel Cells: The Opportunity for Canada, 2002)*

Opportunity discussion: low temperature fuel cell stacks

Opportunity area	Investment required		Fuel cell market potential ***
	$/yr*	Time**	
Stack subsystems for stationary power	~$5-20m	3-8 years	~$1 bn In 2011
Stack subsystems for vehicle propulsion	$100m +	Next 8+ years	~$3 bn in 2011 ~$135bn (long term)

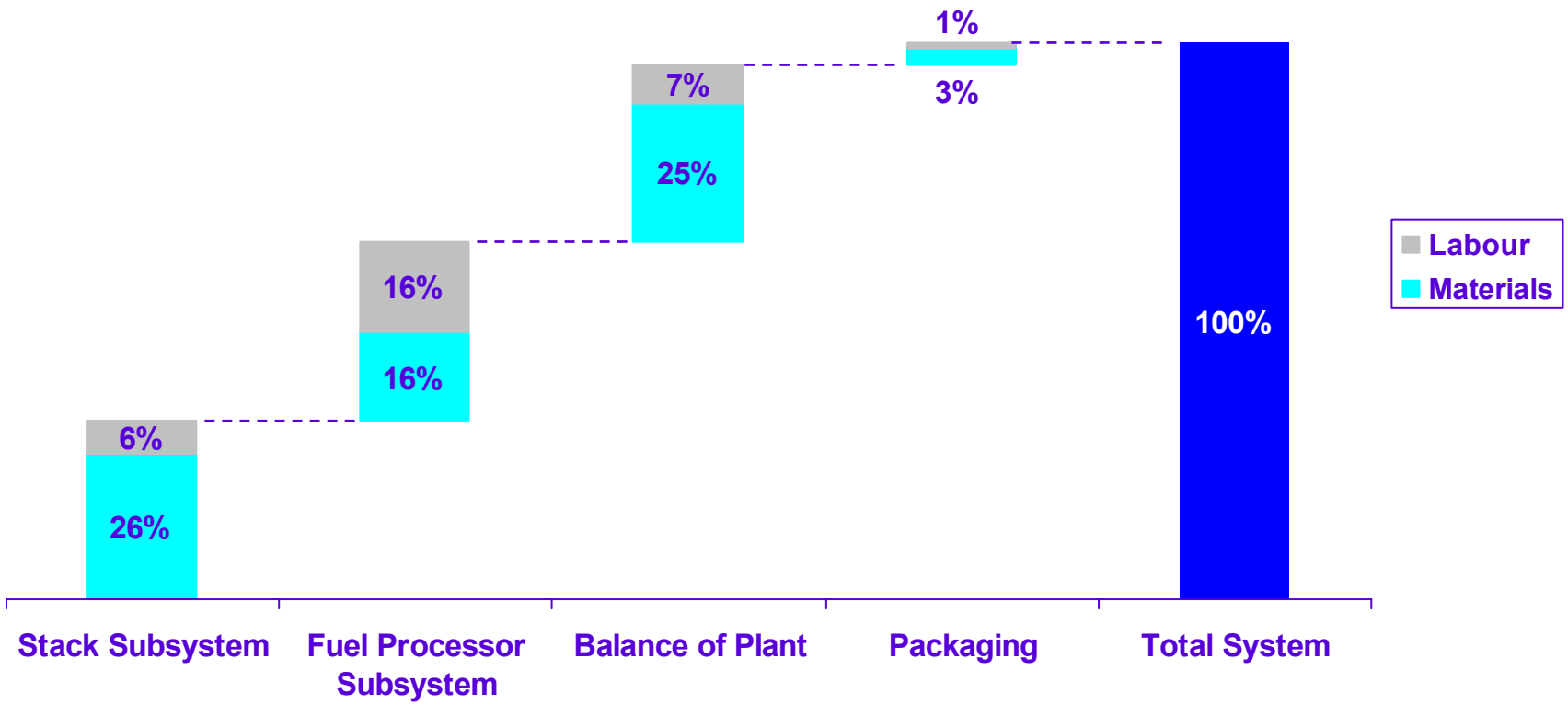
* Estimated typical R&D spend for a single company wishing to pursue this opportunity area *(Source: Conduit Ventures)*

** Estimated duration of spend in order to establish a business with strong prospects of success *(Source: Conduit Ventures)*

*** Estimated global fuel cell market accessible under the spending conditions above*(Source: Industry surveys cited in PwC, Fuel Cells: The Opportunity for Canada, 2002)*

UK challenges / opportunities?	Strategic rationale	Comments
• Continue to commercialise UK stack technology	• Will support supply chain • Potential for linked development of stationary and mobile stacks	• Needs considerable investment esp. vehicles • Competition in this sector is high
• Develop IP in UK, and exploit wherever possible	• Rapid route to R&D payback given early nature of UK fuel cell business	• Manufacture or licensing elsewhere can add value, but difficult to add long term value from IP sale alone
• Attract a technology development centre	• Would encourage UK fuel cell supply chain • Brings international capital to UK	• Need to show strong market commitment • Potential threat for UK stack companies
• Attract inward investment in manufacturing	• Will support supply chain • Ensure long term involvement of UK in fuel cell industry • Early mover advantage (small number of plants for vehicle propulsion stacks will be needed worldwide)	• Could attract European factory of a major stack manufacturer

Cost breakdown for stationary PEMFC <10kW power system DC output (<100units production)



Source: E4tech

Opportunity discussion: low temperature fuel cell components

Opportunity area	Investment required		Fuel cell market potential ***
	$/yr*	Time**	
MEAs for stationary	~$5m	5-10 years	~$0.8 bn in 2011
MEAs for Propulsion	$10m	Next 8+ years	~$2.3 bn in 2011
Bipolar plates	$1m	4-8yrs	~$0.6 bn in 2011
Other stack components e.g. gaskets	~$1m+	5-10 years	~$0.4 bn in 2011

* Estimated typical R&D spend for a single company wishing to pursue this opportunity area *(Source: Conduit Ventures)*

** Estimated duration of spend in order to establish a business with strong prospects of success *(Source: Conduit Ventures)*

*** Estimated global fuel cell market accessible under the spending conditions above*(Source: Industry surveys cited in PwC, Fuel Cells: The Opportunity for Canada, 2002)*

UK challenges / opportunities?	Strategic rationale	Comments
• Continue to commercialise UK technology	• UK has sufficient base upon which to develop world class players with strong IP and high barriers to entry • Assists the development of a supply chain • Without strong UK prospects players may relocate • Risk is spread across several applications	• Most current markets are outside UK • A collaborative development programme with automotive companies could be based in the UK if appropriately structured and supported • Incentives may be required to retain companies in UK
• Establish a technology development centre	• Link expertise from commercial companies and universities for joint development • Provides focus for diverse UK skills in components	• Export-led • Focus on next generation technology challenges
• Encourage new entrants	• Facilitation of UK-based co-operation / partnership in supply chain, particularly for 'other stack components'	• Requires selling of opportunity to new entrants

Opportunity discussion: high temperature fuel cell systems and materials

Opportunity area	Investment required		Fuel cell market potential***
	$/yr*	Time**	
Stationary power stack systems	~$15m+	5-10 years	~$1.9 bn in 2011
Automotive APU stack systems	~$20m	3-5yrs	~$0.9bn in 2011 ~$9.3 bn (long term)
Stationary stack materials	~$1m+	5-10 years	~$1.2 bn in 2011
Automotive APU stack materials	$3m	3-5yrs	$0.6 bn in 2011 ~$5.9bn (long term)

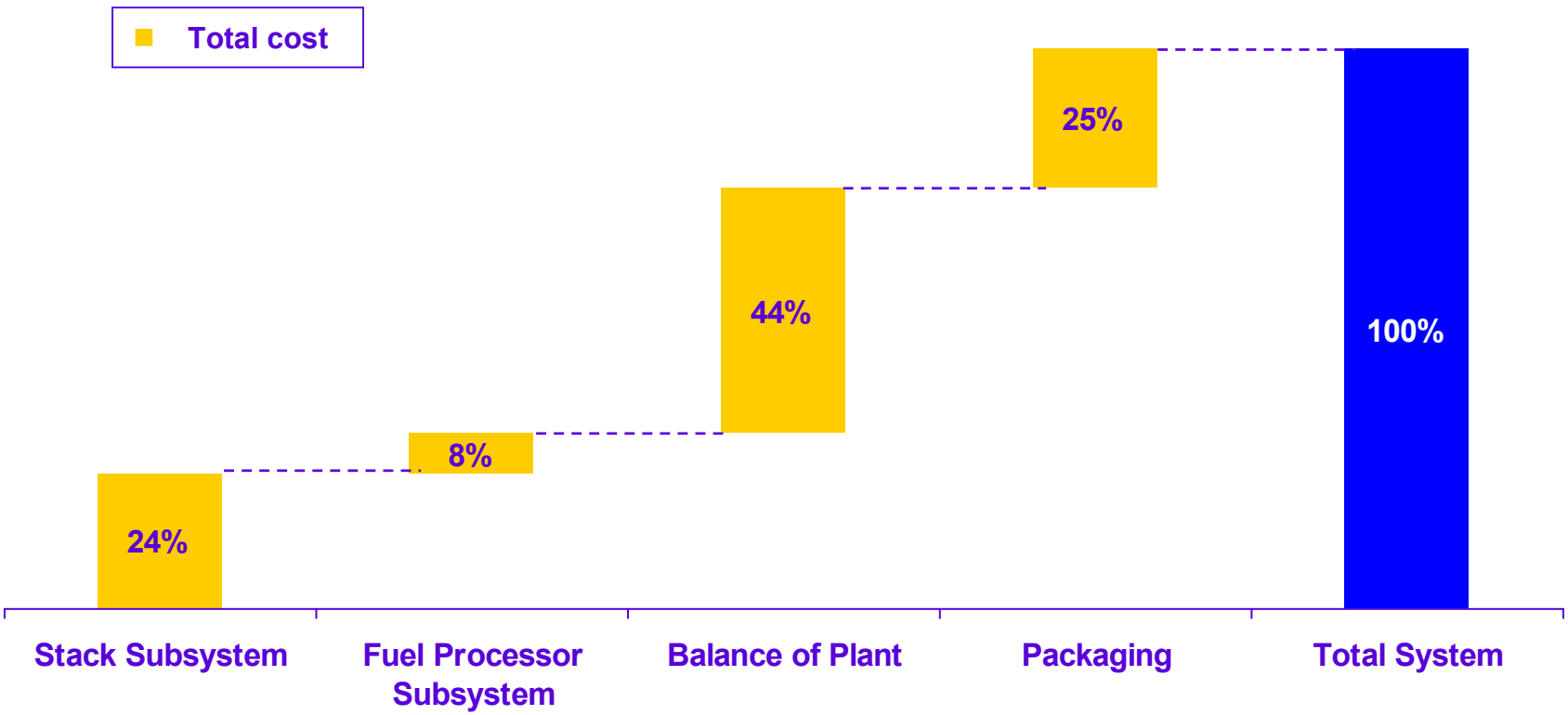
* Estimated typical R&D spend for a single company wishing to pursue this opportunity area *(Source: Conduit Ventures)*

** Estimated duration of spend in order to establish a business with strong prospects of success *(Source: Conduit Ventures)*

*** Estimated global fuel cell market accessible under the spending conditions above*(Source: Industry surveys cited in PwC, Fuel Cells: The Opportunity for Canada, 2002)*

UK challenges / opportunities?	Strategic rationale	Comments
• Continue to commercialise UK stack technology	• Potentially very strong technology • Higher barriers to entry than low temperature fuel cells as system must be developed as a whole	• Needs considerable investment, particularly at large scale and for APUs
• Build on existing materials supply base and encourage new entrants	• UK has strong research base in materials • Materials are key aspect of supply chain	• Requires continued support for R&D • Need to sell fuel cell opportunity
• Develop IP in UK, and exploit wherever possible	• Rapid route to R&D payback given early nature of UK fuel cell business	• Manufacture or licensing elsewhere can add value, but difficult to add long term value from IP sale alone
• Establish a new technology development centre	• Links expertise from commercial companies and universities for joint development • Provides focus for diverse UK skills in high temp fuel cells	• Focus on industry challenges with goal of developing strong UK fuel cell companies
• Attract inward investment in manufacturing	• Will support supply chain	• Need to consider the impact on existing players

Cost breakdown for stationary SOFC 17.5kW power system with integrated air heater (£1000/kW)



Source: Rolls Royce 1999

Opportunity discussion: balance of plant for low and high temperature fuel cells

Opportunity area	Investment required		Fuel cell market potential	UK challenges / opportunities?	Strategic rationale	Comments
	$/yr	Time				
Fuel processors	~$2m+	3-5 years	~$2.0 bn in 2011	•Develop and exploit existing catalysis expertise with FP developers	• Strong UK base • Supports supply chain development • Fundamental area for reformer industry which matches UK strengths	• Facilitated links within supply chain may be required • Requires continued support for R&D
Power conditioning systems	~$2m+	3-5 years	~$5.5 bn in 2011	• Build from existing supply base for large systems to develop low-cost equipment for small applications	• Gap exists in market	• Developments will largely be driven by non-fuel cell markets • Fuel cells will generally use existing systems • Offers access to other markets
Mechanical balance of plant	~$1m+	2-5 years	~$3.7 bn in 2011	• Build on existing supply base	• Specific components are required • Some suitable companies but undeveloped as a market area	• Some existing market pull • Off-the-shelf goods are preferred • Relationships between companies should be encouraged

* Estimated typical R&D spend for a single company wishing to pursue this opportunity area *(Source: Conduit Ventures)*

** Estimated duration of spend in order to establish a business with strong prospects of success *(Source: Conduit Ventures)*

*** Estimated global fuel cell market accessible under the spending conditions above*(Source: Industry surveys cited in PwC, Fuel Cells: The Opportunity for Canada, 2002)*