Fuel Cell Market Prospects and Intervention Strategies

Final Report

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1 STRATEGY OVERVIEW

The strategic long-term environmental goal for deployment of fuel cell technology is achievement of the “hydrogen economy”, at which point there would be very low emissions of greenhouse gases or local pollutants from energy use. UNEP/WMO IPCC’s Assessments of future carbon emissions scenarios are reviewed in this regard and are seen to rely heavily on assumptions of broad fuel cell penetration into power generation, heat and power cogeneration and transportation. Hydrogen fuel is assumed to come from renewable energy by electrolysis of water or biomass and from fossil fuel as syngases. Syngas production would permit separation of carbon dioxide and storage in the deep-ocean or underground. While fuel cells are a key technology, they are not a panacea and should therefore constitute a fraction of the GEF climate change program portfolios as opposed to the majority.

In the near term, fuel cells can use hydrogen reformed from fossil fuels[1] and some fuel cells will reform fossil fuels internally. Carbon dioxide emissions are generally lower than from comparable conventional technologies, as efficiencies of most fuel cells are relatively high compared to conventional small power units. In particular, internal combustion engine efficiencies fall off sharply at part load. Local pollution from fuel cells is very low to zero and noise is substantially less than internal combustion engines.

Thus, availability of hydrogen will not obstruct development of the fuel cell market. Conversely, the ability to use fossil fuels directly may delay development of a ***hydrogen infrastructure***, and the viability of long-term carbon dioxide storage is unclear.

This fuel infrastructure barrier can initially be addressed in GEF programmes by the use of less polluting fossil fuels (natural gas) and high efficiency fuel cells where there are net full fuel cycle benefits in comparison with the conventional technology or baseline. Reforming of diesel for use in lower efficiency fuel cells should generally be avoided, as the full fuel cycle emissions can be higher than diesel engine emissions. Although this may restrict project opportunities, GEF resources are not so large that this restriction will result in a reduction in projects.

Since GEF resources are orders of magnitude less than industry efforts and R&D support from OECD countries, GEF’s primary opportunity to influence price reduction is by opening the door to the large developing country market and catalysing increased investment. ***Technical assistance*** and barrier removal should include:

- ***developing policy***, power purchase agreements, duty relief, quality and safety standards
- supporting the ***establishment of developing country partnerships*** in the fuel cell industry for distribution, operation and maintenance infrastructure, local assembly and eventually production of system components (bus gliders, balance of plant, and fuel cells)
- ***demonstrating*** fuel cell technology in key developing countries to enable early participation in the technology and to build awareness
- assisting the development of ***commercialisation projects*** in developing countries through further targeted programme phases, discussed below

Fuel cell applications can be split into cars, distributed power generation, portable power, buses, 2 or 3 wheelers, and central power generation. Buses, power generation, and two or three wheelers are identified as GEF-eligible. Since cars are anticipated to dominate the fuel cell market development, they must be considered in any strategy. Technical capacity for operation and maintenance can be considered as a general pool that once established can serve any application. This will aid in achieving critical mass for operation and maintenance regionally and is a ***synergy*** that should be considered. Whereas centrally fuelled fleets normally refuel at night, hydrogen production and storage facilities can be used to supply distributed power and heat generation during the day when peak power loads occur. Synergies in R&D and production also exist in some cases and to a certain extent, though they

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[1] Fossil fuel use with CO_2 sequestration is an as yet unproven long term possibility. Syngases can also be based on biomass.

are limited by the differences in fuel cell design targets for transportation versus stationary applications (weight, product life, operating temperature, fuels, efficiency), and by the existence of a range of different fuel cells. Demonstrations should focus on identified GEF-eligible applications but acknowledge that technical capacity will exist in a larger pool and that public awareness may be more strongly affected by buses that the public can ride on and can "feel the differences." The fuel cell bus demonstration phase is underway and includes 5 countries in different regions.

The ***price*** of fuel cells is the major barrier to this technology. Billions of dollars are being spent on fuel cell technology by industry and national funding bodies, and an approximate 50:50 split of estimated future cost reduction is anticipated to come from R&D and from production volume increases. Fuel cells are identified in GEF operational programs as technologies eligible for cost reduction market intervention. Consortia are being formed and the market appears to have a robust diversification of suppliers that will result in a competitive healthy marketplace. Beyond initial demonstrations, a strategy for ***subsidising the cost*** of fuel cells in developing countries is recommended in order to avoid lock-in to other technologies and to maximise developing country capacities to produce components more inexpensively. Bus gliders will be produced at lower cost in the regions where the fuel cell buses were demonstrated, and many of the components that make up the balance of fuel cell power generation plant can be produced in developing countries. Some developing countries have initial experience with fuel cell fabrication. Commitment to technology transfer and ongoing sustained partnerships will be indicated by the amount of co-financing that the technology developers are willing to contribute to developing country demonstration and market development activities. A target of 20% private sector cash contribution was suggested for the FCB demonstrations. Subsidy of fuel cells for distributed power generation is identified to start at about 50% and decline.

The commercialisation of fuel cell buses in developing countries will require support in buying down the incremental costs, and demonstration projects are being introduced with a positive outlook in this regard. International development banks are identified for this role, as public transport and infrastructure is managed by governments. The informal public transport sector is not organised and will follow the car market in terms of technology. The point at which fuel cell buses' incremental cost comes within reach of competitiveness with other environmental technologies (natural gas, light rail) will be the primary timing opportunity for GEF interventions. This is in advance of a market clearing cost that is competitive with diesel buses. An approach to financing allocation under constrained GEF finance could be to identify amounts by tranches for FCB subsidisation (of 40 to 60 M$)[2], and then to set a target for GHG benefit cost at, for example, 20 to 60 $/tonne of carbon dioxide equivalent from direct impacts of the project. Project proponents would compete with proposals to meet this target. Other criteria would be used to ensure regional balance, renewable energy technology integration, sustainability and technology provider competitiveness.

Target costs for fuel cell systems are discussed for distributed power generation. The IFC's contributing report on Fuel Cell Distributed Power Generation has elaborated on the potential to accelerate the fuel cell market in developing countries. The market viability indicator of cost per kilowatt is appropriate in its own context, but having a GEF incremental cost in dollars per tonne of carbon dioxide equivalent for incremental costs of projects and broader estimated impacts is important to meet the intent of GEF Operational Program #11. The cost of GHG benefits indicator will encourage support for the cleaner fossil fuels, cogeneration and higher fuel cell efficiencies within the applications that will be more viable near term, enabling reduced carbon emissions without mandating the use of hydrogen in early phases. Although cleaner fossil fuels may dominate the early cost competitive market, continuous effort on early opportunities for renewable hydrogen production should be sought out and maintained as a portion of the program on fuel cells from the beginning, eventually becoming the primary focus. Carbon dioxide sequestration underground or in the deep ocean should not be assumed viable without a separate technology assessment for developing countries.

This overview was written from UNEP's perspective as implementing agency for the project. The work of the project executing agencies is elaborated in subsequent sections and separate reports.

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[2] The size and number of GEF interventions should be considered in light of Operational Programme portfolio balance.

The UNEP/WMO IPCC assessments and scenarios are discussed as a peer reviewed reference to long term technology development scenarios and development of global solutions that are transferred to developing countries in order to achieve low emission scenarios.

Sections on transport include consideration of cars, as they will dominate the technology evolution. Continued monitoring of all fuel cell applications during fuel cell program execution will be required to determine the best timing and technology focus of interventions. Fuel cell bus demonstrations are underway (US$60m in 5 cities) and there is an identified and agreed need to continue dialogue with the World Bank (and other international financing agencies) regarding conditions under which fuel cell buses may become of interest within their financing portfolio. An appropriate policy environment will be a prerequisite. A particular country's readiness in terms of evolution along transport mitigation strategies including integrated analysis and planning for combined non-motorised transport, demand management, bus lanes and other mass transit modes will be appropriate. World Bank and Regional Development Banks will much more broadly include fuel cell buses when they become competitive with other environmentally sustainable transport technologies.

Fuel cell distributed power generation demonstrations should be initiated as soon as possible. This market is expected to mature more quickly than buses, and the time for incremental cost buy down will come sooner. A total amount for GEF intervention through all Implementing and Executing Agencies in distributed power generation as cost buy down is identified as in the order of US$80M to $200M in three separate phases, plus several demonstration projects of about US$20M total. The consequences of not assisting developing countries to participate in the early adoption process are also discussed. Compromises leading to lower investment scenarios will increase the need to target sustainable markets/applications with higher potential global benefits. A long-term evolution to hydrogen will require ongoing analysis, higher financial support, and a refined longer-term strategy.

2 INTRODUCTION AND BACKGROUND

2.1 The Global Environment Facility

The GEF can play an important role in introducing new technologies, like fuel cells, into developing countries. Paths to long term environmental goals of low greenhouse gas emissions assume broad application of fuel cells. The GEF is a partnership between UNDP, UNEP and the World Bank, currently expanding to engage regional development banks, UNIDO, and FAO. It provides grants and concessional financing to meet incremental costs of activities towards global environmental benefits, e.g. greenhouse gas (GHG) emissions reductions. Additional regional/local benefits, e.g. reductions in local pollution, support sustained efforts toward alternative solutions. The GEF Operational Programmes (OP) support cost reduction efforts for emerging low GHG emitting technologies through OP7 [Reducing the Long-Term Costs of Low Greenhouse Gas Emitting Energy Technologies] and OP11 [Promoting Environmentally Sustainable Transport]. These programmes have funding components that support cost reduction of technologies. Programmes 5 and 6 are concerned with barrier removal and promotion of cost-effective energy efficiency and renewable energy alternatives (though they do not include cost buy down).

2.2 Fuel cells and the GEF

Fuel cells have been identified by the Global Environment Facility (GEF) as a promising technology for future greenhouse gas emissions reductions in the energy and transport sectors in developing countries. However, fuel cells are not yet commercially viable outside high-cost niche applications such as aerospace, and fuel cell systems are still being proven in many terrestrial applications. Funding their deployment in developing countries at this early stage in their life cycle must be clearly justified.

Fuel cell systems offer potentially large societal benefits in both the transport and stationary power sectors. They can be more efficient than conventional technologies, emit significantly less greenhouse gas and regulated pollutants, and produce lower levels of noise. In many GEF programme countries they could be more reliable than grid-supplied electricity.

The United Nations Environment Programme (UNEP) implemented this study for the Global Environment Facility (GEF) with the United Nations Development Programme (UNDP) and the International Finance Corporation (IFC) of the World Bank as executing agencies, focusing on fuel cell buses and distributed power generation respectively. Imperial College as a third supporting agency provided supplementary effort including the consolidation into this final report. The study was to clarify the status and potential benefits of the different fuel cell technologies and possible markets. This study would

> "review the climate change mitigation potential from fuel cell applications in distributed electricity generation and urban buses and develop strategy options for market intervention."

To do this, the study would address the global technical and commercial readiness of the technology, expected emissions reductions arising from its use, and the suitability of developing country markets for early fuel cell system deployment. Fuel cell systems in buses and in stationary distributed power were specifically targeted for analysis as GEF intervention opportunities. The ultimate aim of the project was to assess fuel cell buses and fuel cell stationary power generation investments that GEF could support in order to speed their introduction into developing country markets, to aid in reducing greenhouse gas emissions over the long term, and to make policy and strategy recommendations based on this assessment.

While fuel cell technologies, on account of their high efficiency, are likely to contribute towards reductions in greenhouse gas emissions, they also assist in the achievement of a technology-neutral move towards low-carbon energy sources, specifically hydrogen.

Hydrogen can be produced from a range of renewable – and fossil – resources and used in both transportation and stationary power markets in complement to electricity. This increases the

potential for local, non-GHG emitting energy to be exploited, increasing energy equity for those countries with limited fossil resources while keeping greenhouse gas and other emissions low.

With the use of hydrogen as a form of carbon-free energy storage, fuel cells behave as a transforming/disruptive technology, offering different economics from conventional technologies. This is, in part, because they offer a route to solving the intermittent electricity production problem inherent to solar and wind energy.

This report consolidates analyses on fuel cell buses and fuel cell distributed power generation, assesses possible synergies between respective fuel cell technologies, systems and programmes, and outlines a strategy for GEF participation in these areas.

2.3 Relevant GEF programmes

In formulating its Operational Strategy, in November 1995, the GEF defined Operational Programme (OP) 7 "Reducing the long-term costs of low greenhouse gas-emitting energy technologies". The goal of this programme, as originally stated in the Operational Strategy, is:

> "to reduce the cost of prospective technologies that have not yet become widespread least-cost alternatives. Its purpose is to promote the application of specified technologies so that, through learning and economies of scale, the costs of manufacture will tend to be commercially competitive. It will therefore be necessary to specify technologies whose costs will drop greatly with economies of scale in application. Proven but less mature technologies, such as… fuel cells… may be particularly well suited to this approach. A first step will be to review the proposed technologies, taking into account STAP's advice, to ensure that the essential research and development to make the technologies technically sound has been completed." (GEF Operational Strategy, 1996, p36).

As the Operational Strategy was refined and OP 7 took shape, this commitment to fuel cells was specified even more clearly:

> For cost-effectiveness, the scope of the technologies covered by the Operational Programme needs to be limited to those whose costs will drop significantly with economies of scale in manufacture and application. However, to reduce the portfolio risks and to widen the geographical coverage, the scope of the technologies covered should not be too narrow. Therefore, several backstop technologies for both supply and demand sides will be considered. Initially, following STAP consultations, the following supply-side technologies would be emphasized:….
>
> (f) fuel cells, initially for mass transportation and distributed combined heat and power applications; and …. (GEF Operational Programmes, 1997, p7-3)

To retain its relevance and to remain up-to-date with the latest advances, this programme was to continue to evolve and undergo re-examination:

> 7.8. One of the risks with technology promotion programmes worldwide, experience has shown, is that "surprises" are common. To minimize the risk of backing a loser or not backing a potential winner, the scope above will not be fixed indefinitely but will be reviewed and modified on the basis of experience in the portfolio and new information. (GEF Operational Programmes, 1997, p 7-3)

At the12th Meeting of STAP in Washington, DC 16 June 1998, it was recommended that "The GEF should help accelerate the commercialisation of H_2 fuel cells and enabling technologies (e.g., H_2 storage technologies) for transportation and CHP markets in developing countries, by supporting demonstration projects and strategies for 'buying down' the prices of demonstrated technologies to market-clearing levels." Demonstration projects should focus on applications that are especially relevant to developing countries. Thus, the continuing STAP review process reconfirmed the need for GEF to support the commercialisation of fuel cells for transport and CHP applications in developing countries as they are considered a promising technology for the reduction of greenhouse gas (GHG) emissions.

During 1998 and 1999, the GEF formulated "Operational Programme 11: Promoting Environmentally Sustainable Transport". Approved in 1999, this programme:

> ...promotes the long-term shift towards low emissions and sustainable transport forms. In 1990, the transport sector accounted for a quarter of the world's primary energy use and three-fifths of oil products use. Reduced emissions of greenhouse gases (GHGs) from this sector will be essential for stabilizing GHG concentrations. Widespread shifts towards modes that result in low emissions offer some of the best prospects globally for achieving deep reductions in greenhouse gas emissions over the next century while satisfying a given demand for mobility." (GEF Operational Programme 11, para 11-3)

Among the initiatives eligible for support under this programme, which is focused on the road transport sector, are fuel cell or battery operated 2- and 3-wheelers and (Hydrogen)-powered fuel cell or battery-operated vehicles for public transport and goods delivery (GEF OP11, para 11-10). Thus, while shifting the locus of eligibility from OP7 to OP11, the GEF has retained FCBs as one of the technologies eligible for support – in eligible countries.

2.4 The Need for a Strategy

The breadth of fuel cell technology applications and their good environmental characteristics implies they could play an important role as a clean power and transport technology, enabling significant long-term environmental and economic benefits.

The breadth of possible applications that exists makes it difficult to immediately identify the ideal short-term and longer-term options, and to maximise potential benefits it is important that a coherent strategy is developed. This strategy must be flexible, and have built into it monitoring mechanisms that allow it to evolve as technology and policy develop. In particular, the goal of significant reduction of GHG emissions over the long term should be uppermost.

Specific issues to be considered in developing a strategy are:

- High current fuel cell technology cost
- Requirements for support infrastructures – both for fuel supply and servicing
- Specific GHG emissions benefits in particular countries
- The potential for additional benefits such as improved local air quality and technology transfer, and how these may support sustained use

The use of fuel cells, even with fossil fuels, will generally, but not always, reduce GHG emissions in comparison with conventional technologies. By selecting better initial opportunities and in the long term moving towards the use of hydrogen produced from renewable energy or via carbon sequestration from fossil hydrogen production, GEF can ensure much larger reductions in GHG emissions once those coming from simple efficiency benefits have been exhausted. Additional domestic benefits will come from the very low emissions of other pollutants that are characteristic of fuel cell systems.

In addition, GEF resources are limited, and in order to ensure maximum leverage from their use it is important to be selective regarding fuel cell project investments. One aspect that may provide additional advantages is the potential for some synergies between fuel cell bus demonstration projects and stationary distributed power projects – though this should not be taken for granted.

The potential short and long-term benefits of fuel cell introduction could justify GEF intervention. However, in the long term it is the use of **GHG-free hydrogen**, not simply fuel cells, that is important, and this can only be maximised by a coherent GEF strategy. The strategy combines long-term goals for sustainable hydrogen infrastructure development with short-term opportunities where the initial steps can be demonstrated. As critics have pointed out, "The acquisition of several buses and the support of scattered stationary applications in itself does not represent a coherent programme and the aim of the GEF should be to integrate objectives, identify positive synergies and consider the establishment of binding co-financing targets. The funding needed for commercialisation will be substantial and difficult to raise otherwise."

2.5 Maximising opportunities for GEF

The GEF has a limited amount of funding available for investment, in a wide range of technologies and other programmes, to achieve its desired objectives. To maximise the value of its investments it is necessary to determine that it can make a meaningful contribution to an area or project. If this is the case then a clear strategy for investment is required to maximise the returns.

In the case of fuel cells, the opportunity is very large but the risk is potentially high, as are the potential rewards. Fuel cells can be used in a wide range of sectors, and must be deployed within specific guidelines if they are to meet their full potential for GHG emissions reduction. The availability and type of fuelling infrastructures, possible synergies between stationary and transport projects, and specific policy climates must be carefully considered.

The role of this report is to identify opportunities and mechanisms by which this can be done, and suggest a strategy by which GEF funding can best be used to maximise its potential.

To achieve this, an analysis has been conducted, first focusing on the relative technical and commercial positions of the different fuel cell technologies. (Although they are commonly categorised simply as ‘fuel cells’, five main fuel cell technology types are currently being commercialised, each with different characteristics.) Secondly, the study has investigated and modelled potential markets from a policy and commercial perspective, to identify opportunities in areas that may be most attractive for GEF financing. Thirdly, the study has investigated the synergies that may be achievable between bus and power generation projects, to assess whether there may be opportunities to provide additional leverage by undertaking concurrent projects. Finally, recommendations for strategy have been made based upon this analysis. The whole is an integration of the transportation and distributed generation market assessments.

3 FUEL CELLS AND GHG EMISSIONS FUTURES – IPCC

Critical to the promotion of fuel cell technology is its potential for GHG emissions reduction over the long term, in tandem with a move towards hydrogen fuel sources. Scenarios constructed by the IPCC on long-term GHG emissions include penetration of fuel cells and hydrogen energy as one component of a future low-carbon economy. An indication of the potential importance of the technology under the different assumptions, and hence a proxy measure of the importance to GHG stabilisation, can be assessed from the scenarios.

3.1 The Special Report on Emission Scenarios

The Special Report on Emission Scenarios (SRES) describes scenarios used as input to the IPCC Third Assessment Report (TAR) for evaluating climatic and environmental consequences of future greenhouse gas emissions and for assessing alternative mitigation and adaptation strategies. They include improved emission baselines relative to the second assessment report (SAR) and the latest information on economic restructuring throughout the world, examine different rates and trends in technological change and expand the range of different economic-development pathways, including narrowing of the income gap between developed and developing countries. To create the new scenarios, a storyline approach was adopted to take into account a wide range of scientific perspectives, and interactions between regions and sectors.

3.1.1 A1 Scenario Storyline

The A1 storyline and scenario family describes a future world of very rapid economic growth, low population growth, and rapid technological progress. Major underlying themes are convergence among regions, capacity building, and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. The primary dynamics of the A1 storyline are:

- Strong commitment to market-based solutions
- High savings and commitment to education at the household level
- High rates of investment and innovation in education, technology, and institutions at the national and international levels
- International mobility of people, ideas, and technology

The transition to economic convergence results from advances in transport and communication technology, shifts in national policies on immigration and education, and international cooperation in the development of national and international institutions that enhance productivity growth and technology diffusion.

Energy and mineral resources are abundant in this scenario family. Common technology assumptions in the A1 scenarios can be summarised as follows.

The supply of oil, gas, and biomass is assumed to be very high. Unconventional oil and gas become available at relatively low cost. Large amounts of biomass are utilised and biomass utilisation technologies become available at low costs.

High levels in the use of other renewable energy are reached when technologies for solar photovoltaics and thermal utilisation, wind farms, geothermal energy utilisation, and ocean energy are introduced at low cost. Energy end-use technologies are assumed to progress at medium rates compared with the fast rates of technological change in energy supply technologies.

3.1.2 The A1 Scenario Family

The A1 scenario family was developed into four groups that describe alternative directions of technological change in the energy system ranging from carbon-intensive to decarbonisation. With the "high growth with high technology" nature of this storyline, difference choices in alternative technology development strategies translate into large differences in future GHG emission levels.

The A1B scenario assumes a balanced mix of resources and technologies from energy supply to end use, with technology improvements and resource availabilities such that no single source of energy is overly dominant.

The A1T scenario assumes dwindling conventional oil and gas resources lead to fast development of solar and nuclear technologies on the supply side and mini-turbines and fuel cells used in energy end-use applications, along with enhanced energy conservation.

The other two scenarios assume that the transition away from conventional oil and gas leads to either "clean coal" technologies that are generally environmentally friendly with the exception of GHG emissions (A1C), or to a massive development of unconventional oil and gas resources including oil shales, tar sands and especially methane clathrates (A1G). In the SPM, these two scenarios were reported as a single fossil-energy-intensive scenario.

The A1B, A1T and A1C scenarios are reported here because of their relevance to fuel cell technology.

3.1.3 Scenario A1B

The "balanced" technology development assumption underlying the A1B scenario assumes significant innovations in energy technologies, which improve energy efficiency and reduce the cost of energy supply. A1 assumes, in particular, drastic reductions in power-generation costs, through the use of solar, wind, and other modern renewable energies, and significant progress in gas exploration, production, and transport.

Improvements in energy efficiency on the demand side are assumed to be relatively low in the A1B scenario. Low energy prices provide little incentive to improve end-use-energy efficiencies and high income levels encourage energy intensive lifestyles. Efficient technologies are not fully introduced into the end-use side, dematerialisation processes in the industrial sector are not well promoted, and private motor vehicles are used more in developing countries as per capita GDP increases.

Energy resources are taken to be plentiful by assuming a large future availability of coal, unconventional oil and gas, as well as high levels of improvement in the efficiency of energy exploitation technologies, energy conversion technologies, and transport technologies.

3.1.4 Scenario A1T

In the technology-intensive scenario group (A1T), energy demands are lower than in the other A1 scenario groups, because radical technological change in energy systems favours energy efficiency, non-fossil technologies and synfuels, especially hydrogen from non-fossil sources. Primary energy use and GHG emissions are much lower than in the other A1 scenarios.

The A1T scenarios assume further reductions in cost for solar, wind, and other renewable energies compared to the AIB scenarios. In A1T additional end-use efficiency improvements are assumed to take place with the diffusion of new end-use devices for decentralised production of electricity (fuel cells, microturbines). As a result, final energy demand in the A1T scenario group is between 30% and 40% lower compared to the A1B marker scenario.

3.1.5 Scenario A1C

The high-growth coal-intensive scenario group A1C assumes relatively large cost improvements in new and clean coal technologies. More modest assumptions are made for all the other technologies, except for nuclear technologies. Progress in renewables is also assumed to be substantial.

3.1.6 Assumptions Regarding Fuel Cells

The report states that fuel cells constitute the major potential competitor to CCGT technology, and that fuel cells may be able to offer similar efficiencies at much lower plant sizes and so may be an ideal candidate for distributed combined heat and power generation. Vehicle propulsion is the other promising fuel cell application, because fuel cells offer considerably higher conversion efficiencies than internal combustion engines. The report further states that recent advances in fuel cell technology, have led to their commercial production and application in niche markets for distributed combined heat and power production.

The following six energy technology groups, relevant to fuel cells and hydrogen, were represented in the model.

Coal fuel cell	Coal-based high-temperature fuel cell (internal reforming)
NG fuel cell	Natural Gas-powered high-temperature fuel cell; cogeneration possibilities
H_2 fuel cell	Decentralised stationary and mobile hydrogen fuel cells (cogeneration systems or off-hours electricity generation)
H_2 from fossil	Hydrogen production from fossil fuels (coal or gas)
H_2 from biomass & electricity	Non-fossil hydrogen production from biomass and electricity
H_2 from solar & nuclear	Non-fossil hydrogen production from nuclear and solar

Although the report states that fuel cells can be fuelled with a variety of hydrocarbon fuels (such as natural gas, methanol, gasoline, or even coal) by converting these fuels into hydrogen using on-site or on-board hydrogen production and separation systems, only coal and natural gas technologies seem to be included along with the basic hydrogen fuel cell. Also, only the hydrogen fuel cell seems to be used for transportation applications. The report also states that current fuel cell conversion efficiencies (45 to 50%) have yet to approach their potentials. However, it does not provide the specific assumptions it uses for future fuel cell efficiencies.

Three hydrogen production technologies are listed in the SRES, and several direct combustion applications of hydrogen are included in addition to the fuel cell applications. The SRES states that hydrogen production efficiencies range from 65 to 85% for fossil-based systems, 55 to 73% for biomass-based systems, and 80% to close to 90% for electrolysis.

The SRES further states that in the longer run, to make fuel cells truly zero-emission devices, non-fossil derived pure hydrogen should replace hydrocarbon fuels. None of the technology options used in the A1 group models incorporate CO_2 sequestration, and no CO_2 is sequestrated in any of the SRES A1 group model runs. Although CO2 scrubbing and storage would be equivalent to renewable energy produced hydrogen, potential for implementation is less well known.

3.1.7 Technology Cost Data

The MESSAGE model data set included only technologies demonstrated to function on a prototype scale. Production of hydrogen- or biomass-based synfuels (e.g. ethanol) or advanced nuclear and solar electricity generation technologies were included. Statistical distributions of technology characteristics based on a large technology inventory were used to create the data set of estimated future technology costs for each particular scenario.

Figure 1 and Figure 2 show total power produced for electric technologies and fuels. In the A1B scenario, the NG fuel cell and the H_2 fuel cell make an equal contribution (15 EJ) in 2050, but in 2100 only the H_2 fuel cell is present, and its contribution has increased significantly (100 EJ). In the A1T scenario, the H_2 fuel cell makes a much more significant contribution, going from almost 52 EJ in 2050 to over 320 EJ in 2100. The SRES does not provide a sectoral breakdown of the final energy use, and so it is not possible to determine the proportion of FCDG applications and transportation fuel cell applications. However, it is clear that H_2 fuel cells provide a significant proportion of total final energy needs.

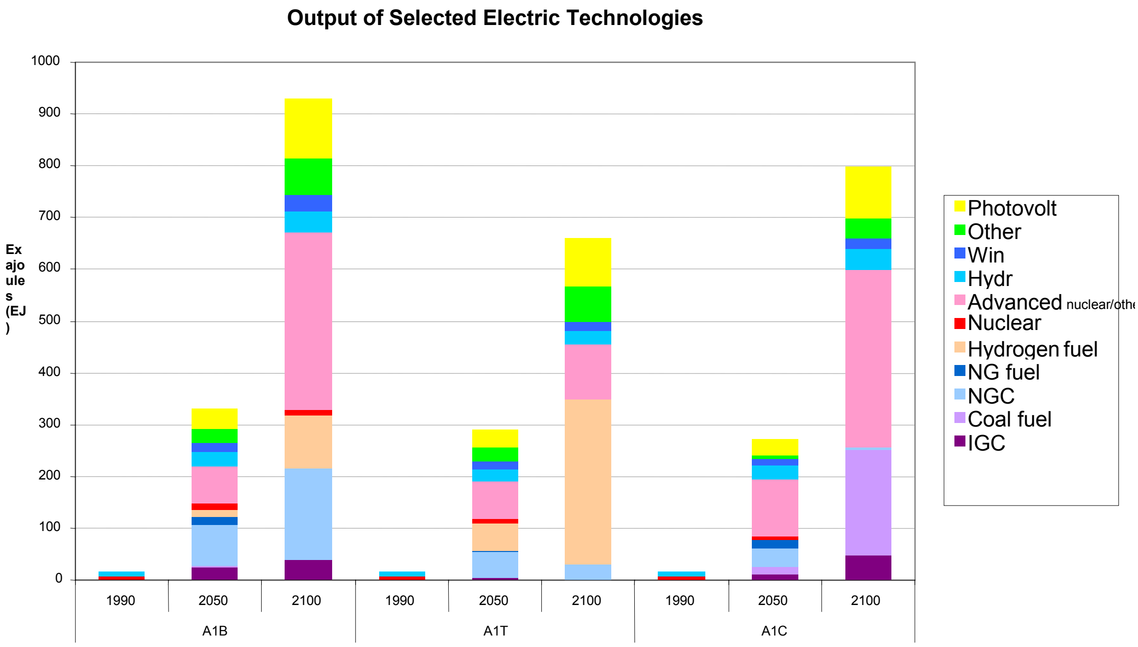


Figure 1: The electrical mix for different scenarios to 2100 under the SRES

The A1C scenario has been included in the tables and figures because of the significant contribution from coal fuel cells, which grows from almost 13 EJ in 2050 to over 200 EJ in 2100.

The source of hydrogen in the A1B and A1T scenarios comes explicitly from solar and nuclear electricity in 2050, but in 2100 shifts to syngases, which are stated to be "from various sources, including biomass and coal gasification." (See Figure 2.)

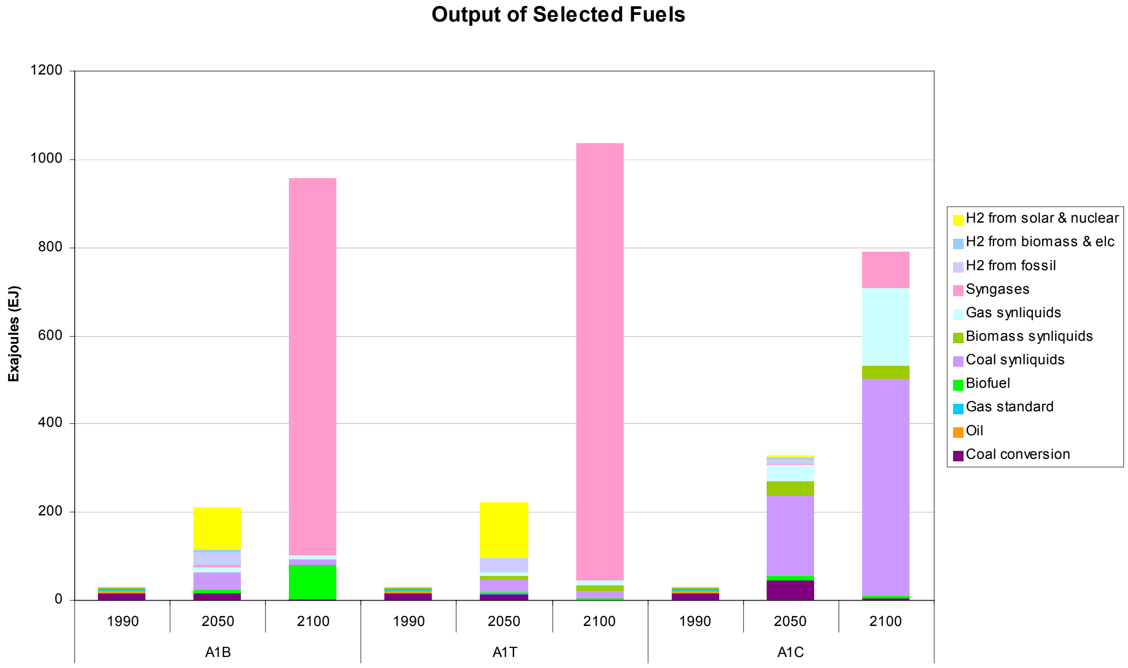


Figure 2: Different fuel mix outputs to 2100 under the SRES

Figure 3 plots the cumulative CO_2 emissions for the three A1 scenarios under discussion. The potential for fuel cell applications to reduce CO_2 emissions is not calculated in the SRES (nor is it reported in the TAR summaries). However, that potential can be calculated using the assumption that the output of the fuel cell displaces only NGCC electricity (a conservative assumption) and that all the hydrogen were produced from renewables, nuclear or fossil fuels with CO_2 sequestration (an optimistic assumption). In the A1B scenario, hydrogen fuel cells would displace about 85 Gt C cumulative through 2100, or about 5% of the cumulative emissions calculated for that scenario. In the A1T scenario, hydrogen fuel cells would displace about 270 Gt C cumulative through 2100, which is about 25% of the cumulative emissions calculated for that scenario. Given the differences between the A1B and A1T scenarios discussed above, it is likely that a large portion of the increased reduction in CO_2 emissions in the A1T scenario is due to additional diffusion of new end-use devices in the household, service, and transport sectors.

It is important to note that the A1C scenario has significantly higher emissions in spite of the important contribution of fuel cells, because the hydrogen source is entirely coal and no sequestration technology is employed to reduce the CO_2 emissions. If CO_2 sequestration were used, the calculated emissions would be reduced by almost 150 GtC, or 7% of the cumulative total for that scenario.

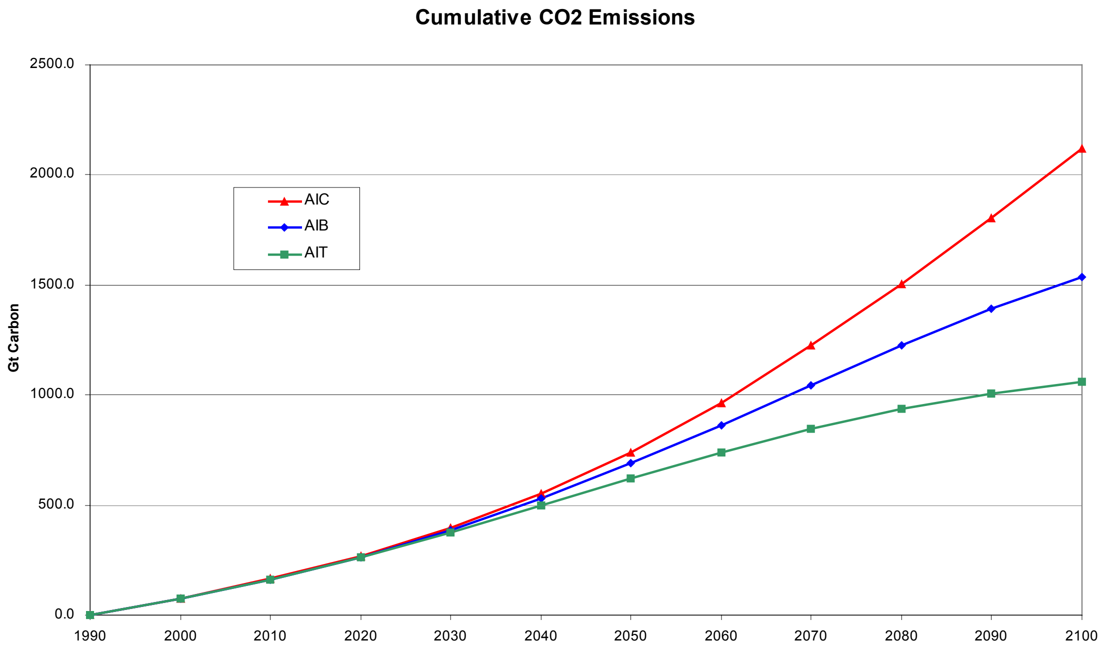


Figure 3: Differing CO_2 emissions for the A1 scenario family

3.2 The Second Assessment Report

The Second Assessment Report (SAR) was produced to focus on the potential impacts of climate change, adaptive responses and measures that could mitigate future emissions. Two chapters in the SAR contain information pertinent to fuel cells: Chapter 19, Energy Supply Mitigation Options and Chapter 21, Mitigation Options in the Transportation Sector. However, these have been superseded by rapid developments in the field and the TAR is considerably more relevant.

3.3 The Third Assessment Report

The Third Assessment report (TAR) assesses the scientific, technical, environmental, economic and social aspects of the mitigation of climate change. A variety of mitigation options are evaluated through differing mitigation strategies within the SRES scenarios. "However, common features of mitigation scenarios include large and continuous energy efficiency improvements and afforestation as well as low-carbon energy, especially biomass over the next 100 years and natural gas in the first half of the 21st century. Energy conservation and reforestation are reasonable first steps, but innovative supply-side technologies will eventually be required. Possible robust options include using natural gas and combined-cycle technology to bridge the transition to more advanced fossil fuel and zero-carbon technologies, such as hydrogen fuel cells. Solar energy as well as either nuclear energy or carbon removal and storage would become increasingly important for a higher emission world or lower stabilisation target."

The TAR addresses fuel cell technology in the transportation and energy sectors. However, only the Summary for Policy Makers and the Technical Summary are available for review, and these contained no details regarding the assumptions on fuel cell technology.

3.3.1 Transportation Sector

The TAR notes that transportation technology for light-duty vehicles has advanced more rapidly than anticipated in the SAR, as a consequence of international R&D efforts. Hybrid-electric vehicles have already appeared in the market. Fuel cell powered vehicles are developing rapidly, and are scheduled to be introduced to the market in 2003.

The TAR states that "New and used vehicles and/or their technologies mostly flow from the developed to developing countries. Hence, a global approach to reducing emissions that targets technology in developed countries would have a significant impact on future emissions from developing countries." Of course, a 'leapfrog' technique introducing fuel cell buses into developing countries could have a considerably greater impact. However, it goes on to note that the risk to transportation equipment manufacturers is an important barrier to more rapid adoption of energy efficient transport technologies.

The TAR further notes that the factors that hinder the adoption of fuel-efficient technologies in transport vehicle markets create conditions under which energy efficiency regulations, voluntary or mandatory, can be effective. Well-formulated regulations eliminate much of the risk of making sweeping technological changes, because all competitors face the same regulations. **The policy framework, therefore, is significant.**

The TAR concludes that growth in transportation demand is likely to remain significant and is unlikely to be influenced by GHG mitigation policies. "Only limited opportunities for replacing fossil carbon-based fuels exist in the short to medium term. The main effect of mitigation policies will be to improve energy efficiency in all modes of transportation. Unless highly efficient vehicles (such as fuel cell vehicles) become rapidly available, there are few options available to reduce transport energy use in the short term, which do not involve significant economic, social, or political costs."

Finally, the TAR notes that intensive R&D efforts for light-duty road vehicles have achieved dramatic improvements in hybrid power train and fuel cell technologies. Similar efforts could be directed at road freight, air, rail, and marine transport technologies, with potentially dramatic pay-offs, and buses are an excellent technology with which to start.

3.3.2 Energy Sector

The TAR states that emerging fuel cell technologies with the commercial combined heat and power (CHP) systems to meet space heating and manufacturing needs could achieve substantial emission reductions. However, the potential for CO_2 emissions reductions of these technologies is highly dependent on further restructuring of the electric utility industry in many developed and developing countries, as is brought out in the country policy analysis in section 6.7. Although there is a growing interest in distributed power supply systems based on renewable energy sources and also using fuel cells, micro-turbines and Stirling engines, the potential of these systems is uncertain at this time.

The key barriers to the adoption of these distributed power supplies are a lack of human and institutional capacity, imperfect capital markets that discourage investment in small decentralised systems, more uncertain rates of return on investment for new technologies, high trade tariffs, lack of information, and lack of intellectual property rights for new technologies. Many of these areas can be directly influenced by the GEF and are explored in detail later in this report.

The implementation of distributed CHP systems is closely linked to the availability and density of industrial heat loads, district heating, and cooling networks. Yet, its implementation is hampered by lack of information, the decentralised character of the technology, the attitude of grid operators, the terms of grid connection, and a lack of policies that foster long-term planning. Firm public policy and regulatory authority is necessary to install and safeguard harmonised conditions, transparency, and unbundling of the main power supply functions.

Opportunities for developing countries include promotion of leapfrogs in energy supply and demand technology, facilitating technology transfer through creating an enabling environment, capacity building and appropriate mechanisms for transfer of clean and efficient energy technologies. In addition, there are significant opportunities for DG technologies outside the use of CHP.

The TAR concludes that new supply options typically take many years to enter into the marketplace. An immediate and sustained commitment to R&D is required if low-carbon low-cost substitutes are to be available when needed. R&D for cost reduction and enhanced performance and increased funding for early market demonstrations would increase near-term commercial applications leading to further cost reductions through learning-by-doing. Extending this to developing country markets would further enhance the potential uptake. This would suggest a clear role for the GEF.

4 FUEL CELL BUS ANALYSIS

4.1 Introduction

Buses offer a promising early platform for fuel cell technology, and have already been tested in several OECD countries. They are typically fuelled by compressed gaseous hydrogen and use a proton exchange membrane (PEM) fuel cell (FC). Tailpipe emissions amount to no more than pure water, and the buses are quiet, using an electric drivetrain. Performance and public acceptance of the first test vehicles has been very good, but cost and lifetime issues remain to be resolved. Nevertheless, they offer an opportunity for technology leapfrogging in many highly-polluted developing country cities, with potentially large associated societal benefits, and thus an analysis has been conducted with regard to the realistic level of potential in these areas.

4.2 Fuel cell bus analysis

The fuel cell bus analysis was executed by UNDP, and carried out by a range of organisations. It has been documented in some detail. Key points have been abstracted from the analysis for the purposes of this report.

4.3 Why are fuel cell buses of interest?

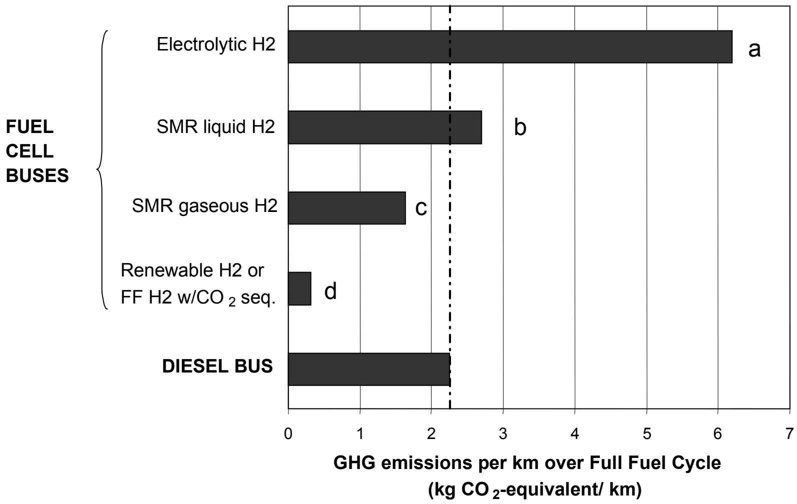
Fuel cell-driven vehicles possess several advantages over conventional vehicles for urban transport applications. First, fuel-cell stacks work most efficiently at lower levels of power output – in contrast to conventional vehicle power trains. In urban transit operation, a FCB will be operating near its maximum efficiency, whereas conventional vehicles operate at very low efficiency under such conditions. Second, FCBs provide significant local environmental improvements over conventional buses. The only tailpipe emissions from a FCB are distilled water; they emit no pollutants. In addition, fuel-cell engines are much quieter than conventional diesel engines, meaning that local noise pollution from FCBs can be reduced to basically the noise of the tyres on the road. Hence, FCBs have distinct advantages over buses driven by conventional diesel engines. These domestic benefits should encourage sustained use of FCBs.

To understand the opportunities for FCBs, an analysis has been conducted to identify cost and emissions reduction potential. Longer term there may be a movement towards general automotive use of fuel cells; this has also been analysed.

For GEF, whose concern is with cost-effectively reducing GHG emissions and concentrations in the atmosphere, the important advantage that fuel cells offer over conventional vehicles is measured in terms of reduced GHG emissions. To estimate this advantage, it is necessary to examine the system-wide GHG emissions of a FCB network against the system-wide emissions of a diesel-bus network – a complex analysis whose conclusions will differ from one set of local conditions to another. In the case of FCBs running on hydrogen, the system-wide GHG balance will depend almost exclusively upon the source of the hydrogen. If the hydrogen is produced by reforming natural gas, there would be a minimum 30% decrease in GHG emissions per bus-km by switching from conventional diesel buses to FCBs. GHG emissions would drop to near zero if the hydrogen were made from renewably grown, gasified biomass. If the hydrogen is made by electrolysis of water, GHG emissions will depend on the source of the electricity. Where electricity is made from fossil fuels, especially coal, the result will probably be a net increase in system-wide GHG emissions (see Box 1). In cases where the electricity is drawn from purely renewable sources (such as off peak hydroelectric power in Brazil), system-wide GHG emissions will be zero.

It must be stressed that for both transport and stationary applications, the ultimate aim for the GEF must be to encourage low-carbon energy pathways and a move towards both renewable electricity and renewable hydrogen as the energy vectors of choice.

Box 1 - GHG Emissions from Fuel-cell Buses are Potentially Lower than from Conventional Buses



Considering tailpipe emissions only, H_2 FCBs have no GHG emissions. But, to adequately gauge the GHG benefits, it is necessary to adopt a system-wide approach to consider emissions also from production of the vehicle fuel:

a) If hydrogen is made by electrolysis of water, using electricity from burning fossil fuels, then GHG emissions for FCBs using this "Electrolytic H_2" can exceed system-wide Diesel Bus emissions, though this strongly depends on the electricity source and will be better if CCGT is used than coal-fired plant;

b) When liquid hydrogen is made from natural gas by steam methane reforming (SMR), GHG emissions can also be high if the electricity used for liquefaction comes from fossil fuels;

c) If hydrogen made by SMR is used in gaseous form, CO_2 emissions will be about 30% lower than for the Diesel Bus; and,

d) When hydrogen is made from renewable resources (e.g., electrolysis of water using hydro, wind or PV electricity; or by thermochemical conversion of biomass) then CO_2 emissions are very low. The same result would be achieved if hydrogen were to be made from fossil fuels, with CO_2 recovered and sequestered (e.g., deposited below ground in secure deep saline aquifers or depleted oil and gas wells).

Given the potential emissions associated with the various fuel cycles, emphasis must be placed on designing an appropriate system to ensure low GHG emissions.

NOTE: All the buses in this example are based on vehicles from California. In all cases, CO_2 emissions associated with electricity are assessed for the average generating fuel mix for U.S. utilities. Emissions for projects in other areas must be analysed individually.

SOURCE: C.E. Thomas presentation (UNDP/GEF Fuel Cell Bus Workshop, April 27-28, 2000)

As shown in section 3, the IPCC considers fuel cells to hold promise for GHG reductions Investing in the development of low-GHG emitting energy technologies in the early part of the century allows them to be utilised to achieve GHG stabilisation goals in the latter half of the century. The early investments in these technologies, including fuel cells, help to make them cheaper and more widely accessible. Indeed, fuel cells are one of the technologies that has:

> "…good prospects for becoming commercial products within the next 1 or 2 decades, if adequate incentives are provided for the needed R&D and for launching the new industries involved."

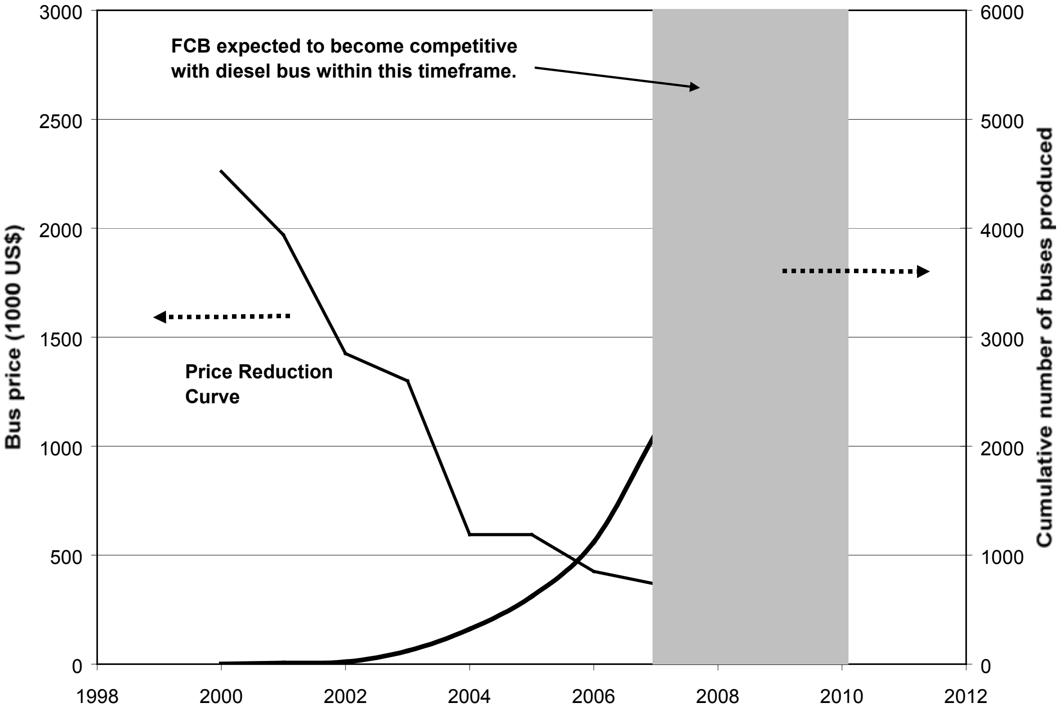
This is precisely the role envisioned for the use of GEF resources in OP 7, which will pave the way for the long-term solution to the climate change problem. Fuel cells play a significant role as part of the IPCC's long-term energy policy scenario. The cost of fuel cells and their operation remains the most significant barrier to their widespread deployment and role in climate change mitigation.

4.4 Will the Costs of FCBs Become Competitive With Conventional Technologies?

At present, FCBs are very expensive compared to conventional diesel buses. Depending upon the source of hydrogen, the lifecycle operating cost per bus-km may exceed that of conventional diesel buses by a factor of 2 or 3. There are several reasons for this. The first is that the capital cost of fuel cells is still very high. Second, the demand for FCBs is very limited, meaning that no FCBs are currently produced on an industrial assembly-line basis. These conditions hold in the case of any new technology and require that the impasse or "chicken-and-egg" situation – where limited demand leads to high costs which, in turn, limit demand – is broken. One role for GEF (as originally defined under OP7) would be to stimulate demand in order to enable industry to invest in mass production facilities. Before committing to this activity, it is worth asking if the costs of producing FCBs will ever fall to a point where both the capital costs and life-cycle costs would be competitive with that of the conventional alternative.

The potential for cost reductions in the FCB area can be approached from a "bottom-up" (or component by component) method or a "top-down" (or progress ratio) approach. The bottom-up approach gives the result that the capital cost of a fuel cell engine in mass production would be competitive with that of a diesel engine. On the fuel-supply side, although hydrogen produced from natural gas may be slightly more expensive that diesel fuel on a per-unit energy basis, it should be competitive with diesel fuel on a per distance travelled basis, due to the greater efficiency of the fuel cell drive over the conventional engine. Finally, on a life-cycle basis, a FCB should have equal or lower life-cycle costs than a diesel bus if the hydrogen supply is drawn either from natural gas or inexpensive off-peak electricity. In summary, the bottom-up approach gives a result that FCBs will become economically competitive with traditional diesel buses once a scaling-up of production occurs. This is illustrated in Box 2.

Box 2 - FCB Prices are Projected to Fall to Competitive Levels between 2007 and 2010



The expected price reduction rate for FCBs, with increasing cumulative volume of FCBs produced, is similar to the cost reduction rates seen for a wide variety of other mass-produced products at the early stages of their commercial introduction (e.g., gas turbines, wind turbines, solar PV cells, etc.). The price reduction curve shows that the price of FCBs is expected to become competitive with Diesel Buses on a lifecycle basis between 2007 and 2010 (2,100 to 5,100 buses produced depending on assumptions; see Table 1 below for a lifecycle costs analysis). Assuming commercial competitiveness is not reached until 2010, Larson estimated that the aggregate incremental cost for commercialising FCBs would be $1.2 billion. If competitiveness were reached earlier, this cost would be less. No account has been taken of environmental externality costs in this analysis.

	(based on New York City conditions)	
	Diesel Bus	Circa-2010 H_2 FCB
Fuel Economy, *litres diesel equiv./100 km*	74	43 (0.12 kg H_2/km)
Bus Price, 1000 $ (1997US$)	251	343
Operation & Maintenance., *$/yr (level 1997US$)*	7500	5000
Bus Lifetime, *years*	12	18
Annual bus travel, *km per year*	40,000	40,000
Total Lifecycle Cost	***(1997 US$ per bus-km)***	
Capital (10% discount rate)	0.92	1.05
Operation & Maintenance	0.19	0.12
Fuel	0.24	0.18
TOTAL	1.35	1.35

Table 1: Lifecycle Costs of "circa-2010 H2 FCBs" will be Comparable to Diesel Buses

Note: Diesel bus costs and performance are based on current New York levels.
Fuel prices: Diesel = $0.33/litre ($8.5/GJ); H_2 = $0.14/m^3 ($11/GJ)

SOURCE: E. Larson (UNDP/GEF Fuel Cell Bus Workshop, April 27-28, 2000); information provided by Ballard for FCB manufacture in the United States or Canada.

The top-down approach gives results that are similar to those of the bottom-up approach. Cost reduction rates shown in projections by the fuel-cell engine industry are similar to those observed historically for a wide variety of new technologies. If these projections hold, the capital and life-cycle costs of FCBs will reach levels that are comparable to those of diesel buses. Depending upon the number of buses or fuel cell systems produced and the progress ratio, this target price may be achieved by the year 2010.

While FCBs are likely to ultimately reach competitive cost levels, there is substantial uncertainty in estimating the aggregate investment that will be needed to "buy-down" the cost of the technology to commercially competitive levels. One estimate has been made based on the top-down analysis noted above. In that case, approximately 2,100-5,100 FCBs will have to be produced by any one producer before the costs of the FCB falls to a competitive level. The corresponding "buy down" (or incremental costs) for this commercialisation period is estimated at about $1.2 billion, but there are wide error margins on the estimates of both the required cumulative production and aggregate incremental cost. The size of these error margins highlights the importance of carefully monitoring progress and periodically reassessing buy-down opportunities as commercialisation proceeds.

In addition, some cost and development synergies are expected to be accessible to the manufacturers of fuel cell bus engines. Fuel cells systems comprise a fuel cell stack – itself made up of hundreds of individual fuel cells – and a range of peripheral equipment, including power electronics, pumps, compressors, heat and water management systems, and other components. As fuel cells are being developed not only for buses but also for cars, for portable applications and for stationary power generation, it is likely that cost reduction can be achieved by learning across the spectrum of applications, and by bulk purchase and mass-manufacture of similar stacks and componentry for different applications. For example, the Ballard buses trialled in Vancouver and Chicago use the same stack as the 250kW stationary power generator, and the recently-announced 60kW generator uses the same stack as the DaimlerChrysler A-Class fuel cell vehicle.

4.5 Fuel cells in the automotive sector

Fuel cell buses will be some of the earliest applications of fuel cell technology, certainly in OECD countries. However, considerable investment is being made in developing fuel cell engines for automobiles, by all of the major automotive manufacturers. The potential for fuel cell cars to penetrate the market has been assessed, to enable an understanding of the 'buy-down' costs associated with their development, and the development of a hydrogen infrastructure with which to fuel the vehicles. A scenario has been produced to give an indication of the speed with which fuel cell cars may be able to penetrate the market, and policy options enabling or hindering the penetration have been investigated. Critical points from the analysis have been introduced into this final report.

Strategy: Hydrogen is used first in centrally refuelled fleets, moving to general automotive markets. In this scenario, hydrogen fuel cell vehicles are implemented first in centrally refuelled fleet vehicles, and later move to general automotive markets. Many analysts see use of hydrogen fuel cell vehicles in fleet markets, such as buses or fleet cars or trucks, as feasible for the following reasons:

- For centrally refuelled fleets, only a limited hydrogen infrastructure is needed. All vehicles are refuelled at a single location, and hydrogen can be delivered via truck or produced onsite via small scale steam reforming or electrolysis.
- Technically trained personnel at a central site would do fleet refuelling, gathering experience in a more controlled environment than that of a public refuelling station.
- For fleets, onboard storage constraints are not as serious as for private passenger cars, and current compressed hydrogen storage should provide adequate range.

This gives rise to a number of questions:

- How many fuel cell vehicles must be produced to reach lifecycle cost competitiveness with other low polluting vehicles?
- Are fleet markets large enough to significantly “buy down” the cost of fuel cell vehicles via mass production? Or would hydrogen fuel cell vehicles remained “stalled” at low production and high cost in niche fleet applications, never reaching costs that could compete in larger automotive markets?
- How would hydrogen fuel be provided for fleet applications? How much would a hydrogen infrastructure for fleet vehicles cost?

4.6 Moving to General Automotive Markets with Hydrogen in the Long Term

For this analysis it is assumed that a large-scale hydrogen infrastructure would be built in the long term, in response to strong policies enacted to address environmental concerns.

4.6.1 Infrastructure Implications of Using Hydrogen As An Initial Fuel For Fuel Cell Vehicles

A number of near term possibilities for producing and delivering compressed gaseous hydrogen transportation fuel exist, employing commercial or near commercial technologies for hydrogen production, storage and distribution. These include:

- hydrogen produced from natural gas in a large, centralised steam reforming plant, and truck delivered as a liquid to refuelling stations,
- hydrogen produced in a large, centralised steam reforming plant, and delivered via small scale hydrogen gas pipeline to refuelling stations,
- hydrogen from chemical industry sources (e.g. excess capacity in refineries which have recently upgraded their hydrogen production capacity, etc.), with pipeline delivery to a refuelling station.
- hydrogen produced at the refuelling station via small-scale steam reforming of natural gas
- hydrogen produced via small scale water electrolysis at the refuelling station,

In the longer term, other centralised methods of hydrogen production might be used including gasification of biomass, coal or municipal solid waste, or electrolysis powered by wind, solar or nuclear power. Thermochemical hydrogen production systems might include sequestration of byproduct CO_2.

The capital cost of developing an extensive gaseous hydrogen refuelling infrastructure has been estimated to be in the range $300-800/car, depending on the hydrogen supply pathway and level of demand. For the first few demonstration projects, the cost of hydrogen refuelling stations will be considerably higher than this. However, once a hundred large hydrogen refuelling stations have been built (serving fleets totalling perhaps several hundred thousand vehicles), refuelling station capital costs should drop to about $300-800 per car.

4.6.2 Buying down the cost of fuel cells in the automotive sector

Estimates can be made of the number of vehicles and total "buy-down" cost required to reduce the cost of fuel cell vehicles via mass production to the point that they can compete with other advanced low polluting vehicles on a lifecycle cost basis. The base case automotive competitor is an advanced gasoline spark ignited hybrid electric vehicle (gasoline ICE/HEV), a technology that is already commercial and is likely to play an important role in clean vehicle markets in the next few decades. The gasoline ICE hybrid electric vehicle is assumed to be a mature technology by the time fuel cell vehicles enter the market, so its cost does not vary in time.

The buy-down cost of fuel cell vehicles is estimated as follows:

- The projected cost of fuel cell vehicles is estimated as a function of cumulative mass production, based on recent estimates for mass produced costs of fuel cells.
- The lifecycle cost of transportation is estimated for alternative types of fuel cell vehicles and internal combustion engine vehicles. (This includes vehicle first cost, fuel costs, non-fuel O&M costs and environmental costs.) As the fuel cell vehicle cost is reduced, its lifecycle cost is reduced.
- The cumulative vehicle production required for fuel cell automobiles to reach lifecycle cost competitiveness with advanced gasoline ICE hybrid automobiles is estimated.
- The "buy-down" cost required to bring fuel cell vehicles to lifecycle cost competitiveness is estimated. This cost is the cumulative lifecycle cost difference between fuel cell vehicles and internal combustion engine hybrid vehicles, during the time period that fuel cell costs are approaching competitive levels.

4.6.3 Manufacturing Cost Estimates for Fuel Cell Vehicles

Today's PEM fuel cells are custom designed for research and demonstration purposes, rather than being commercial products, and at present production levels (a few one-of-a-kind units per year) PEM fuel cell systems for automotive applications would cost an estimated $1500-10,000/kW. However, the manufacturing cost of PEM fuel cells is projected to drop rapidly with increased levels of production. Once large scale mass production is reached, estimates indicate that the first cost of ICE hybrid vehicles will be $1300-1900 more than conventional gasoline cars and fuel cell vehicles $2500-5100 more.

4.6.4 Learning Curve Model for the Projected Capital Cost of Fuel Cell Vehicles Versus Cumulative Production

A "learning curve" is used to develop the potential reduction in the cost of fuel cell drive trains as a function of cumulative production over 25 years.

A plausible scenario for FCV manufacture by a single firm is assumed (see Figure 4):

- For the first 5 years, 10 FCVs are produced annually "by hand" for small fleet demonstrations, during which time the FCV design for factory manufacture is developed;
- For the next 5 years, 10,000 FCVs are produced annually in a pilot manufacturing facility, during which time the manufacturing process is tested and refined;
- For the following 15 years, 300,000 FCVs are produced annually in a commercial factory.

The learning curve provides a way of estimating cost reductions as a function of cumulative mass production. Care must be taken not to extend the learning curve too far, where total cost might be seen to drop below cost of materials, for example.

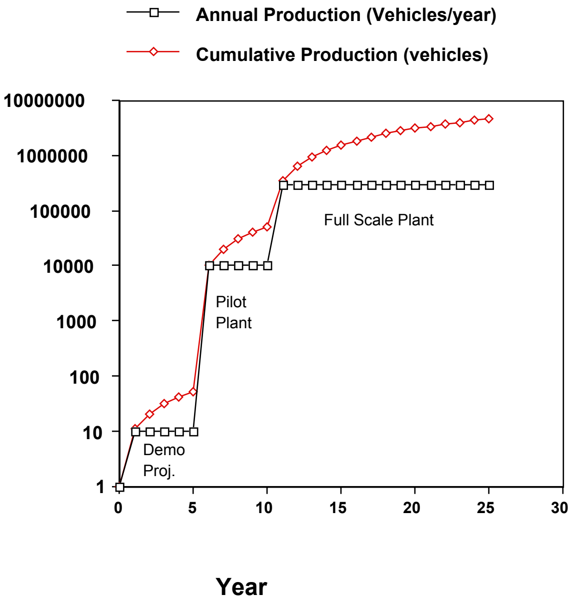


Figure 4: Fuel cell vehicle manufacturing scenario for a single firm

It has been assumed that a single firm is involved in developing fuel cell drive trains. If more than one firm became involved in manufacturing drive trains, there could be some benefit to other manufacturers, so that costs for a single firm might be reduced more quickly than the curve shown in Figure 5.

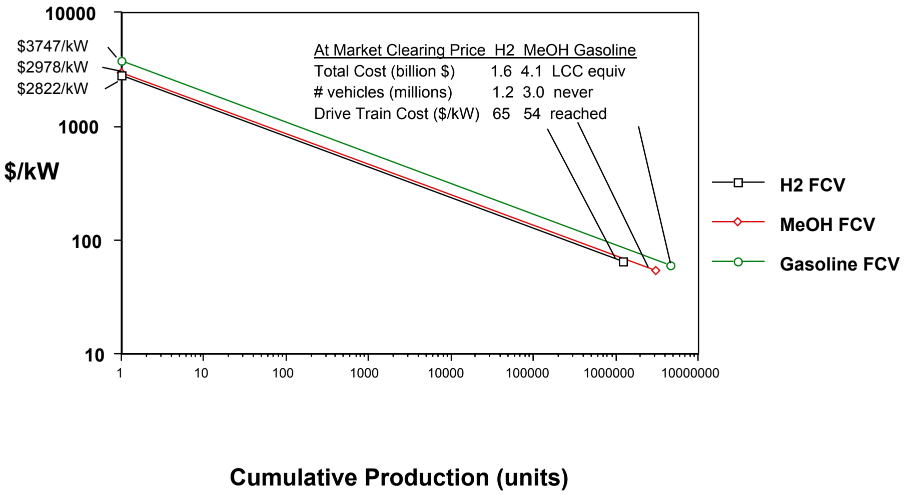


Figure 5: Fuel cell vehicle cost reduction with cumulative production

4.6.5 Estimating The Lifecycle Cost Of Alternative Fuelled Vehicles

For the purpose of comparing among alternative fuelled vehicles, the lifecycle cost (LCC) is defined as follows:

LCC ($/vehicle) = vehicle first cost + lifetime fuel cost (present value)

+ non-fuel O&M cost (present value) + lifetime air pollution damage cost (present value)

+ lifetime greenhouse gas cost (present value) [1]

In calculating the vehicle first cost, it is assumed that cost of the "glider" (i.e. the vehicle excluding drive train and fuel storage components) is the same for all vehicles. It is further assumed that non-fuel O&M costs are the same for all automobiles. In the LCC calculations that follow we compare only drive train first costs plus fuel costs and environmental damage costs.

4.6.5.1 Air Pollution and Greenhouse Gas Damage Costs:

In this study environmental costs were based on:

- estimated full fuel cycle emissions of air pollutants and greenhouse gases. Both vehicle emissions and upstream emissions are included.
- estimates of damage costs per gram of emitted air pollutant from studies carried out under the European Commission's ExternE Programme, and
- the assumption that GHG emissions are valued at $100 per tonne of carbon (tC)[3], the cost estimated by the World Energy Assessment for removing carbon from coal-fired power plants.

4.6.5.2 Lifecycle Cost Comparison of Alternative Fuelled Vehicles

In Figure 6, environmental damage costs are compared for a range of alternative fuelled automobiles. Figure 7 shows the projected lifecycle cost of fuel cell vehicles compared to conventional ICE vehicles and to advanced hybrid ICE vehicles. Comparing the alternatives shows that the hydrogen (H_2) fuel cell vehicle (FCV) stands out as offering the least environmental damage cost among all the advanced options. When fuelled with H_2 derived from natural gas, damage costs are 1/8 as large as for today's gasoline ICEVs without CO_2 sequestration and 1/15 as large with CO_2 sequestration.

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[3] 100 $/tC = 27.3 $/tCO2 = ~28$/tCO2e depending on the release rate of other GHGs

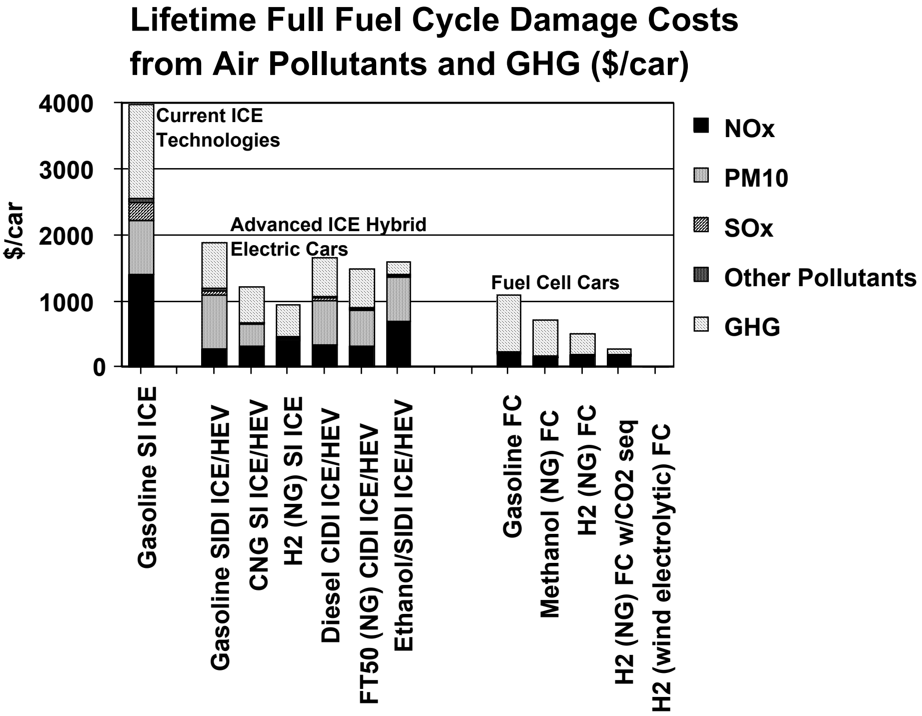

Figure 6:Life cycle damage costs for different vehicle emissions

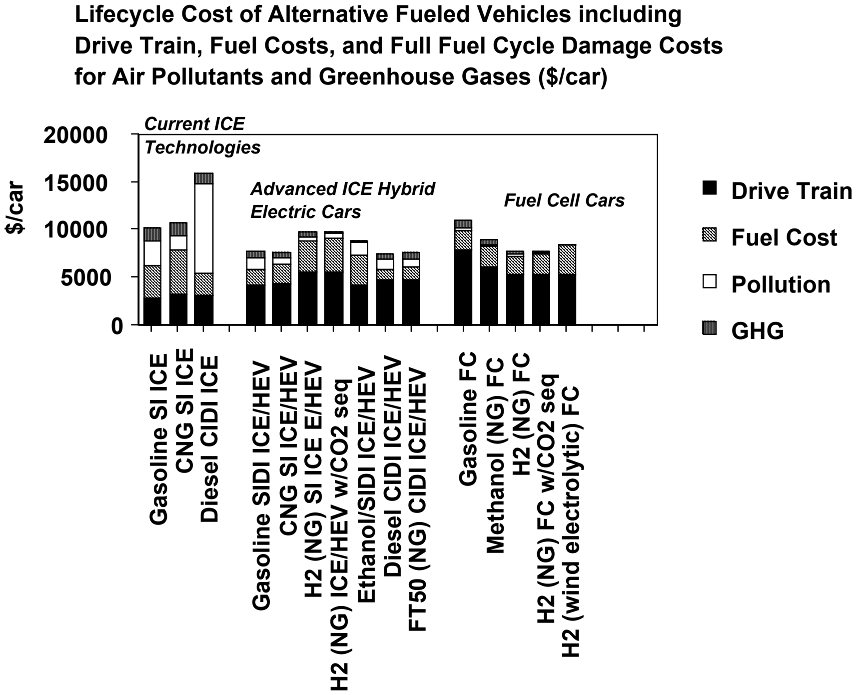

Figure 7: Full life cycle costs for different vehicles

4.6.5.3 When Do Fuel Cell Automobiles Reach Lifecycle Cost Competitiveness?

To understand the timeframe in which fuel cell cars may become cost-competitive with alternatives, a plausible scenario for fuel cell vehicle introduction was constructed.

4.6.5.3.1 Estimating the Buy-Down Cost

The fuel cell vehicle's first cost is assumed to vary with cumulative production. When the lifecycle cost for the fuel cell vehicle is exactly the same as for the gasoline ICE hybrid, we say that the cost of the fuel cell vehicle has been "bought down" to market clearing cost levels on a lifecycle cost basis. The buy-down cost is the cumulative incremental lifecycle cost difference between the FCV and the baseline gasoline ICE hybrid.

4.6.5.3.2 Buy-down Cost for Hydrogen Fuel Cell Vehicles

The time required to reach lifecycle cost parity is shown in Figure 8 for H_2, methanol and gasoline FC, with both air pollutant and GHG damage costs included in lifecycle costs. In this figure the cumulative lifecycle cost difference between the FC car and the gasoline ICE/HEV is plotted versus time for each FC car type. The maximum point on each curve represents the time at which lifecycle cost parity is reached, and the cumulative incremental lifecycle cost at that point is the buy down cost. We see that buy-down happens first for hydrogen.

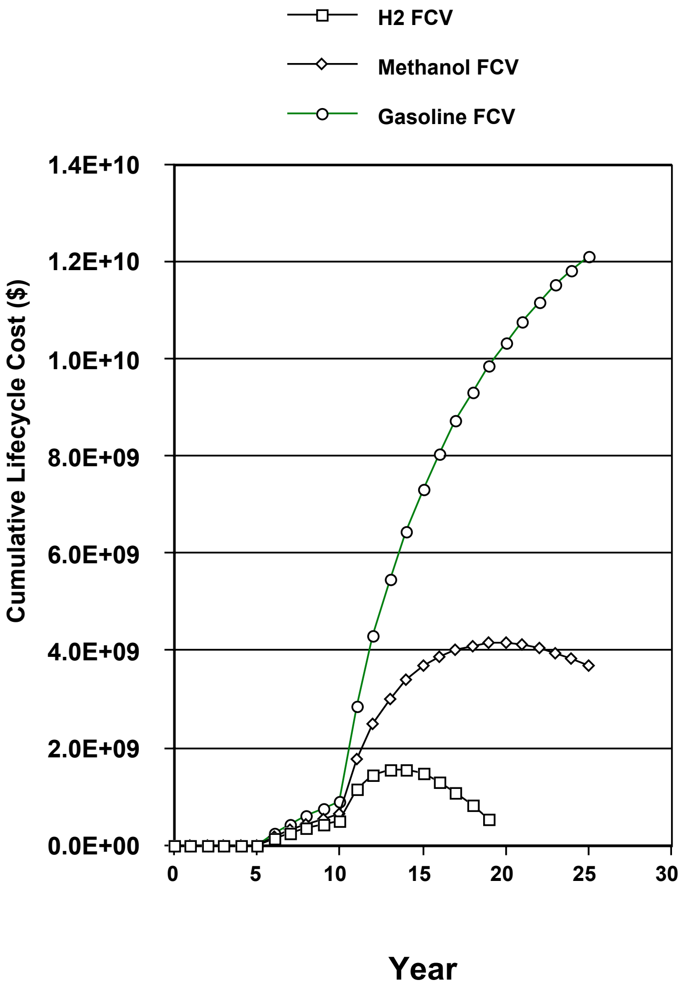

Figure 8: Cumulative lifecycle cost difference between fuel cell automobiles and gasoline internal combustion engine hybrid automobiles

For the base case, the H_2 FCV reaches breakeven with the gasoline ICE/HEV after 1.2 million vehicles have been produced, (about 4 years into the operation of the large fuel cell drive train manufacturing plant).

4.6.5.3.3 Sensitivity of the Buy-down Cost to Changes in the Assumptions

The projected future cost and performance of fuel cell vehicles is uncertain. There are also large uncertainties in estimating environmental damage costs. We have carried out a sensitivity analysis to examine the robustness of our results to changes in assumptions about 1) damage costs of air pollutants and greenhouse gases, 2) fuel cell drive train mass production costs, 3) fuel processor cost and technical performance.

Sensitivity to Costs of Environmental Externalities: Buy-down costs were also calculated assuming that environmental externalities were not included. We see the same trends as in our base case. Hydrogen vehicles become cost competitive first, at the lowest cost, followed by methanol and gasoline fuel cell cars. Without any external environmental costs included, it takes about three times as many cars, ten years longer, and three times the cost for hydrogen fuel cell cars to reach lifecycle cost equivalence. If only greenhouse gas emissions costs are included (at \$100/tC), the buy-down curve is intermediate between. Buy-down costs for hydrogen FCVs are about twice as much, and reaching market clearing costs takes about 5 years longer (requiring 2.7 million cars). Reducing the damage cost of greenhouse gases from \$100/tC to \$10/tC delays the H_2 FCV from reaching the market clearing level by about two years, and increases buy-costs to about from about \$1.6 to 2 billion.

Sensitivity to Assumed Costs for Fuel Cell Drive Trains: In Figure 9, we explore the effect on buy-down cost, if mass-produced electric drive train components turn out to be twice as costly as the projections. With these assumptions, only the hydrogen FCV eventually becomes lifecycle competitive, and this point is delayed by about five years. The number of cars required to reach lifecycle cost competitiveness is doubled and the total buy-down cost is approximately tripled.

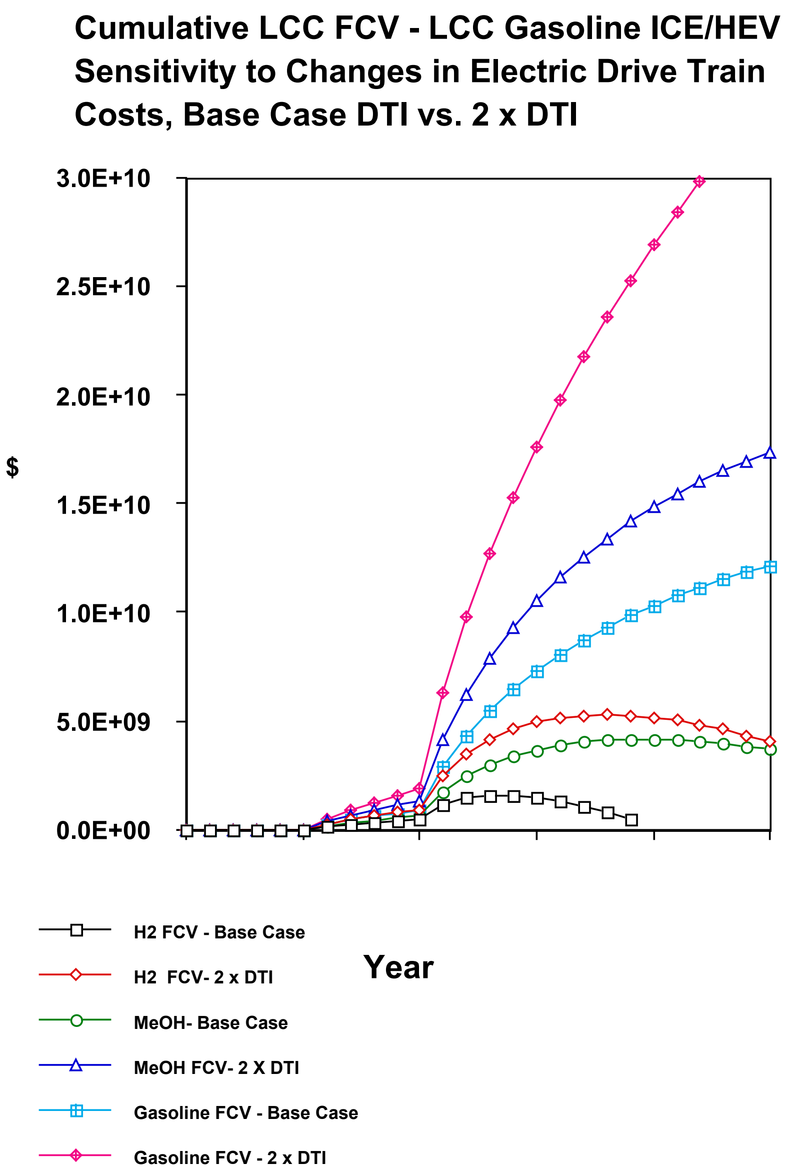

Figure 9:Cumulative lifecycle cost difference, assuming electric drive train costs are doubled

<u>Sensitivity Study Summary</u>: For almost all of the cases considered, hydrogen fuel cell vehicles appear to offer the lowest cost route to bringing fuel cells to lifecycle cost competitiveness with gasoline ICE hybrids. The total buy-down cost for hydrogen fuel cell vehicles is from two to several billion dollars (after total production of 1 to several million vehicles).

4.6.5.4 The potential role of fleet markets in buying down the cost of fuel cell vehicles

A recent study by Ogden, Williams and Larson (2001) found that centrally refuelled fleet markets (both light duty vehicles and buses) might be large enough to accomplish significant buy down of FCVs over perhaps a decade. In the US, mandated ZEV markets could be helpful in reaching LCC competitiveness. If H_2 FCVs were introduced into centrally refuelled fleets this would assist with the challenge of developing a widespread H_2 infrastructure.

4.7 An Optimistic Market Penetration Scenario for Hydrogen Fuel Cell Vehicles World-wide

In this section, an optimistic scenario is presented for determining how fast hydrogen fuel cell vehicles might potentially penetrate automotive markets. The scenario is not intended to be a projection of what is most likely to happen. Rather, it is intended to be a plausible scenario of how fast fuel cell vehicles might be introduced, assuming that fuel cell vehicle technology meets its cost and performance goals, and that strong policies are in place to encourage zero emission vehicles.

4.7.1 Assumptions Underlying FCV Market Penetration Scenario

The assumptions underlying the optimistic FCV scenario reflect a world where environmental concerns are paramount, fuel cells meet cost and performance goals, and strong policies are put in place to encourage ZEVs:

- increasing concern around the world during the next 25 years.
- Over the next decade, governments in a small number of countries respond to these concerns by enacting both measures aimed at internalising environmental damage costs in consumer vehicle/fuel purchase decisions and at technology-forcing (e.g., modest ZEV mandates) to encourage vehicle manufacturers to accelerate H_2 FCV commercialisation.
- Vehicle manufacturers respond to such initiatives by quickly making and deploying enough H_2 FCVs to buy down costs to market-clearing levels.
- As FCV prices approach cost-competitive levels, governments in these same countries enact further technology-forcing policies to encourage accelerated widespread deployment in densely populated urban areas of cost-competitive H_2 FCVs.
- Fuel producers respond to such initiatives by rapidly ramping up H_2 fuel infrastructure development for cars.
- As H_2 FCVs become cost competitive, a rapidly growing number of countries introduce incentives that induce both accelerated expansion of H_2 FCV manufacturing and sales and accelerated H_2 infrastructure building.
- H_2 FCV prices continue to fall with cumulative FCV production, eventually reaching levels where FCVs are cost-competitive even without taking credit for environmental benefits.

4.7.2 Optimistic scenario for Introducing Hydrogen Automobiles

The scenario based on these assumptions begins with the production activities of a single H_2 FCV manufacturer, as outlined below:

- *2000-2004*: 10 FCVs are produced annually "by hand" for small fleet demonstrations.
- *2005-2009*: 10,000 FCVs are produced annually in a pilot manufacturing facility.
- *2010*: 300,000 FCVs are produced annually in the first commercial factory.
- *After 2014*: When LCC parity[4] has been reached with the gasoline ICE/HEV, both measures internalising environmental damage costs and aggressive (~ 50%) ZEV mandates are enacted in growing numbers of regions around the world, and the H_2 FCV becomes the technology of choice for meeting these mandates.
- *2015-2019*: Three new factories, each producing 300,000 H_2 FCV drive trains per year, go into operation each year to meet the growing demand for ZEVs, and sales into markets served by distributed refuelling stations begins.
- *2020-2025*: The number of new H_2 FCV drivetrain factories going on line increases to ten per year, with new sales targeted for countries with policies that do not yet internalise environmental damage costs. By 2022, H_2 FCVs become cost-competitive without taking into account the environmental benefits they offer.

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[4] Assuming lifecycle costs include air pollutant and GHG damage costs.

Under this scenario, percentages of H_2 FCVs in the overall global car population are 0.3% in 2015, 2.1% in 2020, and 8% in 2025, when there would be 108 million FCVs on the road worldwide. Annual worldwide sales of H_2 FCV sales grow from 1.2 million in 2015 (1.4% of new car sales worldwide) to 7.8 million in 2020 (7.6% of worldwide sales) to 23 million in 2025 (19% of worldwide new car sales). Continuing on this track, the H_2 FCV could come to dominate automotive sales throughout much of the second quarter of this century.

This scenario shows that, even under optimistic circumstances, the H_2 FCV will not be able to "solve" the environmental and energy insecurity problems posed by today's transportation technologies during the first quarter of this century. However, by 2025, the H_2 FCV could be poised to make major contributions to solving these problems sometime during the second quarter of this century.

4.7.3 Supplying Hydrogen to Automobiles in the Optimistic Scenario

How quickly could a hydrogen infrastructure be put in place to meet the growing demand for hydrogen? A course of hydrogen infrastructure development is sketched below in parallel to adoption of hydrogen vehicles.

In the 2000-2004 timeframe, hydrogen is likely to be provided to small demonstration fleets (10 cars or a few buses) by truck or perhaps small-scale onsite production.

From 2005-2009, fuel cell vehicles produced in the 10,000 unit per year pilot plant will probably be used in centrally refuelled fleet markets. Onsite hydrogen production systems could be sited at centrally refuelled fleet garages, or hydrogen might be delivered by pipeline from nearby central production sources.

In 2010, the full-scale fuel cell drive train plant begins operating, producing 300,000 units per year. Most of these cars are sold into centrally refuelled fleets. Onsite hydrogen production systems are sited at centrally refuelled fleet garages. Alternatively, hydrogen might be delivered by pipeline from nearby central production sources.

By 2015, we assume that the production of fuel cell cars “ramps up” from 1.2 million new H_2 FC vehicles per year in 2015 to 4.8 million new FCVs per year in 2019, a level which may well exceed global fleet markets. In the 2015-2019 timeframe, the hydrogen infrastructure takes a leap from supplying only centrally refuelled fleets to beginning use in general automotive markets. When the demand for ZEVs becomes sufficiently dense, development of central hydrogen supply systems with pipeline delivery is begun.

Starting in 2020, H_2 FCVs begin to compete in general automotive markets. Central hydrogen supply systems are built in many cities around the world. Where feasible, sequestration of CO_2 is done. The capital cost of building hydrogen infrastructure on a large scale ($300-800/car for 10s of millions of new H_2 cars per year) is on the order of tens of billions of dollars per year. By 2025, 8% of all cars worldwide are hydrogen fuel cell vehicles.

4.8 Implications for Developing Countries

If industrialised countries could successfully develop and bring to market near-zero emissions technology for transportation over the next 10-15 years, and if policies were enacted to promote the transfer of such technology to developing countries, those countries would have the opportunity to “leapfrog” then to state-of-the-art super-clean transportation technologies. Providing the near-zero emission transportation technology needed by developing countries 15+ years from now would require extensive collaborative international research, development, and demonstration activities in the interim, to shape such technology to the conditions and needs of developing countries (PCAST Panel on International Cooperation in ERD[3], 1999). Small passenger vehicles (e.g., two- and three-wheeled vehicles), buses, trucks, and locomotives (all of which are widely used in developing countries), as well as cars, would have to become foci of serious international collaborative developmental efforts (e.g., via international industrial joint ventures and new public-/private-sector partnerships) during the next 10-15 years to provide a basis for technologies characterised by near-zero emissions subsequently playing major roles in the transport sectors of developing countries.

Developing country partnerships should result in economic activity in the production of bus gliders and balance of generating plant at low costs. In addition, GEF-eligible countries such as China and Russia are developing fuel cell technologies themselves. Partnerships and technology licensing systems will be needed as the commercialisation phase is launched.

5 MARKET PROSPECTS AND FINANCING FOR FUEL CELL DISTRIBUTED GENERATION

5.1 Introduction

It is becoming generally understood that distributed generation (DG) can provide a wide range of benefits depending on the type of resource deployed, where it is installed, and when and how it is operated. The benefits fall into a number of categories and can have a high value in comparison with conventional economic benefits. In some cases it is reasonable to attribute an increase in the value of the project of up to 50% to these DG benefits, and it is clear that they should be included in the evaluation of specific projects.

1. Generation

DG can provide capacity (kW) and energy (kWh) benefits, as well as some related services and benefits at smaller increments in capacity than is commonly the case. These include spinning reserve, black start capability, load following, and reactive power.

2. Distribution and Transmission

Properly sited and operated distributed generation resources can reduce and defer investment in transmission and distribution plant. Operated in a way that reduces line and transformer loadings, DG can reduce losses and the high operating temperatures that shorten plant life, and may make it possible to configure a distribution system so outages affect fewer customers. Where insufficient transmission and distribution capacity exists, DG may provide a low-cost and low-risk alternative to establishing additional grid- and generation-capacity.

3. Environment

Fuel Cells can produce environmental benefits in the form of lower local and global emissions and lower noise than conventional generation technologies. On the generation side, environmental improvements are likely from high efficiency gas-fuelled sources. Much of the potential environmental benefit associated with DG in general comes from improved potential for co-generation, and fuel cells also have significantly greater efficiency over the lower portions of the load curve than do conventional technologies.

4. Reliability

Under the general heading of reliability, increased distributed generation use can lead to shorter and less widespread outages. The small size of distributed resources means the same level of reliability can be achieved with lower installed generation. There is also reduced risk associated with shorter lead times and greater mobility.

a) Lower Reserve Margins. The larger the size of generating units, and the higher the forced outage rate, the greater the level of reserves required to deliver a given level of reliability. Distributed resources, because of their very small size and modular nature, will almost always reduce the amount of reserve capacity needed to meet a given level of reliability. Resources with low forced outage rates would further reduce required reserves.

b) Reduced Transmission Loading. Reliability is also influenced by the capability of transmission facilities. If located in the right place and operated at the right time, distributed generation can increase reliability by freeing transmission lines to serve reliability purposes. Closely related is the ability of strategically located distributed resources to reduce or eliminate load pockets and provide local voltage support.

c) Reduced Outages. The extent of outages and the time needed to restore service after an outage can be reduced by the deployment of distributed resources.

d) Improved Customer Reliability. An individual customer's reliability can be improved when distributed generation is located on her site and sized to meet all or at least the essential portion of her load. This provides the opportunity to continue to receive electric service when the remainder of the electric system is down.

e) Improved Neighbourhood Service. Improved control and communication technology installed in the distribution system may make it safe and economical to ”island” parts of the system.

f) Rapid introduction. Distributed resources are inherently modular in nature, and therefore have short lead times – often in the order of days. They can additionally be introduced in close relationship with demand.

Fuel cell distributed generation (FCDG) is expected to precede the majority of transportation applications of fuel cells due to less restrictive cost targets, weight requirements, spatial specifications and fuel storage constraints. Generally speaking, the Proton Exchange Membrane (PEM) and Molten Carbonate (MCFC) fuel cell vendors are forecasting a mid-2002 to 2005 period of “Initial Commercial Availability” for stationary applications – primarily defined as sales under near-commercial terms. Post-2005, the same vendors are forecasting “Substantial Commercial Availability” – products produced with high volume equipment. Solid Oxide fuel Cell (SOFC) and high temperature PEM technologies may be launched 1-3 years after the standard PEM and MCFC. Phosphoric Acid fuel cell (PAFC) vendors are currently producing and selling their units in a heavily subsidised or premium power market, ahead of other technologies, and there is some probability that the PAFC will proceed to Sustained Commercial Availability based upon competing fuel cell and non-fuel cell distributed generation alternatives. Likewise, Alkaline fuel cell (AFC) developers expect market share for their technology, especially in stationary applications, based on its comparatively low cost profile.

An outline of current technology readiness is shown in Table 2. It is worth noting that the majority of costs shown in this table are for one-off, hand-built demonstration systems, and that even the first mass-produced systems will be markedly less costly.

Phosphoric Acid (PAFC)	Have been used in premium applications for many years, with proven reliability. *Prices* are now in the $3500-4000/kW range. Current production capacity is 40 MW/year in US/Canada. The prospects for continued and substantial cost reductions are unlikely due to limited expectations that the power density can be increased (although participants in the Paris workshop suggested that costs could decline to $2000/kW with high production volume).
Alkaline (AFC)	Have been used in space applications for about 40 years with proven reliability. Modified systems are under development for stationary, marine and transport applications, with *prices* currently in the region of $3,000/kW. Projected costs are low. However, the power density and sensitivity of the AFC to carbon dioxide will limit its use in some applications. Current production capacity is 10MW/year in Germany, with further capacity being added in the USA and Russia.
Proton Exchange Membrane (PEMFC)	Appear poised to attain commercial viability soonest, with efficiencies now ranging from 24-40% operating on natural gas reformate, and higher on direct hydrogen. Sizes are being tested to 250 kW, but commercial versions are likely to first appear in sizes up to only 10 kW. Costs for stationary demonstration units are still around $4,000-$10,000/kW, but are projected to come down to $700-1500/kW by 2004-2008 with high-volume production. Current production capacity is 20 MW/year in US/Canada, which is expected to double in the short-term, driven primarily by vehicle markets.
Molten Carbonate (MCFC)	Could also become commercial by 2003-2008, achieving 55% efficiency (in comparison with today’s 47%). Current costs are $8000/kW but are dropping and may soon reach half that. Expected costs for the 2003-2008 time frame are $1000-1900/kW in sizes from 250-kW to 3 MW with high volume production. The low end of the size range is expected first. Current production capacity is 10 MW/year in US/Canada.
Solid Oxide	These are attaining 47% efficiency but still cost over $10,000/kW for a 100-kW demonstration version. In the period 2004-2008, 47-63% efficiencies

(SOFC)	could be attained at costs from $800-1500/kW with high volume production. Current production capacity is 4 MW/year in US/Canada.
FC/turbine hybrids	Existing hybrid systems are attaining 57-59% efficiency in sizes to 220 kW, but still cost more than $10,000/kW for power generation (no heat recovery). With "mass customisation" through the Solid State Energy Conversion Alliance (SECA), these costs could decline to $1000-1200/kW by around 2004, and achieve 70% efficiency for sizes in the 1-20 MW range.

Table 2: Fuel cell technology readiness summary

Fuel cells are expected first to capture niche markets, moving into mass markets once costs come down. Table 3 gives an indication of possible markets from the point of view of a PEM developer.

Table 3: One PEM Vendor's Forecast of Progressive Market Development

Innovators	**Early Adopters**	**Mass Markets**
Government Agencies	Utilities	New Homes
Utility Partners	High cost to serve areas	Grid Independent
Channel Partners	Load pockets	Micro Grids
	Reliability Markets	Developing Countries
	High Income Consumers	
	Innovative Builders	

The rise in the interest in fuel cell markets is noted in North America, Europe and Japan. Companies are joint-venturing to cover all geographic markets. Figure 10 identifies over thirty PEM fuel cell developers that have joint ventured with other technology companies. The GEF-eligible developing country market, however, is currently of limited interest to the private sector. The current low level of marketing interests in the developing countries by the fuel cell vendors is due to their prioritising premium and green power opportunities in OECD countries during a period when manufacturing capacity is constrained. This represents a large baseline effort that could be built upon in developing countries, with the effect of accelerating production capacity development and reducing costs.

5.2 Demonstration and early commercialisation experiences of fuel cell technology

Worldwide over 400 demonstration plants of widely varying sizes have been installed, and these represent around 60MW of electrical generating capacity. Nearly 60% has been installed in Japan, over 25% in North America and 15% in Europe. Presently underway are a number of 1-250 kW AFC and PEMFC and 3kW – 1MW SOFC and MCFC demonstration projects. By the end of 2001, each of the near term commercial candidate technologies, in a variety of size ranges, will be have operating demonstrations in Japan, North America and Europe. Only three 200 kW PAFC projects are scheduled in a developing country, Brazil. This pattern of minimal developing country penetration is forecast to continue for at least another decade without an intervention from the multi-lateral lending institutions.

5.3 The US, the EU and Japan

The US and Canada have been proactive in supporting fuel cell technology. Government support for fuel cell and hydrogen activities in the two countries in the year 2001 is estimated at US$220 million. Government funding made available through competitive bids has provided support to a diverse range of technologies and unit sizes. In Japan, NEDO's support to FC RD&D for 2002 could be as high as US$200 million. PEMFC systems are receiving most attention, with more than 20 companies along the FC value chain taking an active role in their development. The European Commission is expecting to grant funding of about 87M€ for the period 1998-2002 and more than 20 companies are developing fuel cells, while national European governments are providing an additional 30-35M€ per year.

5.4 The International Energy Agency

The Advanced Fuel Cells Implementing Agreement (IA) of the IEA was established in 1990 with seven countries and two Annexes. During the second phase, 1996-1999, 12 countries participated[5], working on five Annexes. By the end of the next period (1999-2003) the programme is expected to add one more country and continue working on the 5 Annexes in the current agreement, on PEM, solid oxide and molten carbonate fuel cells, stationary and transportation applications.

Programmes and support are also required for removing barriers, and developing markets for fuel cells. The development of codes and standards requires immediate attention to enable the commercialisation of fuel cell systems. Efforts are also required in the understanding of regional markets for fuel cells in relation to competing technologies, their phase-in and potential long-term benefits.

5.5 Current and planned commercialisation schedule and teaming of international fuel cell companies

Significant depth and breadth can now be seen in the fledgling fuel cell industry, in the shape of the industrial teams that has been formed to develop commercial systems. The strength of the fuel cell industry in terms of private capitalisation, strength of individual corporate participants, the formidable joint ventures and the diversity of the technologies make it pronouncedly different from the photovoltaic, wind and micro gas turbine industries. This should provide some assurance to the multi-lateral lending institutions and the consumers that there will be price competition not only amongst fuel cell vendors, but also the embedded alternatives of grid connected power supply and diesel gensets.

Figure 10 indicates that there is an impressive list of international companies and joint ventures now pursuing fuel cell technology in the early stages of commercialisation. Some of the perceived leaders are:

- Ballard with Alstom, EBARA, Coleman, GPU, Tokyo Gas and Matsushita, Daimler-Chrysler, Ford;
- Plug Power with GE MicroGen, Joh. Vaillant GmbH, Kubota and Axiva GmbH;
- H-Power with US Rural Electric Cooperatives, Air Products, Osaka Gas and Fortum;
- International Fuel Cells with Shell Hydrogen, Buderus Heiztechnik and Toshiba;
- Idatech with Nuvera, Syntroleum and Tokyo Boeki;
- Fuel Cell Energy with MTU, Marubeni Corp., Enron and PPL Corp
- Siemens Westinghouse
- Energy Conversion Devices (ECD) with Texaco;
- Ishikawajima-Harima Heavy Industries, Co. Ltd. (IHI) with Chubu Electric Power;
- Sanyo;
- Fuji Electric with Kansai Electric;
- Nuvera Fuel Cells with Air Liquide and Caterpillar
- Mitsui; Hamburg Gas Consult; and Mitsubishi Electric Corporation (MELCO)

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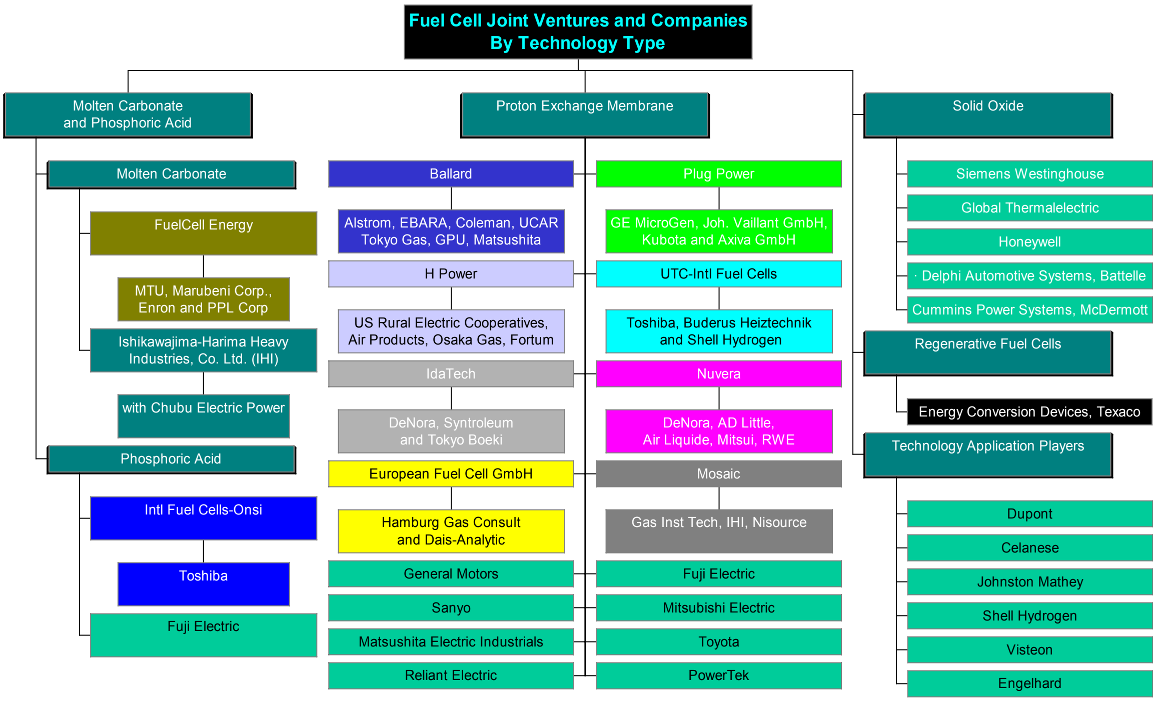
[5] Canada, Norway, France, Sweden, Netherlands, Germany, Switzerland, Italy, UK, Japan, USA and South Korea.

- Reliant with Texaco
- Toyota
- General Motors
- Honeywell
- Delphi Automotive Systems and Battelle
- Cummins Power Systems and McDermott
- Dais-Analytic and Hamburg Gas Consult

No other clean energy technology has even remotely the same depth and breadth of industrial participation considering the current early state of technology development.

Figure 10: Some alignments of Major Joint Venture Teams and Companies



5.6 Market prospects for stationary fuel cell applications in GEF-eligible countries

To understand the potential market for stationary fuel cell applications in GEF-eligible countries, an analysis of the market for DG in general is required, coupled with further detailed consideration of the number of these markets accessible to fuel cell systems over a given timeframe. Existing policy support for distributed generation at electric utilities within GEF-eligible countries is important for this latter analysis.

Discussion throughout the course of a workshop held in Paris in May 2001 revealed the application perspectives detailed in Table 4:

Industry	For industrial applications (200-5000 kW), competition with engines and small turbines will be an important factor. FCs of this size are not yet ready. Applications may require process heat and thus need high temperature fuel cells. The first to be available may be 250 kW MCFCs by about 2005, which would address the lower end of this application range. Larger fuel cells, MCFC and SOFC, will come later. ESCOs, utilities and industry associations could be “champions” to work with in implementing intervention strategies.
Commercial/ service	For commercial and other applications such as hospitals (10-1000 kW), fuel cells will also have to measure up against engines and small turbines. Fuel cells are likely to be available in

	the lower capacity range (10-250 kW) in the short term 2003-2005, with PAFC already commercially available at a premium price. Larger systems (500-1000 kW) could become commercially available in the period 2005-2010. These applications can also use the 'waste' heat, but may have lower load factors, making capital-intensive technologies like FCs less attractive. Because of lower load factors, net metering, time-of-use metering, or reverse power sales becomes an important issue. ESCOs, utilities and public authorities could be "champions" to work with in implementing intervention strategies.
Residential high income	A potential market exists for high-income urban and peri-urban households who want full-service power in the 5-10 kW range, otherwise served by diesel gensets. The amount of fuel displaced (and hence the GHG benefits) may be small if FCs are to be used only for grid-outage power. These applications would tend to value the noise reduction and other qualities of FCs highly. The coming of commercial PEM FCs by 2004 up to 10 kW could serve this market. Champions could be ESCOs, property managers or developers, or diesel genset suppliers.
Residential middle income	A potentially larger market is urban middle-income households in areas with frequent grid interruptions who want stand-by power for their most important needs. These households could be served by a 0.5 to 1-kW PEMFC (perhaps with reusable canisters of hydrogen gas), which could be on the market before other FC types[6]. These households would otherwise buy small diesel or kerosene gensets. The fuel displacement may be small, unless net metering and time-of-use metering allows households to also profitably contribute FC power as utility peaking power. A variety of public agencies, property developers or business associations could serve as champions, or perhaps the existing diesel genset dealers.
Residential – general	Many fuel cell developers (PEMFC and SOFC) are targeting the broad residential sector where they see scope for fuel cell systems replacing boilers. This market is potentially very large, but is affected by a variety of climatic and market considerations and is highly cost-sensitive.
Off-grid	One of the most potentially appealing markets is off-grid village power applications in the range 5-100 kW. These are currently served primarily by diesel gensets, of which 100,000 are estimated to be operating in villages around the world. FCs in these applications could be competitive sooner than in many others, due to the high cost of power production from the diesel gensets. Reversible FCs could also facilitate the introduction of renewable energy technologies into these systems. The biggest issues for consideration in these applications are the fuel(s) on which they would be operated, and their operation and maintenance, which might require retraining of existing diesel technicians or the bringing in of other qualified service personnel into remote areas.

Table 4: Potential early fuel cell applications and their characteristics

5.6.1 Global Market Trends in Distributed Power

A review of the global market for distributed generation systems less than 1MW and 1-10MW for 1996, gives an indication of market potential – as shown in Figure 11. For the under 10MW capacity installations, there is a fairly even distribution; 80% being under 1MW and 20% being in the 1-10MW size range. The 0-10kW, 26-50kW and 500-900kW sized units experienced the greatest growth rates from 1992 to 1996. Approximately 33,863 MW of new generating capacity was installed worldwide in the sub 2MW size range, and 60% of this new capacity was in units less than 250 kW. The sub 1MW unit orders were dominated by OECD regions, and thus 42% of new capacity under 1MW was in developing countries.

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[6] Commercial portable PEM fuel cells of 1200W have been announced for release by Ballard, with Coleman Powermate.

Figure 11: New Installation Growth Trends by Unit Size

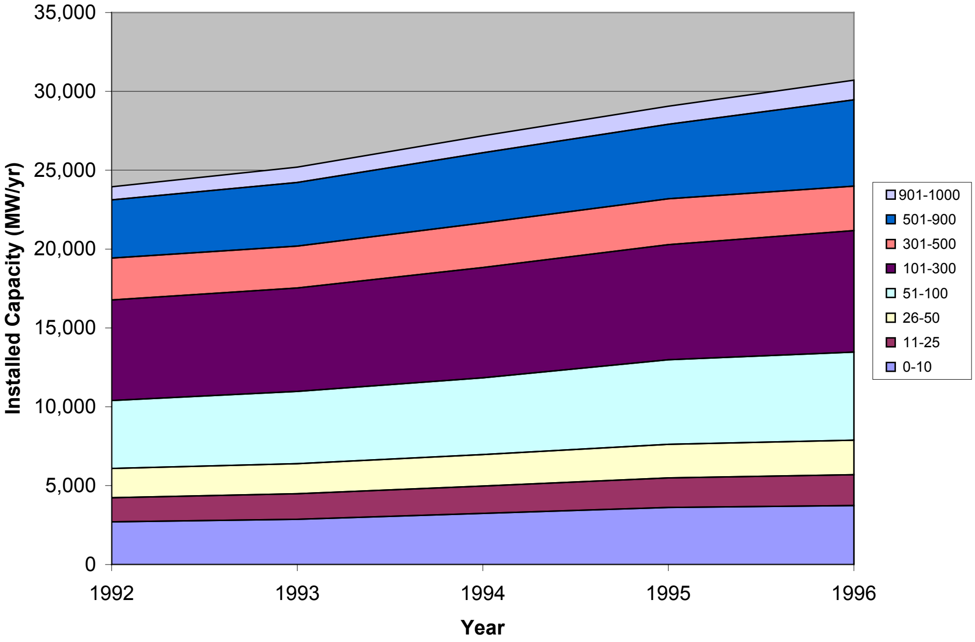
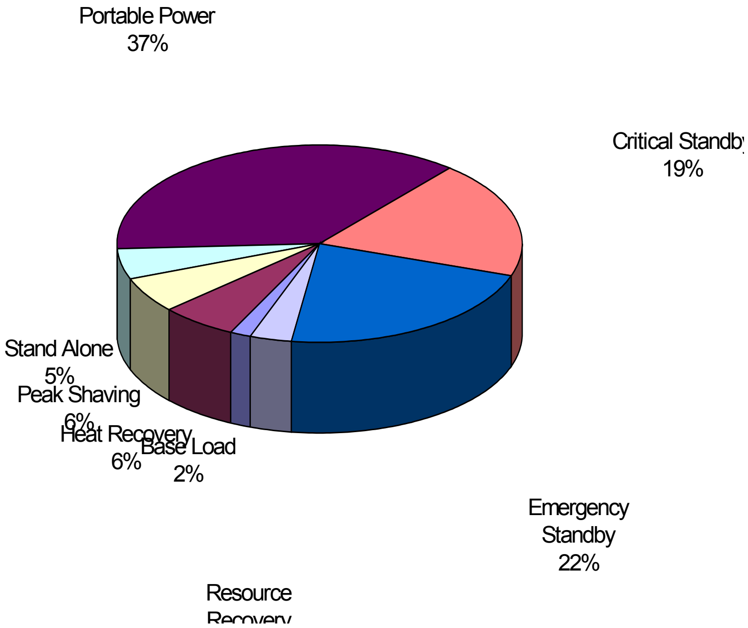


Figure 12: Global Distributed Power Applications, 1996



As shown in Figure 12, applications for this distributed generation were portable power (37%), critical standby (22%) and emergency standby (19%) while standalone power (5%), peak shaving (6%) and baseload (2%) represented only 13% of the global 1996 market. The total continuous duty units installed in 1996 were estimated to 10,957MW. The sub 1MW units were used in continuous duty only 14% of the time while the 1-10MW units were in continuous duty 52% of the time; otherwise the units were regarded as being intermittent in use. Of greatest environmental importance to the evolution of fuel cells as substitute technology, diesel fuel represented 81% of the fuel type used on this 33GW of new demand, while gasoline represented 14% and natural gas only 5%.

5.6.2 Review of Regional Findings for Distributed Generation

Surveys of fuel cell developers show a nearly universal deferral of developing country market interest until the latter stages of commercialisation. The primary reasons for the vendors deferring the targeting of the developing country markets at this time are presented in Table 5.

Topics	**Specifics**
Market Readiness	Most DCs lack a hydrogen rich fuel supply infrastructure
	Most DCs lack a liberalised energy market that authorises and encourages DG
	Subsidisation of grid-connected supply generation inhibits price competition
	Creditworthiness of customers is a concern
	Lack of market aggregators, particularly for the unserved populations
	Premium power markets are large and concentrated in OECD markets and current manufacturing capacity is limited.
	Lack of existing marketing, warehousing and service resources
Technology Readiness	Increased installation, O&M costs due to untrained labour pools for products that have not reached full technical maturity and reliability

Table 5: Vendors' Reasons for Deferring DC Market Penetration

The primary issue indicated in the interviews was that local, national and regional marketing partners are being structured in industrialised countries with existing marketing, warehousing and service resources in place. These partnerships in and of themselves represent a sufficiently large challenge for vendors – and a significant market – making any diversification into the developing country market less attractive in the short term.

If developing country markets are to be prepared for the introduction of fuel cell technology, and the potential for technology leapfrogging is to be exploited, there is clearly a role for the GEF in expanding the market opportunities and facilitating early participation by developing countries..

6 MARKET AND POLICY CLIMATE FOR FUEL CELL DISTRIBUTED POWER GENERATION

6.1 Introduction

Imperial College acted as the execution agency for this section of the project, with additional work carried out by E4tech. Reports on the full work undertaken are available, with key sections used in the development of this consolidated analysis.

6.2 The policy framework

In any market, individual policy instruments, discussed below, will function as part of a more widely developed policy framework. In Europe, for example, the EU's Energy Policy is towards full market liberalisation, with the provisos that increased energy security is fundamentally important, and that environmental performance should also be improved. In many developing countries the move towards liberalisation is still in progress – with the World Bank lending influence being a main driver – providing different opportunities and risks. However, in any market, in order to ensure the desired effect from any given policy it must be analysed in the context of other surrounding policy elements. In terms of future GEF strategy this is clearly important; both in the context of identifying a policy framework in which fuel cell distributed power generation FCDG may be a promising option, and in identifying individual policy levers that can be pulled to enhance its uptake.

6.3 Introduction to Policy Instruments

Policy instruments affecting FCDG will almost universally be those affecting DG technologies in general, though some of the perceived or actual benefits of fuel cells (e.g. very low emissions) may allow them to be uniquely targeted with very specific policies.

GEF funding may enable fuel cell technology to enter developing country markets earlier than would otherwise be the case, and may thus bring down future carbon emissions in comparison to what they would otherwise have been. In the same way, careful application of policy instruments may enable the same outcome, and it is almost essential that targeted funding be carried out where policy climates are favourable.

Potential developing country markets for FCDG have a wide range of characteristics. Typically the power market is less structured than in the industrialised countries, with limited existing infrastructure and large requirements for growth. A wide range of policy sectors must be considered:

- Technical Capacity Building
- Economic and industrial
- Energy
- Environment
- Transport

Within these sectors a wide range of instruments may be deployed to reduce or eliminate market distortions in pricing and access, or to force early market entry through mandates and standards. *Market-based* instruments affect market prices and thus influence technology choice without stipulating it; and *legislative* instruments may be more prescriptive – such as mandates. The former are intended to allow innovative and flexible solutions to problems, and should theoretically lead to least-cost solutions of a particular problem. The latter may be required if it is difficult either to categorise or monitor the policy goals within the marketplace. For example, CO_2 emissions from individual vehicles are much more complex to monitor and assess than overall CO_2 emissions from the transport sector.

The following policy instruments could have a particular bearing on the market penetration of fuel cells for both stationary and transport uses.

Market Based Instruments

- RD&D subsidies
- Taxes and levies on:
    - Emissions
    - Energy
- Duty exemptions
- Subsidies:
    - Reduced cost of capital
    - Capital contribution
    - Price support
- Tradable permits
    - Emissions trading
    - Renewable energy certificates
    - Efficiency certificates

Regulatory Instruments

- Government targets
    - Renewable energy market share
    - Combined heat and power market share
    - Government equipment procurement
- Standards
    - Product emission standards
    - Product efficiency standards
    - Customer self-imposed standards
- Sales mandates for manufacturers
- Energy market restructuring:
    - Price controls
    - Competition in generation
    - Energy services

Voluntary agreements

- Manufacturer self-imposed standards
- Consumer self-discipline through education

6.4 Market barriers and failures

Fuel cells are currently too expensive to be competitive in developing country markets, the primary market barrier being price. Other major barriers include a lack of fuel and support infrastructures, including trained personnel, and are discussed in more detail below.

6.4.1 Technology cost barriers

Technology cost barriers exist when the capital or operating costs of a new technology do not allow it to compete with existing ones. It may, however, exhibit characteristics that are considered beneficial, and governments may wish to intervene specifically to lower the costs, mainly through support for further R&D and for 'technology learning'. R&D support can be provided either as direct funding or through other mechanisms, such as tax benefits, which create a favourable environment for R&D.

'Technology learning' co-exists with economies of scale and of mass-manufacture in reducing technology costs. Governments or multi-lateral agencies may wish to contribute to the 'learning investments' to reduce technology costs for technologies with potential social benefits. They can do this by using their own purchasing power, and/or by setting market rules (e.g. mandates).

Evidence suggests that government policies supporting learning investments can stimulate other market actors and need not cover the entire cost differential between new technologies and the less expensive alternatives. A role may also exist for co-ordinated international action in supporting learning investments; perhaps a spread of projects funded by international bodies such as the GEF. Governments may also participate in private-public demonstration projects, to help reduce the high initial cost.

Fuel cells are most likely to receive direct funding in recognition of specific environmental attributes, so one way of reducing the initial cost barriers may be to have market prices reflect environmental externalities. Depending on the local conditions further support may also be required.

6.4.2 Infrastructure barriers

The introduction of some technologies depends also on the availability of infrastructure. Infrastructure investment may need to be carried out by someone other than the technology user, or require action from several different actors, and may not happen in the absence of technology uptake. Governments can play an important role in addressing this ‘chicken and egg’ problem. They can invest directly in infrastructure or provide incentives for the private sector to do so, through tax breaks, subsidies and expedited regulatory review. A key role of government is in facilitating investment decisions and sending the long-term signals to provide investor confidence.

6.4.3 Capital stock turnover barriers

Energy and transport technologies and infrastructure are frequently characterised by slow rates of capital stock turnover, which retard the adoption of new alternatives. Governments can influence the replacement of old technologies through information programmes and a variety of market and regulatory instruments. They may focus on increasing the turnover rate of stock as a whole, which will tend to enhance uptake of new technologies, or they may prefer specifically to address the replacement of old stock with new.

6.4.4 Market organisation barriers

These barriers apply frequently to the uptake of energy efficiency measures in the buildings and industrial sector, where investments on the part of end-users and energy suppliers may be discouraged because of the way the market is structured or regulated. Organisational barriers can be overcome through, for example, regulation aimed at integrating energy efficiency principles into sector policies, and economic incentives aimed at investment in improved equipment and infrastructure. Incentives for energy service companies may be provided, potentially enabling new technologies and more efficient use of resources through flexibility in providing solutions to problems.

6.5 Policy areas for consideration

No single policy can indicate which markets might be targeted for early GEF funding; a portfolio of policy measures will be appropriate. GEF support is more likely to be effective in a market that already has established policies that are favourable to DG. These can be broadly broken down under the headings identified earlier:

6.5.1 Energy/market policy

Without specific incentives for DG in a regulated electricity market, the tendency in the past has been towards large-scale centralised plant. A liberalised market, however, *should* offer the opportunity for increased competition, and allow niches for distributed generation to be exploited.

The liberalisation framework must allow the correct incentives for DG. Many aspects of the market need to be considered. Well-organised access to existing networks should be possible, and pricing policies must allow the market to find its own level, rather than being artificially capped. Flexible power exchanges with time-of-day pricing and some opportunity for companies to hedge risks are also appropriate, but less likely in developing countries. However, DG may also succeed outside of these conditions, perhaps in individual microgrids.

Broader energy market issues will also have a bearing on the penetration of FCDG. Liberalisation of a natural gas market, if there is one, may provide incentives for actors within this market to pursue technologies running on natural gas. Fuel cells may fit this niche.

Areas of support for renewable generating technologies are important opportunities for support to FCDG. Most renewable sources are DG by their very nature, and synergies should exist regarding the utilisation and capacity of integrated renewable-FC systems. Use of remote renewable capacity to generate electricity when required and hydrogen when there is no demand for electricity, enables energy storage within the system. The hydrogen can later be used to generate electricity using a fuel cell system, increasing the utilisation of the resource and maintaining a carbon-free electrical supply capacity.

A policy towards diversification of energy supplies could also have a positive bearing on FCDG. The ability to convert a variety of primary resources, including wind, solar, biomass and even coal into electricity, at high efficiency and with low emissions in comparison with competing technologies, may favour the fuel cell. Policies assisting rural electrification may also be beneficial. Opportunities exist for use of local fuel resources such as biomass for local generation of electricity using fuel cells.

6.5.2 Environmental policy

Strong or specific environmental policies are likely to assist FCDG penetration. As fuel cells are intrinsically low-emissions and low-noise devices, policies favouring these characteristics will be important. Many of these tend to be highly location specific, as noise and pollution requirements within urban areas can be much stricter than those in rural situations.

Policies favouring reduced CO_2 emissions will favour fuel cells under certain circumstances. Generally it is true to say that fuel cells offer reduced greenhouse gas emissions, and in some cases these emissions can be markedly less than competing alternatives. Full fuel cycle analysis should be used to avoid those cases where increased GHG emissions can result, e.g. from fuel transportation and reforming.

Environmental policies that will tend to support fuel cells include:

- taxes on polluting emissions
- some form of monetary support for clean technologies
- relaxation of standard permitting requirements for proven clean systems

6.5.3 Technical Capacity Building Policy

For any potential GEF funding to have a long-term impact, there needs to be backing of education and training within the sectors targeted. For FCDG to expand into wider markets, skills and training for local support of the technology will have to be developed. This will depend not only on general standards of education and training, but also on policies favourable to new technologies and skills development. The technical capacity for safety, operation and maintenance should be a minimum goal. If local sourcing of components and eventual manufacturing of subsystems or even full systems can be encouraged, the opportunities for sustained use of FC technology will be much greater than if it is simply brought in and supported from overseas.

6.5.4 Economic and industrial policy

Aspects of economic and industrial policy can also be brought to bear on new energy technologies. Relaxation of import duties for clean energy technologies may be an important near-term step to enhancing their competitiveness in a new market. Support, perhaps in the form of reduced taxation rates, for specific sectors of industry may provide a useful driver.

Many OECD governments and other organisations, such as the IEA, are examining policy issues such as market liberalisation, DG interconnection standards (IEEE 1547), net metering, siting and permitting, and emissions standards. A wide variety of policies may assist in providing the right framework for the introduction of fuel cells, including electricity and gas market liberalisation; use of regulatory instruments such as government targets and standards; utility tariff policies incorporating reliability and power quality bonuses, time-of-use charging, and capacity charging; and a variety of environmental policies, particularly those favouring emissions reductions. A schematic of how policies may affect fuel cell markets is shown in Figure 13.

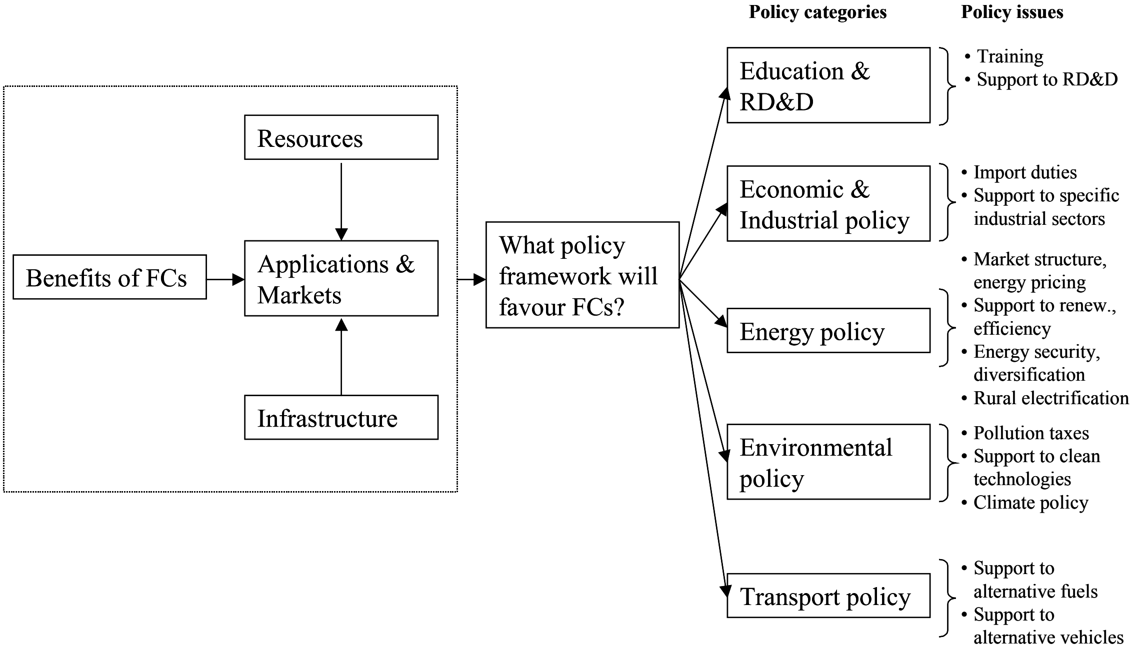


Figure 13: The policy framework for fuel cells

6.6 Policy Development Opportunity

The discussion above suggests that the policy framework in which fuel cell distributed power generation may be effective is varied and complex, and that no single policy is likely to be either necessary or sufficient to enable fuel cell systems to penetrate into DG markets without support. It may thus be reasonable to develop a preferred 'portfolio' of policies that may be expected to broadly help or hinder FCDG, to assist in identifying areas in which early demonstration projects may be considered.

6.7 Regional policy drivers for DG

An analysis of the local drivers and policy frameworks for DG was carried out for GEF-eligible countries. A screening matrix was devised to assess a country's amenability to DG, using a measurable set of key criteria. The results of this screening led to further detailed consideration of countries, namely Brazil, Bangladesh, India, the Philippines, and South Africa. Three key countries – China, Indonesia, and Mexico – were not included in the more detailed analysis. Although they constitute excellent markets for renewable energy technologies, these countries offer fewer clear policy incentives for utility adoption of DG technologies. This report includes brief summaries of these three second-tier markets for utility-based distributed generation. For FCDG a more specific analysis will also be required for the individual countries, projects and circumstances.

6.7.1 Sub-Saharan Africa

This region is characterised by an almost uniform under-development of energy infrastructure, limiting electricity access in most countries to less than one-fourth of the population. Utilities in most countries lack the budgets to expand access and are at best keeping pace with population growth.

Almost no identified or commercially available natural gas resources exist, and hydropower constitutes much of the installed capacity for the region. Average prices are often high because of a reliance on imported power or primary fuels, offering a long-term rather than near-term opportunity for fuel cells run on renewable energy sourced hydrogen.

Installed capacity requirements are generally unclear. Actual demand may only be slowly increasing, but there may be a high willingness to pay for small quantities of power delivered from batteries and traditional fuels, demand could be said to be significant. Power quality and reliability remains limited for much of the region.

Most foreign private investment in the electric sector is presently in the form of bulk generation facilities, increasing supplies to population centres. A general lack of sector restructuring has prevented competition and privatisation of energy distribution that might increase sector financial health and reduce corruption, thereby limiting investment in new infrastructure.

Cote d'Ivoire, Kenya, Mozambique, South Africa, and Senegal have all enacted at least early-stage sector reforms. Only Cote d'Ivoire, Mozambique, and South Africa, however, have near-term prospects for the commercial availability of natural gas. Of these countries, the South African electric (Eskom) and coal gas (Sasol) utilities in particular have the financial strength to adopt emerging DG and face increasing competition from both gas and electricity liberalisation that could speed adoption of DG. Sector restructuring policies aimed at bringing economic development to historically marginalised black rural populations are also setting the stage for Eskom and other energy service companies to pre-electrify these areas with solar PV and hybrid mini-grids.

6.7.2 Middle East-North Africa (MENA)

With few exceptions, the MENA region has ample access to natural gas resources, developed increasingly for electricity generation, largely replacing oil-fired capacity. Most governments are encouraging increased gas dissemination to industrial and residential consumers via growing distribution networks. Rural electrification efforts have achieved near universal access in many MENA countries (Egypt, Jordan, Tunisia). Most other countries have also significantly raised access levels.

Utilities are concerned with meeting the near-term rapid growth in demand (at least 7-10 % per year for much of the region). Although MENA countries have begun to allow or encourage expanded private participation in the development of new capacity, capacity additions continue to trail growth in demand, as governments remain reluctant to pay IPPs the tariffs they demand.

Many smaller market countries have focused on near-term grid interconnection with large power generators, making them less likely near-term candidates for adoption of a distributed generation model. Additionally, utilities have mainly avoided brownouts or reductions in power quality that might open the door for broader reform.

The country showing the best prospects for near-term adoption of DG is Egypt.

6.7.3 Eastern Europe and Central Asia

The region remains largely defined by its past incorporation in the Soviet Union and the promise of regional market integration. In terms of physical infrastructure, Soviet-era electricity sector development focused on equal access and regional cooperation that resulted in extensive distribution networks providing high levels of basic electricity access as well as establishment of regional transmission grids enabling select countries to import much of their necessary power. However, since the mid-1990s, the region has become increasingly fragmented with dozens of power systems operating in increasing isolation. As a result, almost the entire region has some access to electricity, but the power quality and security of supply have steadily diminished.

Many countries in the region face seasonal or daily shortfalls in supply. Utilities in many of these countries have had little choice but to offset growing shortfalls with gas and electricity imports purchased or bartered from neighbouring countries with excess capacity.

Utilities have fallen behind on import payments and efficiency improvements. Governments throughout the region have tried to phase in tariff increases to raise revenues for sector improvements, as well as comply with donor assistance packages. However, tariffs continue to lag behind long-run marginal production costs and EU prices, which have continued to limit utility or private sector financed modernisations and have blocked end-user incentives to pursue more efficient means of supply.

Certain Central Asian countries embraced political reforms beginning in the late 90s in an effort to attract new investment. Similarly, most Eastern European countries have enacted at least first-stage reforms and developed privatisation plans driven largely by the terms of EU accession and the subsequent promise of economic revitalization. These reforms have resulted in new private sector and donor investments that have stabilized conditions in these countries, generally in the form of large-scale generation and transmission projects designed to re-establish the integrity of regional grids and forge new links to the EU.

This is not to say that distributed generation no longer has a role to play in augmenting the early resurgence of electricity grids, but only to suggest that utilities and investors have made market integration and export capacity higher priorities than localized solutions. However, the Soviet infrastructure legacy is also one of district heating networks that have institutionalised the concept of CHP plants. Efficiencies of most district heating networks throughout the region remain low. The IFC has invested in energy service companies in Hungary with an eye toward similar investments in Poland and possibly other Eastern European countries, where pricing reforms have begun to establish a basis for efficiency improvements. If an ESCO network could be developed in these countries, it might constitute a good medium-term platform for commercialisation of fuel cells after lower cost efficiency upgrades have been realized.

In general, large market countries in advanced stages of energy sector reform and with near-term access to larger markets, notably Poland, will likely rapidly absorb initial investments aimed at strengthening export opportunities and refurbishing and/or replacing obsolete large-scale generators. Given the significant level of inefficiencies remaining in distribution and district heating networks, these countries will still be well positioned to utilise DG.

Turkey represents another possible candidate for DG. Turkey faces soaring annual load growth of 10-14%, in addition to a significant supply deficit, which has brought recent blackouts and has forced Turkey to pursue legislation calling for improved sector efficiency and liberalisation of gas and electricity markets in line with the European Union, for which Turkey is now a fully-fledged candidate.

6.7.4 South Asia

Most countries in this region face growing power shortages and have yet to bring access too much of their rural populations. Unlike many countries in Africa, however, the countries reviewed in this region have managed to develop more advanced power sectors due to industrialisation in urban areas and development of fossil fuel and hydro resources.

The rapid economic expansion of India has coloured much of the region's strategic energy development. With respect to natural gas, the region is one of stark contrasts, with Bangladesh, Pakistan, and to some extent India having significant resources, while Nepal and Sri Lanka have none. This absence of gas constitutes a serious negative issue for utility adoption of fuel cells or micro turbines in the near-term, but utilities and governments in non-gas countries are actively courting investment in a range of DG solutions (solar PV, wind, small hydro and biomass/biogas) for rural electrification and grid-connected schemes.

Electricity export prospects do not dominate electricity sector development prospects as in many Eastern European and Central Asian countries. Most utilities have well-developed rural electrification programmes, which will remain priorities for the near-term.

With the exception of Pakistan, which currently enjoys a power surplus, peak power shortages and seasonal shortfalls limit the power quality and reliability of those with access to grid electricity. The poor financial condition of most state utilities, brought on by non-rationalized tariffs, theft, non-payment, non-metering, and poor collections, have largely hindered necessary investments in both generation and delivery infrastructure. Perhaps more critically, utilities and governments have focused more on bolstering and reforming the generation sub-sector in an effort to avoid shortages. State and IPP mega-projects, mainly in India, have largely languished because the poor creditworthiness of the state distribution utilities made financing such projects next to impossible.

Donors and some governments have begun to recognize that reforms and investment at the transmission, but particularly the distribution, end must precede wholesale additions to installed capacity.

The best prospects in the region for utility adoption of DG are therefore in India, but also Bangladesh. India faces major renovation of its transmission and distribution networks. Even with new donor funding and potential privatisation of distribution assets, tremendous scope will remain for distributed generation. At least one utility in India is already experimenting with micro turbines to improve grid stability. In Bangladesh, significant gas resources and at least a partial emphasis on small power generation schemes under its Small Power Generation Policy could lead to the incorporation of fuel cells or micro turbines into the well-managed projects of the country's Rural Electrification Board or small-scale IPPs.

6.7.5 East Asia and Pacific

The region's recent economic crisis triggered the expansion and acceleration of electricity sector reforms throughout the region as it brought about reductions in electricity demand and utility financial stability. These reforms, coupled with persistent serious urban air pollution problems, low supply- and demand-side energy efficiencies, and difficulties electrifying remote and rural populations, present numerous opportunities for utility adoption of DG.

Development of gas resources has become an increasingly central component of electric sector plans throughout the region as a means to improve energy security/fuel diversification, reduce emissions, and raise generation efficiencies.

District heating using gas-fired CHP plants is a trend that China expects to pursue in the medium-term in its northern provinces. China already actively promotes cogeneration to improve industrial efficiency. Many countries have policies promoting cogeneration under energy efficiency programmes as well as renewable energy incentives, indirectly or directly linked to rural electrification efforts. Most of these programmes offer donor subsidies or government incentives. China has adopted a more regulatory approach, requiring all regional grids to obtain at least 5.5% of all electricity from renewable energy resources by 2003. This renewable energy portfolio standard will heavily impact eastern utilities, which presently source limited amounts of renewable electricity, and might lead to opportunities for micro turbines or fuel cells used in combination with village biogas or biomass gasification.

To keep pace with growth in demand, governments in many countries have relaxed price controls to encourage conservation and attract IPPs. Countries are also pursuing broader electric supply industry restructuring to level playing fields for IPPs vs. state utilities, though lingering monopoly advantages continue to frustrate IPPs, as well as purchase price negotiations.

At the same time that China is mandating investment in renewables and opening the door for new DG, it has required authorities to shut down inefficient small-scale plants and concentrate on constructing thermal power plants with single-generation capacity in excess of 300 MW. The central government has also mandated regional grids to purchase the off-take from mega-scale projects, notably the Three Gorges Dam, and is investing in grid unification and high voltage direct current transmission lines to increase the scope for mega-projects. Countries of the greater Mekong river delta have also prioritised regional grid interconnections and national grid unification to even out supply conditions and reduce prices. These commitments are not necessarily mutually exclusive with the use of DG to strengthen grid functions, however with the exception of China few countries possess the resources to support both grid extension and DG-based grid strengthening.

Rural electrification remains an investment priority for much of the region. However, most utilities remain shielded from competition to serve these rural areas and tend to rely on donor or government subsidised conventional grid extension projects.

Based on the rapidly shifting sector policies in much of the region, identifying the best prospects in the region for utility adoption of fuel cells, micro turbines, and other DG is very much a moving target. Based on existing and pending policies, China presents an increasingly favourable environment for clean and efficient technologies and innovative solutions fostered by competition. However, policies emphasizing grid unification and the phase out of small-scale thermal plants, as well as potential residual difficulties enabling private competition tend to work against near-term adoption of DG. There is tremendous scope for efficiency improvements through adoption of cogeneration-based DG, including fuel cells and micro turbines, by a range of industries that may become viable under a subsidised multi-lateral lending agencies' investment. However, in the absence of clear policies favouring the buy-back of excess power and equal access to the grid these facilities may do well to invest in commercially available technology improvements. As such, China may not be a first round candidate for fuel cell adoption, but this situation could change rapidly.

Other countries constituting solid near-term candidates include the Philippines. Like China, the Philippines appears close to enacting deep sector reforms designed to increase competition at the level of generation and power marketing. Existing regulations and financial incentives favour private investment in the power sector and have begun to level the playing field for renewable resource power production and cogeneration vs. thermal generation. The government's ambitious rural electrification programme has stimulated a variety of local utilities and IPPs to participate in the new and renewable decentralised grid-connected projects. In conjunction with the rural electrification programme, the National Power Corporation, the state utility, has established several expensive and inefficient diesel-fired small-island grids. These small grids may constitute good candidates for fuel cell integration.

6.7.6 Latin America and the Caribbean

The region is largely defined by widespread electric sector liberalization aimed at attracting needed infrastructure investment to keep pace with rapid growth in demand, to diversify the electricity mix, and to smooth out supply constraints.

The development of many power sectors in the region was initially linked to exploitation of hydropower resources, leaving these sectors vulnerable to periodic droughts, and causing many countries to look towards gas and regional grid integration to diversify and stabilise energy supplies. Additionally, although regional grid integration efforts are a top priority particularly for Southern Cone and Central American countries, implementation challenges remain significant.

Large-scale projects were not only limited to hydropower, and many countries have focused on development of large thermal plants. Dependence on a limited number of large-scale, site-specific generation facilities and imported electricity has necessitated large investments in transmission lines to reach urban and industrial loads. Large transmission distances have by their very nature resulted in high loss levels, and in some countries have proven vulnerable to a range of non-technical problems that have led to widespread blackouts. Transmission systems have largely remained under state ownership or privatised under fixed rate of return concessions.

Other countries continue to face generation and/or distribution under-investment largely due to tariffs below marginal costs. Until new operators have taken over and restructuring legislation and regulation has been solidified, utilities in these countries constitute less attractive candidates for DG adoption. Other countries in further along in the restructuring process with regulator-capped or banded tariffs have recently allowed significant price hikes to reflect increasing generation costs. This combination of increasingly competitive markets and higher prices could open the door for utility adoption of DG.

In Central America, increased prices have increased the pressure on utilities to develop new domestic renewable resources. Similarly, persistent low rural electricity access is prompting governments to consider decentralised renewable energy based approaches to rural electrification. While this pressure has resulted in the development of decentralised projects and consideration of renewable energy incentives, there remains limited scope for decentralised energy amongst utilities focused on regional grid interconnection linked to large projects. Similarly, although the current market conditions and new policy directions of select Caribbean countries make them increasingly amenable to DG adoption by utilities and a range of commercial end-users, the limited market pull of the entire region makes these countries less attractive for an investment aimed at catalysing economies of scale in DG production.

In general, the large market countries of South America, notably Brazil, and Mexico constitute better candidates for multi-lateral lending agencies' fuel cell market intervention.

6.8 Matrix Approach to a Bottom Up Analysis by Country, by Region

A matrix was produced to analyse the potential for DG markets by region. It consists of eight evaluative criteria loosely aggregated into two categories: market conditions and legal and regulatory framework. The matrix does not review small island countries or countries with small populations (under one million), due to their limited global market pull. It also does not review countries that are not eligible for GEF funding. The matrix uses a simple rating system to relay a country's amenability regarding a specific criterion that perhaps results in less flexible interpretations of favourable and unfavourable conditions. To minimise potential mischaracterizations, criteria overlap slightly to allow a general picture of a given country's conditions to emerge. Even so, a country's ratings should be considered in general terms and representative only of initial investigation.

The approach to evaluating each criterion is defined in the following paragraphs. Criterion conditions are evaluated on a relative scale of "highly favourable", "moderately favourable", or "less favourable".

6.8.1 Market Conditions

6.8.1.1 Access to a Hydrogen Fuel Source

This criterion has essentially been interpreted as access to natural gas and its derivatives. Although other fossil fuels could also have been selected, natural gas represents a common non-site specific option for utilities interested in improving local and global emissions and efficiency aspects of electricity generation. As such, gas availability could constitute a highly favourable but insufficient condition for distributed generation to emerge. Furthermore, data are uniformly available on natural gas consumption across developing countries, allowing for a quick reference point. Although renewable resources such as solar and wind can be harnessed to create hydrogen via hydrolysis, the system costs per unit of hydrogen produced are not competitive. Similarly, a variety of biomass and waste substrates can be cost-effectively processed to produce hydrogen rich gases and liquid fuels. They are not currently part of the fuel portfolio of most developing country utilities, but represent good opportunities for the longer term.

Ideally this criterion would be evaluated on the basis of access to a gas grid and rate of increased connections. However, these data points are not readily and uniformly available. The metrics used to evaluate the criterion are total consumption (both import and domestic) supported by market information regarding planned pipelines and size of reserves.

6.8.1.2 Electricity Supply/Growth Equilibrium

This criterion takes into consideration the rate of growth in electricity demand and the projected near- to medium-term need for installed capacity. For countries with demand bordering between ratings or with near-term installed capacity needs of 500 MW or less, considerations of current and expected bi-national or regional grid interconnection affected ratings. Countries with limited near-term prospects for meeting the majority of demand growth with increased electricity imports were considered neutral to positive environments for developing localised and possibly decentralised generation solutions. Those countries intending to meet much of new demand with grid interconnection were considered negative environments for DG development.

6.8.1.3 Unserved Population

This criterion would ideally compare estimates of populations with limited access to grid power or that lives within near-term extension of the countries electric and gas grids. The metric used for this criterion was left at the percentage of national population lacking access.

This rating system could be inverted by suggesting that countries with little electricity access need massive grid investments before they look to DG to marginally expand the reach and quality of grid access. Other criteria, such as strength of service provider and support for system expansion, counter-balance this dual interpretation.

Additional consideration was given to the fact that a high national access percentage can obscure a relatively high absolute number unserved. Similar considerations were given to countries with stark regional differences in access. Both of these factors are interpreted as positive factors for distributed generation markets.

6.8.1.4 Cost of Modern Energy

This criterion compared available data on end-user tariffs for electricity. Comparing end-user tariffs gives an idea of the pressure that utilities will face to reduce their prices as large- and small-scale users contemplate self-generation.

Aside from issues of limited data availability, considering tariffs outside the context of total energy expenses or even as a percent of total income makes defining a high, moderate, or low tariffs a somewhat arbitrary task. Nevertheless, an arbitrary division is useful as a first cut at identifying markets at the high tariff end of the spectrum.

6.8.2 Legal and Regulatory Conditions

6.8.2.1 Level of Sector Restructuring

The rankings relied upon the data supplied from a 1999 ESMAP report entitled "Global Energy Sector Reform in Developing Countries: A Scorecard." This report surveyed power reforms in 115 countries to determine which had taken the following six reform steps with respect to the electric power sector:

- Privatisation or commercialisation of a state-owned utility
- Laws permitting divestiture and unbundling
- A functioning regulatory body
- Vertical and horizontal unbundling of the core state-owned utility
- Laws permitting private-sector concessions or greenfield investment
- Privatisation of any of the existing state-owned enterprise assets

One of GEF's objectives is to aid the evolution of power reform that favours low GHG emissions through technical assistance and policy development support.

6.8.2.2 Level of Competition / Private Participation

This criterion examines in closer detail how reform in both electricity and gas sectors has allowed for private participation. The criterion is based again on data from the ESMAP scorecard report, specifically whether independent power production is allowed on the electricity side, and whether private investment is allowed in gas transportation and distribution.

6.8.2.3 Third party access / Wholesale spot market

This criterion begins to evaluate the barriers of electricity producers to freely sell their power to more than one purchaser. Although third party access policies and regulations of select countries could be found, the matrix required a more uniformly accessible means of comparison and looked for information on the presence and viability of wholesale spot markets.

6.8.2.4 Clean Energy Incentives

This criterion evaluates the strength of the government's interest in shifting electricity production towards cleaner technologies and fuels. The means by which this interest is measured include the adoption of the policies including: production tax credits, soft financing for clean energy projects, a renewable energy portfolio standard or some sort of clean energy set aside requirement, standardized purchase terms including fixed tariffs for clean energy production.

6.8.3 Profiles of Individual Countries

Cross-referencing of all of the matrix categories produced the following short-listed candidate countries:

Table 6: Initial Candidate Countries

South Africa	Egypt
Brazil	Bangladesh
India	Philippines

6.8.3.1 South Africa

South Africa is in the midst of restructuring its electricity sector and on the verge of enacting comprehensive legislation covering the gas sector. These changes have recently resulted in the development of the country's first IPP with others soon to follow, and increased private investment in gas transmission and distribution. However, the virtual monopolies of electricity (Eskom) and coal gas (Sasol) may present formidable challenges to future competition. Government pressure to provide expanded modern energy access to unserved rural areas is driving significant opportunities for stand-alone and mini-grid renewable energy based systems. Eskom appears committed to embracing new technologies and fuels to meet electrification goals and future demand. Eskom's non-regulated subsidiary is exploring opportunities for use of fuel cells and micro turbines through joint ventures with Sasol and Honeywell's regional distributor respectively. Commitments on the part of the government and Sasol to increase consumption of gas through domestic development and pipeline imports may increase the number of niche markets for fuel cells and micro turbines. However, without some kind of donor intervention, Eskom will likely not take the lead on distributed generation. The gas sector may present better opportunities and more information is needed on Sasol's interest in distributed generation technologies. Beyond utilities however, more entrepreneurial energy service companies and non-grid concessionaires may constitute better possible targets for an intervention aimed at scaling-up, particularly micro turbine market demand. Unfortunately, the full fuel cycle carbon emissions of gas from coal used in SOFC or hydrogen from coal used in PEMFC is much higher than most other technologies. If there are natural gas reserves, domestic or imported, that have the potential to displace coal gas, the GHG benefits can be said to be larger.

6.8.3.2 Egypt

The Egyptian electricity sector faces two major and interrelated problems: (1) a pervasive culture of non-payment on the part of large public sector end-users, and (2) insufficient resources to support the necessary near-term generation additions and transmission improvements to keep pace with rapidly escalating growth in demand. Although both issues are currently the focus of legal and regulatory reforms, to hedge a future crisis the utility has begun working with an energy service company to deploy micro turbines and donors to gain familiarity with fuel cells.

6.8.3.3 Brazil

The energy industry in Brazil is in the midst of a deep restructuring process designed to promote cost-effective, private sector participation across all energy sub-sectors and improve electricity access. Key changes implemented through sector restructuring thus far include concepts such as free consumers, independent producers and traders, tariff regulation based on service by price, energy wholesale market, free access to transmission and distribution networks, and system independent operators. However, the regulatory framework for distributed generation remains marginally developed and mainly within the context of rural electrification and efficiency improvements through self- and co-generation.

Large industrial consumers, particularly in the South and Southeast, are increasingly bargaining with utilities for lower tariffs and better supply conditions, and replacing their suppliers in certain cases. This trend, coupled with pending Government and Eletrobras incentives for natural gas thermal generation and cogeneration, could create opportunities for power parks using micro turbines or fuel cells.

6.8.3.4 Bangladesh

Modern energy supply and access levels in Bangladesh rank among the lowest in all of Asia. Installed capacity regularly fails to meet demand resulting in peak shaving and blackouts. Consistent 8-10% p.a.

growth in demand continues to outstrip capacity additions. Access problems are largely the responsibility of under-funded but capably managed rural electric cooperatives. Co-op grid extension programmes add roughly 200,000 customers per year, but can not cost effectively reach much of the rural population in the near-term and provide marginal quality at the grid periphery. Unauthorized private operators of diesel mini-grids have sprung up to serve off-grid and periphery grid communities. The government intends to authorize these operations with the publication of a small power generation policy, and further intends to provide fiscal incentives for captive power generation in the private sector for systems around 10 MW in size. As proposed, the policy does little to promote generation under 50kW.

6.8.3.5 India

Over the last decade the Indian power sector has steadily increased capacity and expanded access to the point that roughly 80% of the population has *some* access to electricity. However, peak power shortages and inefficient transmission infrastructure continue to result in blackouts and variable power quality throughout urban and rural areas. Federal and state governments are simultaneously attempting to accelerate capacity growth through IPP mega projects and to elevate power quality through a range of reforms designed to encourage necessary investment. Reform has advanced in a patchwork and gradual fashion that has both delayed mega projects and limited the pace of service improvements. Policymakers have linked sector growth to increased use of cleaner fuels, namely natural gas. Significant private-sector investment in gas infrastructure may soon increase access and supplies, however the regulatory framework necessary to stabilize and promote that investment has only begun to take shape. Many users already rely upon back-up power systems, and can sell excess power to the grid in most states.

6.8.3.6 Philippines

The Philippine electricity sector currently remains largely dependent on imported fossil fuels and dominated by the National Power Corporation (NPC), which exercises tight control over the generation and transmission sectors. The expected marketing of abundant off-shore gas in 2002 should begin to address the first issue, while restructuring legislation could soon curtail the state's generation hegemony and ramp up competition across the sector. Independent of pending reforms, the policy framework is relatively neutral with respect to utility adoption of emerging DGTs, with notable exceptions for cogeneration and rural electrification. Policies promoting the aggregation of premium power users in "economic zones" may also allow captive generation to flourish and compete within distributor franchise areas. On the generation-side, numerous expensive and inefficient small-island grids receive power subsidized by the financially-weak NPC constitute another niche opportunity for emerging DGTs. A recent study on the market assessment for fuel cell technologies indicates that there is significant market for fuel cells in the Philippines. This includes requirements for premium power, commercial application for co-generation and rural electrification for off-grid.

6.9 Expected Cost Reduction Profile for FCDG Over Time

6.9.1 Capital Cost and Operation and Maintenance Cost Reduction Trajectories

It is important to assess whether fuel cells operating in a distributed generation can achieve cost parity with energy delivered from conventional power plants or other competition. Cost parity is assumed when the costs of electricity from the fuel cell and conventional system are equal, taking into account capital, O&M, fuel usage, transmission and distribution (T&D) costs and differing performance. Note that efforts to influence the policy environment and develop technical capacity are not considered part of the cost of buying down the technology in the structure of this report.

The study's objective was to assess with prevailing World Bank methodologies the current and future cost competitiveness of fuel cells with conventional power and T&D delivery systems. Thus, the study sought to determine the competitiveness of the central station power versus a distributed generation fuel cell technology; rather than carry out a comparative analysis of fuel cells versus microturbines, photovoltaics and reciprocating engines. Within this methodology the deferred T&D capital and O&M costs of central station power are not fully reflected; and thus the benefits of distributed generation are not fully captured. Methodologies outside of the World Bank do capture the economic costs of delivered energy from central station power plants versus the avoided T&D costs of distributed generation, and would show the FCDG systems in a better light.

Background

Several factors are critical in determining the cost of power from fuel cells in DG applications. The most important factors determining the competitiveness are:

- First cost of the fuel cell system
- Annual fuel cost (determined by efficiency and fuel prices)
- Non-fuel operating and maintenance (O&M) costs
- Use of co-generation
- GHG benefits and value of the GHG emissions reduction

Another factor that influences both the competitiveness and the operating strategy and design of fuel cell systems is applicable competing grid rate structure.

Capital Cost Components

The first cost or capital cost currently represents the highest cost barrier to the implementation of fuel cell systems. The capital cost elements for different fuel cell technologies vary, but a number of component sub-systems tend to be common in their contribution to fuel cell system capital cost. These component sub-systems include:

- *Fuel cell stack*. Has a major impact on the cost of all fuel cell systems.
- *Fuel Processor (if applicable)*. Can be a considerable cost factor in PEMFC fuel cell systems. MCFC and SOFC do not necessarily require a reformer.
- *Balance of Plant.* The balance of plant includes the interconnecting piping, valves, controls, air movement equipment, thermal and water management systems, and can be a considerable cost factor.
- *Power Electronics.* To convert the DC power produced by the stack to AC, power electronics are required. The projected cost of these represents a potentially smaller proportion of the cost.
- *Heat Recovery Unit (if applicable).* Where co-generation is desired, a heat recovery unit is required. Estimates indicate that the heat recovery unit will add between ten to twenty percent (or around $100/kWe) to the capital cost of the unit, comparable to a similarly sized boiler. However, in the case of a new system, the cost of a conventional heating system with the same capacity would be comparable, and thus there is no net additional cost to the heat recovery unit, and hence our analysis considers cost both with and without the co-generation package.
- *Delivery and Installation.* For smaller mass-produced systems, installation and delivery cost will add around 30-45% to the factory cost. This value could vary widely in developing countries, especially in remote regions. This study did not attempt to resolve the installation cost factors for different geographic locations.

One cost component that does not play a role in fuel cell DG systems is the T&D cost. As this cost is frequently more than half of the cost of delivered electricity for grid-based power, it is clear that this is one of the key drivers for DG in general, and for fuel cell technology which can provide DG at small scale.

Capital Cost Estimates

Based on sparse interview results and published information, the current estimates for the cost of the first generation of fuel cells are typically around $4000/kW (factory cost, based on input from a few developers across different fuel cell platforms). This first generation technology would reach markets in the 2002 to 2006 timeframe, depending on the developer and the type of fuel cell. This cost does not compare well with conventional power generation technology, which ranges in cost from around $200/kW for very large gas turbines to around $1200/kW for state-of-the-art coal-fired power plants.

Competing DG technologies (predominately engines and micro turbines) have costs in the middle of that range.

However, currently fuel cells are still in various stages of prototype testing and demonstration, and hence these initial unit costs are based on very low production volumes. In order to achieve some degree of market penetration, these early models may have to be subsidised to penetrate broader DG markets early on.

The costs of fuel cell systems will be reduced as they achieve greater market acceptance and as more experience is gained. Various studies have indicated that fuel cell installed costs must be reduced to around \$1500/kW (installed) or less for DG applications and to \$1000/kW (installed) or less in order to address broad DG markets. Acceptable prices with co-generation may be somewhat higher, and in niche applications and in areas with poor or non-existing grid infrastructure, allowable costs may be significantly higher.

Table 8 shows the general cost and timing parameters for the most important fuel cell technologies. The ranges, reflecting the uncertainty in cost, clearly are overlapping for the different fuel cell technologies: all fall in a range between around \$900/kW and \$2000/kW installed cost.

As the table shows, PEMFC and SOFC technology have the potential to achieve installed costs of well below \$1500/kW (installed). MCFC technology also appears to also have the potential to approach this cost level. PAFC technology would also be able to reach this mark, though the developers appear to be refocusing and thus it may not receive the investment required to do so. In order to achieve these costs, successful further development and demonstration of each technology, as well as high-volume production (10,000 to over 100,000 units per year) will be required.

Given that these cost estimates are long-term projections, the current difference in development status between the different technologies has only a modest effect on the projections.

Fuel Cost

Of course, annual fuel costs are strongly influenced by applicable fuel prices, which are subject to the same sort of fluctuations as electric power grid prices. The trade-off between the two is treated in the economic analysis.

In practice, the primary factor in the system efficiency is the electrical efficiency. Electrical efficiency varies somewhat between different fuel cell technologies. In general, the high-temperature fuel cell technologies (SOFC and MCFC) can achieve somewhat higher efficiencies than the low-temperature technologies. This is mostly because low-temperature fuel cells can only use the hydrogen that is produced by the reformer, whereas high-temperature systems can use virtually all combustible species and sometimes do not require a reformer at all. High temperature fuel cells can also be integrated into combined cycles with turbines, thus boosting their efficiencies into the 60-75% range.

A second factor determining the system efficiency is the system capacity, where system efficiency can be traded off against cost effectiveness. As a result, small-scale (less than 10 kW) PEMFC or SOFC systems will tend to have efficiencies a few percent lower than larger-scale systems (around 50 kW or larger).

Overall, fuel cell efficiencies are reasonable to good compared with the grid average efficiency in most countries (typically 30-40%), or compared with other DG technologies (e.g. micro turbines or engines), and especially good at part-load, where many systems operate for much of the time. Fuel cell DG efficiencies are not necessarily good compared with the grid efficiency based on modern gas turbines, which constitute the majority of new installed power capacity in many countries, though their use does avoid T&D losses, which can be large in the developing world.

Co-generation can have a very clear positive effect on the overall annual fuel cost. Given their high capital cost, most co-generation fuel cell systems will be designed and operated to maximize electrical production, and have the thermal loads follow demands. This means that the effectiveness of the co-generation will vary drastically over the year. Of course this varies dramatically with the climate, but typically, co-generation in the heating mode will be feasible for less than thirty percent of the year. Depending on the location, cooling loads could be either higher or lower. In most developing countries cooling is of more interest. The higher temperature fuel cells are capable of driving absorption chillers.

Co-generation could have a significant impact on the fuel cost and increase the overall system efficiency to around 85%. In the case of PEMFC systems there is an additional limitation, stemming from the fact that the waste heat is available at a rather low temperature, typically around 60°C – though the use of a reformer may mean that higher-grade waste heat is available. The low local environmental impact of fuel cells may mean that they can be used in close proximity to human occupants or other sensitive installations, making cogeneration possible.

Operating & Maintenance Costs

Fuel cell systems can have few moving parts and hence could have the potential for long life with little maintenance. However, the stack and of the catalytic systems in fuel processors are expected to require periodic replacement. Currently, insufficient data exist on the durability of these components, but most manufacturers expect stack life to exceed five years of operation. This figure represents a significant O&M cost, directly proportional to the stack capital cost. In addition, it is expected that in most locations, an annual check of the system would be required, which is a small cost for systems larger than 10kW, but could be considerable for systems below 10kW. An overview of the O&M cost estimates for the major fuel cell technologies is given in Table 7.

Table 7: Operating and Maintenance Cost Estimates

Fuel Cell Type	Operating Cost Elements			
	Equipment Replacement	Labor for Equipment Replacement	Routine Service	Total Cost
Proton Exchange Membrane (PEMFC), Residential	**1 - 2 ¢/kWh** • ~$200 /kW stack cost + additional components (catalysts, filters) • 40,000 hr life @ 80% capacity)	**0.17 ¢/kWh** • $200 /unit (half day one trained professional) • 40,000 hr life @ 80% capacity)	**0.48 ¢/kWh** • ~$100 /yr / unit (one trained professional two hours)	**1.7 - 2.7 ¢/kWh**
Proton Exchange Membrane (PEMFC), Commercial	**1 - 2 ¢/kWh** • ~$200 /kW stack cost + additional components (catalysts, filters) • 40,000 hr life @ 80% capacity)	**0.03 ¢/kWh** • $400 /unit (half day two trained professionals) • 40,000 hr life @ 80% capacity)	**0.03 ¢/kWh** • ~$100 /yr / unit (one trained professional two hours) • Same as residential, just a bit bigger unit	**1.1 - 2.1 ¢/kWh**
Molten Carbonate (MCFC), Commercial	**1.9 - 2.6 ¢/kWh** • $600 -$800 /kW stack cost + additional components (catalysts, filters) • 40,000 hr life @ 80% capacity)	**0.02 ¢/kWh** • $1500 /unit (half day two trained professionals + equipment lift) • 40,000 hr life @ 80% capacity) • Same as tubular SOFC, maybe optimistic	**0.03 ¢/kWh** • ~$500 /yr / unit (one trained professional four hours + consumables charge)	**2.0 - 2.7 ¢/kWh**
Tubular Solid Oxide (SOFC), Commercial	**1 - 1.5 ¢/kWh** • $300 - $450 /kW stack cost + additional components (catalysts, filters) • 40,000 hr life @ 80% capacity)	**0.04 ¢/kWh** • $1500 /unit (half day two trained professionals + equipment lift) • 40,000 hr life @ 80% capacity) • Same as MCFC, probably pessimistic due to solid electrolyte	**0.07 ¢/kWh** • ~$500 /yr / unit (one trained professional four hours + consumables charge) • Same as MCFC, probably pessimistic due to solid electrolyte	**1.1 - 1.6 ¢/kWh**
Planar Solid Oxide (SOFC), Residential	**1 - 1.5 ¢/kWh** • $300 - $450 /kW stack cost + additional components (catalysts, filters) • 40,000 hr life @ 80% capacity)	**0.17 ¢/kWh** • $200 /unit (half day one trained professional) • 40,000 hr life @ 80% capacity) • Same as PEMFC	**0.48 ¢/kWh** • ~$100 /yr / unit (one trained professional two hours) • Same as PEMFC	**1.7 - 2.1 ¢/kWh**
Planar Solid Oxide (SOFC), Commercial	**0.8 - 1.1 ¢/kWh** • $150 - $250 /kW stack cost + additional components (catalysts, filters) • 40,000 hr life @ 80% capacity)	**0.03 ¢/kWh** • $400 /unit (half day two trained professionals) • 40,000 hr life @ 80% capacity) • Same as PENFC	**0.03 ¢/kWh** • ~$100 /yr / unit (one trained professional two hours) • Same as PEMFC	**0.8 - 1.2 ¢/kWh**

Cost Reduction.

Given the current status of fuel cell technology, several forms of cost reduction will be necessary to achieve the allowable cost for broad DG applications. Modest to high-volume production will be necessary to move to a cost structure more in line with commercial products. This is expected to require the production of hundreds of megawatts of capacity per year industry-wide.

These impacts come from a range of factors listed in Table 9. It is clear that cost reduction is most strongly affected by reductions in factory cost. In addition however, in any region reduction of the installation and maintenance cost, derived from increased availability of trained and qualified local personnel and a streamlined permitting programme are key to achieving low cost. Additionally, significant improvements in the technology are required to achieve the long-term cost projections. For most technologies an increase in power density will be necessary without sacrificing life or performance of the stack.

Clearly, technology improvements can occur prior to market introduction, and they should where possible. However, fuel cell R&D is a very expensive activity, and further R&D is traded by developers against accelerated market introduction.

Impact of Automotive Technology.

Considerable investments are being made in PEMFC as a propulsion power source for automobiles. For transportation applications, cost targets are much more aggressive than for stationary applications (around $50/kW), and driving towards this is of direct benefit to the DG markets. First of all, most transportation fuel cell R&D is aimed at aggressive cost and size reduction. This has led to significant increases in power density, reductions in catalyst loading, and improvements in operability of PEMFC technology over the past five years. Also, manufacturing technology for the stack components has been improved, and proven. Similar advances have been made in fuel processing and system integration.

Second, transportation markets could eventually help significantly reduce component costs for stationary PEMFC systems, once transportation PEMFC technology becomes commercial. At the much higher volume related to projected automotive markets, an additional volume-related economy of scale would occur, at least in stack components and possibly in balance of plant components for some capacities.

Transportation markets are unlikely to considerably affect other fuel cell technologies, with the exception of planar SOFC technology, which is being considered for auxiliary power applications by some manufacturers.

It is important to note that the cost analysis within this report is generally conservative in its predictions, a point that was raised at the workshop in Paris. Potential cost reductions driven by engineering analysis tend to err on the side of caution, and in the long term learning curve methodologies have been shown to be robust in treating the opportunities created by mass-manufacture and of experience – as used in the FCB analysis earlier. It is likely that fuel cells will exhibit ‘learning coefficients’ within the common range for modular technologies – 16-19% – and that costs will drop more rapidly than is put forward here.

Table 8 Forecasted Timing, Efficiency and Factory Cost

Technology	Market Model Inputs						
	Representative System Size	Initial Commercial Introduction[0]	Initial Factory Cost (US$/kWe)[1]	Initial Operating & Maintenance Cost (¢/kWh)[2]	Substantial Commercial Availability[0]	Large Volume Factory Cost (US$/kWe)[3]	Operating & Maintenance Cost (¢/kWh)[4]
Proton Exchange Membrane (PEMFC)	3 kWe	2003 - 2004	2500 - 5000	5 - 11	2004 - 2006	700 - 1150[5]	1.7 - 2.7
	50 kWe	2003 - 2004	2500 - 5000	5 - 11	2004 - 2006	650 - 1150	1.1 - 2.1
Molten Carbonate (MCFC)	100 kWe - 3 MWe[6]	2003 - 2005	2500 - 4000	5 - 9	2005 - 2007	1100 - 1900	2.0 - 2.7
Tubular Solid Oxide (SOFC)	200 kWe - 3 MWe[6]	2002 - 2003	1500 - 2500	2 - 4	2004 - 2005	800 - 1350	1.1 - 1.6
Planar Solid Oxide (SOFC)	3 kWe[7]	2002 - 2004	2500 - 5000	3 - 7	2004 - 2006	1000 - 1350	1.7 - 2.1
	50 kWe	2004 - 2006	2500 - 5000	3 - 7	2006 - 2008	600–900	0.8 - 1.2
Phosphoric Acid (PAFC)	250 kWe	current	3500 - 4000	2 - 3	?	2000 - 4000	2.0 - 2.7

Source - ADL estimates.
Notes: See next page

Table 9: Major Cost Reduction Factors

Cost Reduction Factor	Applicability	Relative Impact
Market-Related Cost Reduction Factors		
Increased production volume/outsourcing components	All technologies	Significant, would likely reduce cost of current PEMFC, SOFC, and MCFC technology to $1000-$2000/kW
Availability of trained and qualified maintenance personnel	All technologies	Early on, limited availability of such personnel significantly increases installation and O&M costs.
Permitting cost	All technologies	The first units in any permitting jurisdiction may bear additional costs associated with first-of-a-kind permits. Later units avoid this cost at savings ranging from several hundreds to thousands of dollars per unit
Technology-Related Cost Reduction Factors		
Stack Power density	All technologies	Significant, could reduce costs by several $100/kW
Design for easy installation	All technologies	Moderate, will reduce installation costs
Low-cost components	All technologies	Significant, could have impact of ~ $100/kW
High temperature membranes	PEMFC	Significant, could have impact of hundreds of dollars per kW
Stable thin-electrolyte technology with internal reforming	SOFC	Significant, is expected to have impact of several hundred dollars per kW
Low-cost, efficient power electronics	All technologies	Moderate. Impact expected to be in the fifty to one hundred dollars per kW
Improved System Integration	All technologies	Significant. Reduction in system complexity is desirable and necessary for all systems. This will strongly affect both capital and O&M costs

6.10 Total Resources Required to Accelerate Cost Reduction Phase

To understand the impact of additional investment in fuel cells on the rate of cost reduction, one must refer back to two factors mentioned earlier: high-volume production and technology development. To put the discussion in perspective, it is useful to consider current spending levels in the fuel cell industry, which amount collectively to several billion dollars per year on the development of fuel cells. This is a very considerable level of funding for an emerging energy technology, and incremental funding from the multi-lateral lending agencies must therefore be considered in the context of what could be done to further accelerate cost reduction for developing country applications.

From a wide range of experience with other technologies, we know that technology development can be accelerated by additional spending only up to a point. Given the amount of funding currently directed to this effort, it appears unlikely that incremental additional funding would considerably accelerate cost reduction. However, a relatively small fraction of current funding is aimed at basic technologies that would fundamentally improve and simplify the system, such as high temperature membranes for PEM. Incremental funding in such areas would be much more likely to accelerate overall cost reduction of the systems, but it is doubtful whether multi-lateral lending agencies could assist here, as funds would almost certainly have to be directed specifically at this purpose and at specific developers.

With respect to the cost reduction associated with the high-volume production factors, the effect of incremental funding can be much greater. If resources are appropriately timed and directed at reducing the exposure of the early movers in the field, it could appreciably aid cost reductions, especially in the locations where the funding is aimed. A support instrument of US$100 million could support around 30MW of early systems if it bore the complete cost of installation, and about 50MW if it bore just the difference between actual and economically acceptable cost. This is equivalent to the necessary investment in the fuel cell system plant necessary for the production of 10,000 units per year, or about 500MW/yr. This could be a considerable impact, but given current spending on fuel cells it would not necessarily be an overwhelming effect, and it would need to be spread over several firms and technologies. The acceleration of cost reduction achieved through supporting such early commercial sales can work in multiple ways:

- It can increase the confidence of investors that fuel cell companies can in fact commercialise their technology and thus provide leverage for additional investments.
- It can simply “buy down” the cost of fuel cells, absorbing the differential between the actual cost and the economic cost in the developing country markets
- It will, if properly guided, establish a local base of trained and qualified maintenance and installation personnel, which will significantly reduce the cost of installation and the O&M cost. In many of the GEF-eligible countries, labour rates would be lower than in the OECD countries and, with proper training, it could reduce the cost of installation in GEF-eligible countries to below that for OECD countries.
- It will establish permitting rules and procedures appropriate for fuel cell in the local markets.

While the last two benefits can be achieved almost independent of timing, the cost reduction potential is more limited. The greatest potential benefit would come from the first item mentioned. However, correct timing is critical, as benefit will only accrue to the first truly commercial units produced, probably worldwide. This requires keen planning and careful monitoring. If the funding comes too early, or while the eventual feasibility of cost reduction is unclear, the programme will not lead to real cost reduction, and the technology commercialisation stalls. If it is implemented too late, it will be applied to already partially cost-reduced units, but without significant impact.

A complex set of iterative discussions and analyses are ongoing with respect to the timing of the multi-lateral lending agencies’ market intervention. The three largest governing factors against an accelerated schedule of 2003-2004 are:

1) the time required for multi-lateral lending agencies to make a market intervention initiative operational
2) the multi-lateral lending agencies' budget trade-off of (a) subsidizing fewer MWs on an accelerated schedule but at a greater price per MW installed versus (b) larger volumes in 2005-2008 at a lower $/MW subsidy to stimulate production volume, and
3) the private sectors' current marketing orientation towards OECD premium power and residential markets rather than GEF-eligible markets.

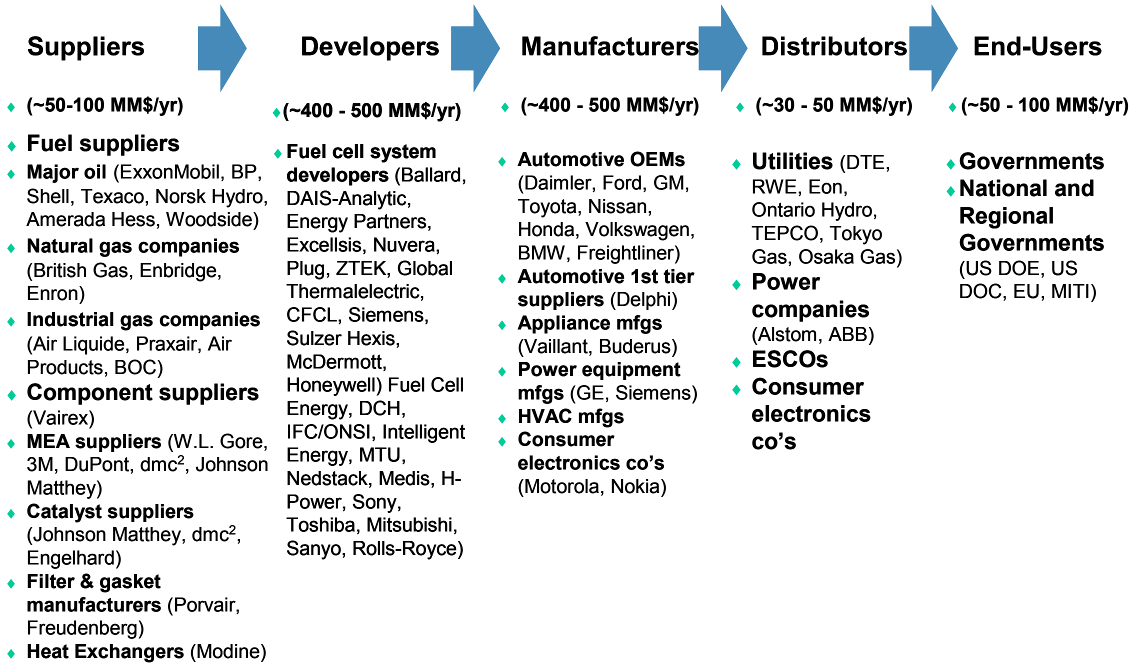
The two strongest arguments against a conservative schedule are:

1) regulators and policy-makers, utility, commercial, industrial and residential markets in developing countries need to re-orient their energy planning, policy and infrastructure activities to anticipate the commercialisation of fuel cells in the mid-term rather than in the long term, and
2) technology vendors need to re-orient their product development for operations in the developing country market.

Since the scheduling of the multi-lateral lending agencies' market intervention strategy has not yet been established, continued work is required in this area.

Table 10 gives a conservative estimation of the resources currently being expended on fuel cell technology development across a range of sectors. It is indicative of the high level of investment required to accelerate cost reduction in the sector, of careful targeting of resources is not carried out.

Table 10: Estimated current spend by developers and others



Suppliers	Developers	Manufacturers	Distributors	End-Users
♦ (~50-100 MM$/yr)	♦ (~400 - 500 MM$/yr)	♦ (~400 - 500 MM$/yr)	♦ (~30 - 50 MM$/yr)	♦ (~50 - 100 MM$/yr)
♦ **Fuel suppliers** ♦ **Major oil** (ExxonMobil, BP, Shell, Texaco, Norsk Hydro, Amerada Hess, Woodside) ♦ **Natural gas companies** (British Gas, Enbridge, Enron) ♦ **Industrial gas companies** (Air Liquide, Praxair, Air Products, BOC) ♦ **Component suppliers** (Vairex) ♦ **MEA suppliers** (W.L. Gore, 3M, DuPont, dmc^2, Johnson Matthey) ♦ **Catalyst suppliers** (Johnson Matthey, dmc^2, Engelhard) ♦ **Filter & gasket manufacturers** (Porvair, Freudenberg) ♦ **Heat Exchangers** (Modine)	♦ **Fuel cell system developers** (Ballard, DAIS-Analytic, Energy Partners, Excellsis, Nuvera, Plug, ZTEK, Global Thermalelectric, CFCL, Siemens, Sulzer Hexis, McDermott, Honeywell) Fuel Cell Energy, DCH, IFC/ONSI, Intelligent Energy, MTU, Nedstack, Medis, H-Power, Sony, Toshiba, Mitsubishi, Sanyo, Rolls-Royce)	♦ **Automotive OEMs** (Daimler, Ford, GM, Toyota, Nissan, Honda, Volkswagen, BMW, Freightliner) ♦ **Automotive 1st tier suppliers** (Delphi) ♦ **Appliance mfgs** (Vaillant, Buderus) ♦ **Power equipment mfgs** (GE, Siemens) ♦ **HVAC mfgs** ♦ **Consumer electronics co's** (Motorola, Nokia)	♦ **Utilities** (DTE, RWE, Eon, Ontario Hydro, TEPCO, Tokyo Gas, Osaka Gas) ♦ **Power companies** (Alstom, ABB) ♦ **ESCOs** ♦ **Consumer electronics co's**	♦ **Governments** ♦ **National and Regional Governments** (US DOE, US DOC, EU, MITI)

Understanding some of the costs, policy drivers and country-specific opportunities available to FCDG makes it possible to develop an tentative forecast of market penetration, and to elaborate from that what GHG emissions reductions might stem from an introduction of fuel cells into decentralised generation in developing countries.

6.11 Global FCDG market assessment

Based on the potential for DG in general and on other criteria, the potential for FCDG has been assessed for the period to 2020. An estimation of corresponding GHG emissions reductions and benefits is derived from a scenario analysis.

The analysis has been carried out on a regional basis based on the geographic breakdown used by the International Energy Agency in its World Energy Model presented in the World Energy Outlook (IEA, 2000). The results have then been aggregated to provide global estimates. The analysis covers the period 1997 to 2020.

6.11.1 Method

A spreadsheet model has been developed for providing an assessment of the FCDG market. The model is divided into three main modules, FCDG potential being calculated from a forecast of DG potential which is derived from the overall growth in electricity generating capacity. The model provides forecasts of energy generating *capacity* rather than *energy generated*, since capacity is the key determinant of fuel cell sales.

6.11.2 Electricity demand

Global installed electric capacity is estimated to increase to 5515GW in 2020. This is estimated to result in about 3055GW of new installed capacity, inclusive of replacement capacity, by 2020. A regional/country breakdown for growth in installed capacity over the period 1997 to 2020 in shown in Figure 14.

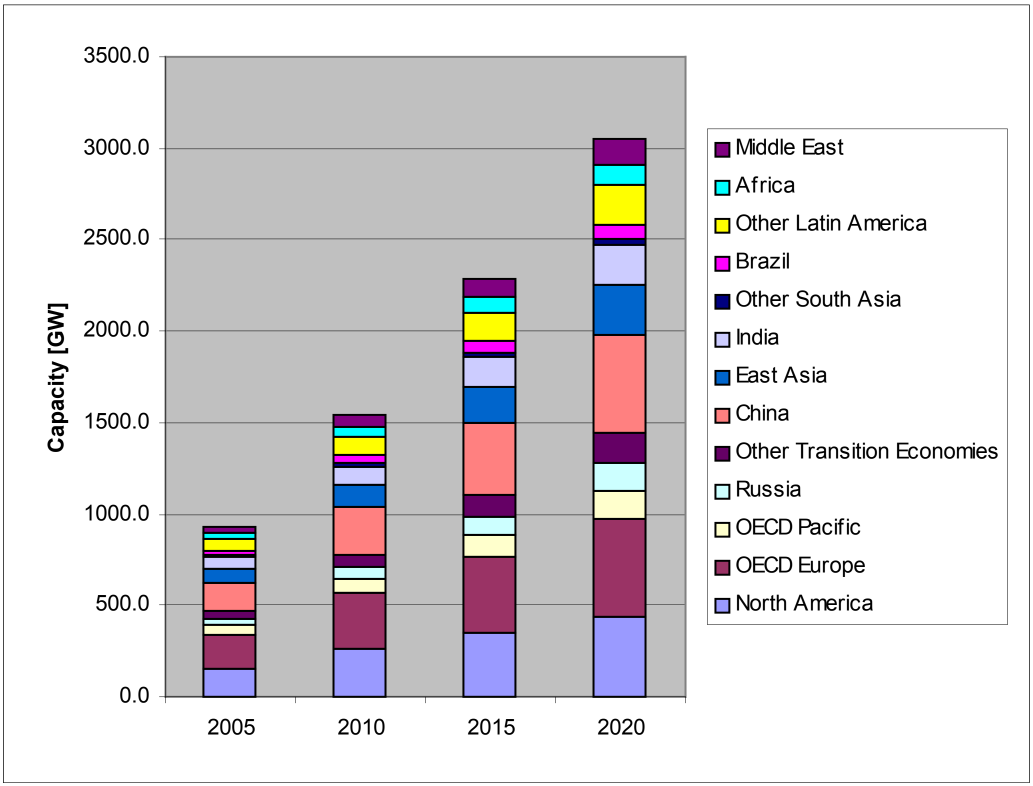


Figure 14: Global growth in installed electrical capacity to 2020

6.11.3 Decentralised generation scenario

Cumulative decentralised generation capacity below 10MW is estimated to rise to about 185GW in 2020. A regional/country breakdown for growth in installed decentralised capacity by region/country over the period 1997 to 2020 in shown in Figure 15. A split of decentralised generation capacity by market segments and capacity ranges considered is provided in Figure 16 and Figure 17.

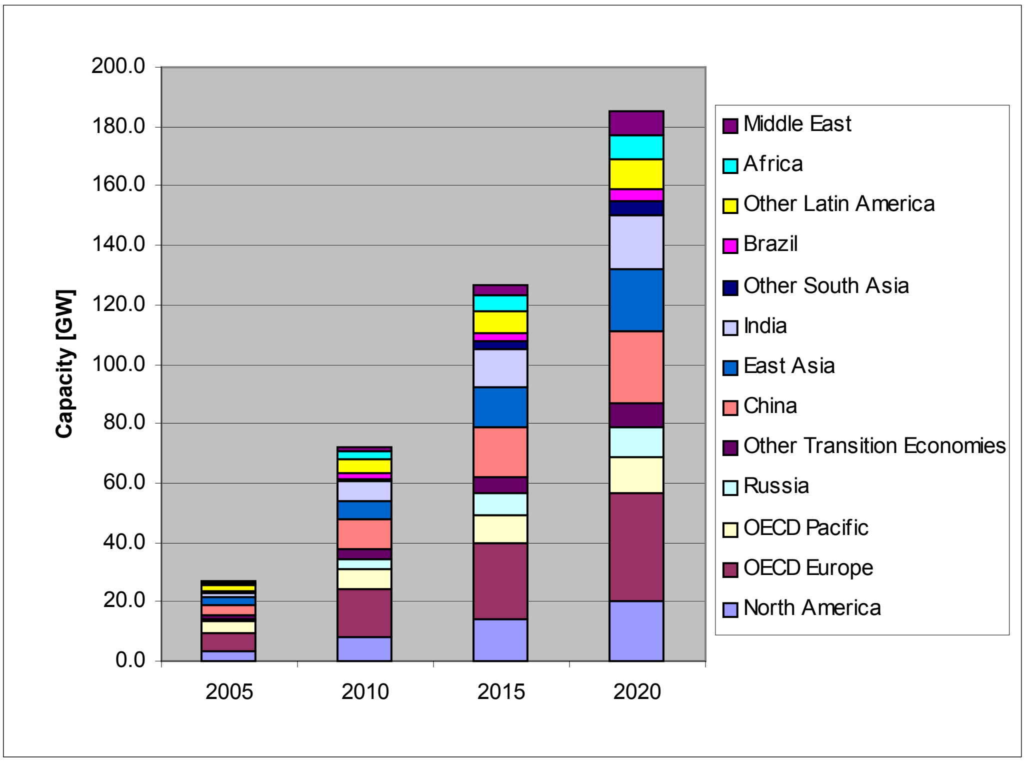


Figure 15: Estimated growth in DG capacity to 2020 by region

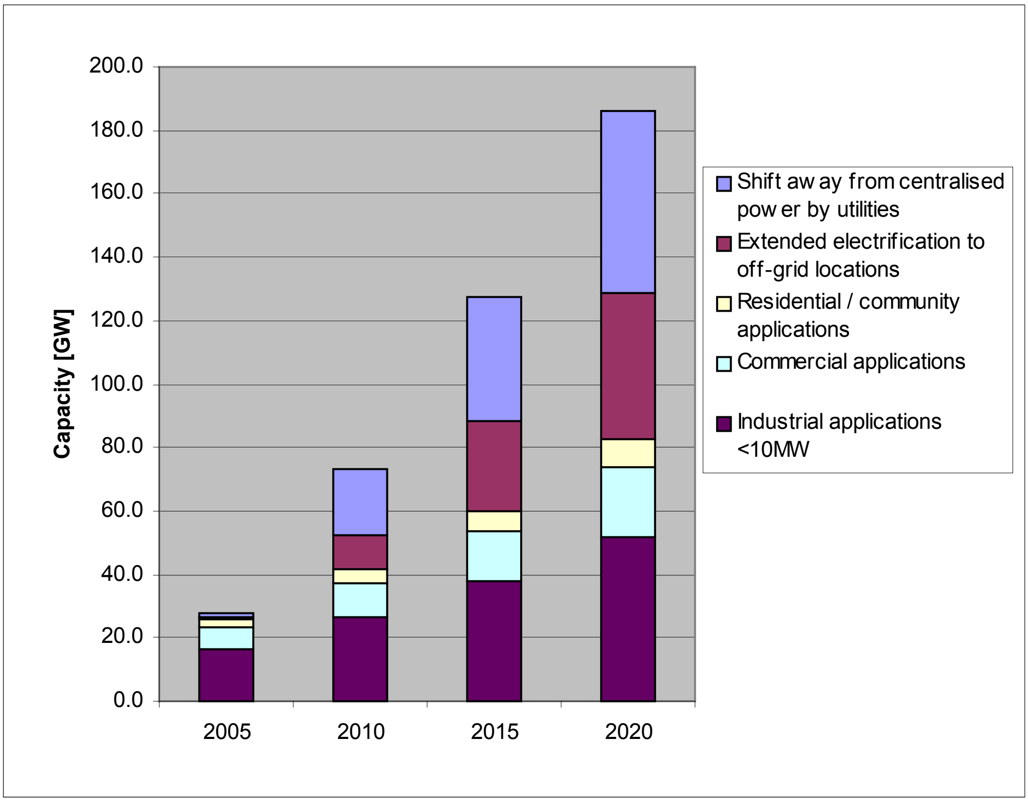


Figure 16: Estimated growth in DG capacity to 2020 by sector

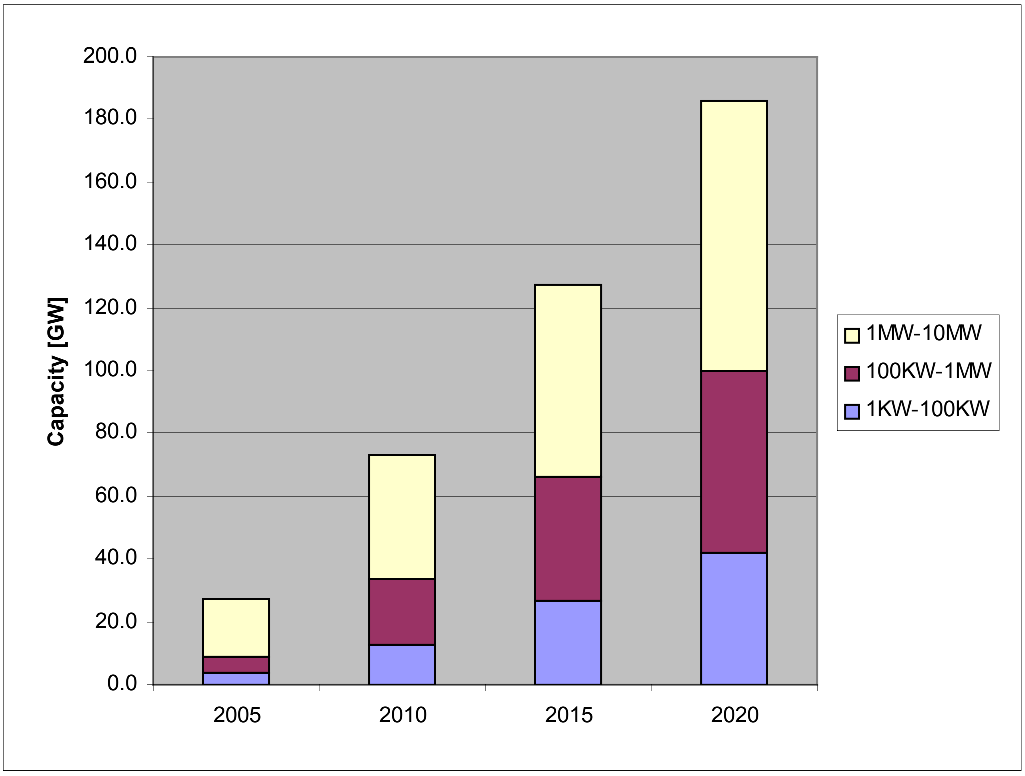


Figure 17: Estimated growth in DG capacity to 2020 by capacity range

6.11.4 Fuel cell decentralised generation scenario

Cumulative fuel cell decentralised generation capacity is estimated to rise to about 95GW in 2020. A split of FCDG capacity by region/country and capacity ranges considered is provided in Figure 18 and Figure 19.

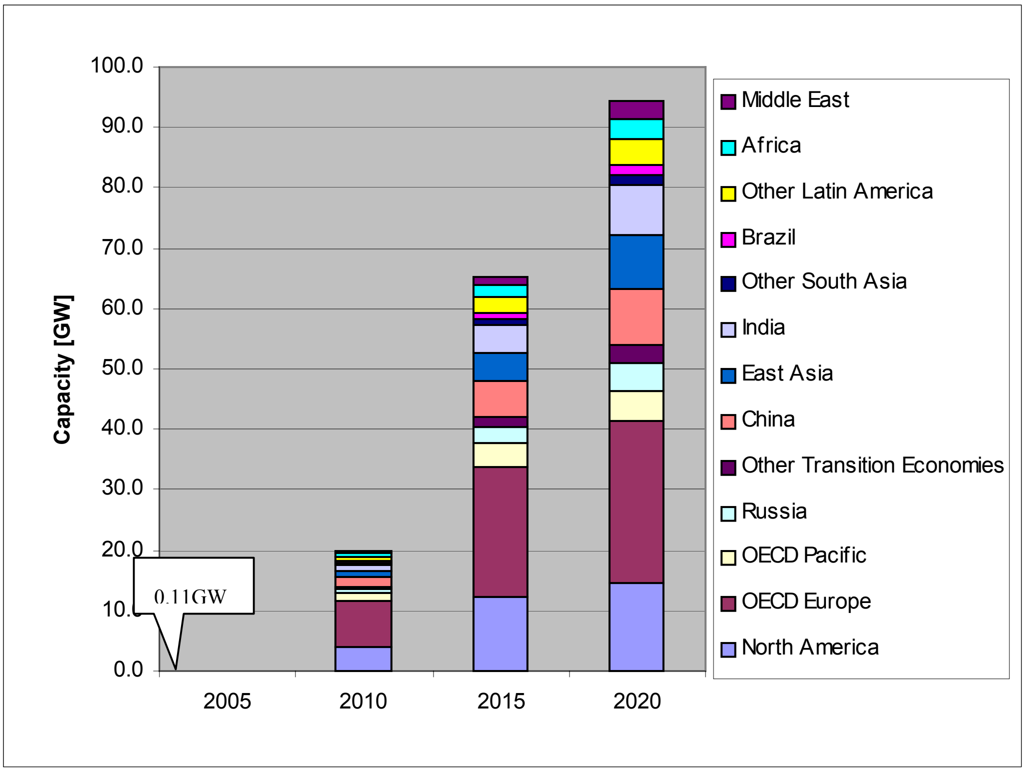


Figure 18: Estimated growth in FCDG capacity to 2020 by region

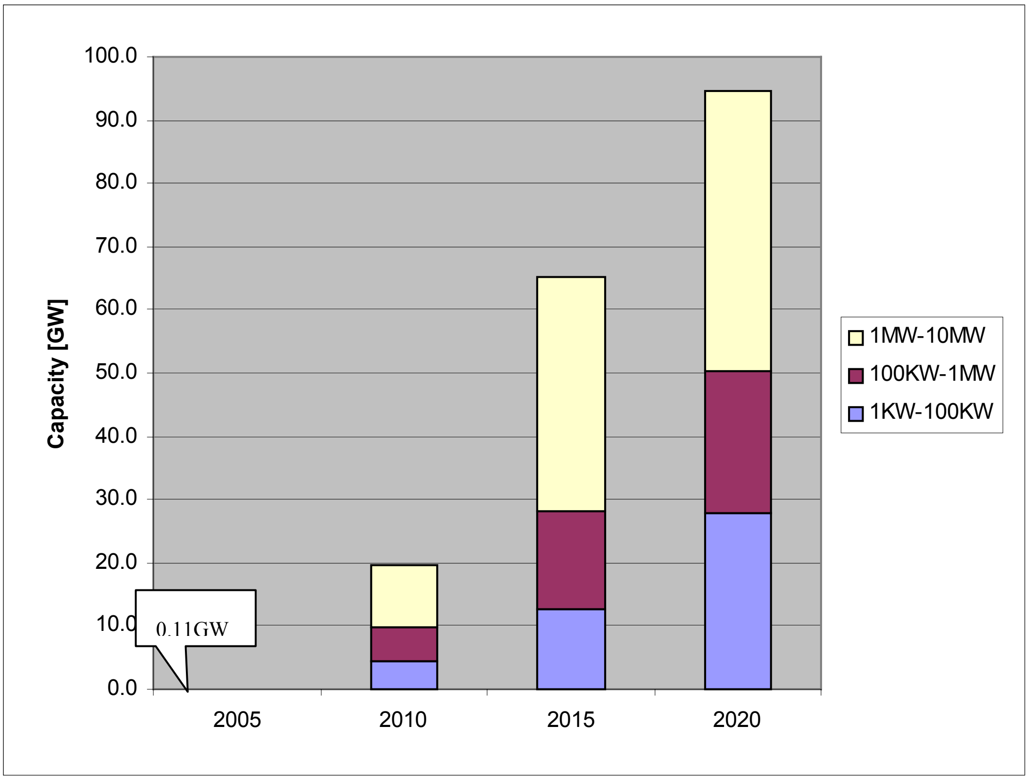


Figure 19: Estimated growth in DG capacity to 2020 by capacity range

It is also interesting to note that the FCDG market penetration, calculated on the basis of the expert inputs on FCDG systems costs and demand curve over the period to 2020, implies an average learning factor for the different capacity ranges of 89%, i.e. every doubling in production of FCDG systems, in terms of power capacity, results in a cost reduction of 11%. This is a conservative figure for most modular technologies, and it may be that greater cost reductions and even greater penetrations can be achieved.

6.12 Emissions

Emissions calculations suggest that fuel cells (FCs) offer significant environmental benefits over competing technologies and hence the environment is a strong driving force behind the development of FC systems for transport and stationary applications. This paper provides a comprehensive comparison of FC and competing systems, and points out strengths and weaknesses of the different FC systems, suggesting areas for improvement. The results presented in this paper build on earlier work and provide a detailed analysis of a wider range of systems. The analysis takes the form of a model, which compares system emissions (global, regional and local pollutants) and energy consumption on a full fuel cycle basis. It considers a variety of primary energy sources, intermediate fuel supply steps and FC systems for transport and stationary end-uses. These are compared with alternative systems for transport and stationary applications. Energy and pollutant emissions reductions of FC systems compared to alternative vehicle technology vary considerably, though all FC technologies show reductions in energy use and CO_2 emissions of at least 20%; and reductions of several orders of magnitude in regulated pollutants compared to the base case vehicle. The energy, CO_2 and regulated emissions advantages of FC systems for distributed and baseload electricity are more consistent than for transport applications, with reductions in regulated pollutants generally larger than one order of magnitude compared to competing technologies. For Combined Heat & Power (CHP) applications, the advantages of FC systems with regard to regulated pollutants remain large. However, energy and CO_2 emissions advantages are reduced, depending largely on the assumptions made for the heat/power ratio and system comparison.

6.12.1 Greenhouse gas benefits in developing countries

Greenhouse gas benefits associated with the deployment of fuel cell technologies in developing countries will depend on a variety of factors, particularly the fuel input. As an indication of the possible benefits, generic fuel chains have been calculated and compared, both for greenhouse gas emissions and for regulated pollutants. The results are shown in Table 11 Fuel Chain Calculations and Comparisons.

Application	Options	Fuel	GHG emissions [g/kWh]		Other emissions [g/kWh]				
			CO2	*CH4*	*NOx*	*SOx*	*PM*	*CO*	*NMHC*
Remote power		<50kW							
	Engine	Diesel	906.8	0.26	12.6	2.0	0.15	0.65	2.1
	PEMFC	Diesel	971.5	0.16	0.39	0.48	0.007	0.068	0.84
	PEMFC	Propane	723.0						
	SOFC	Diesel	680.1	0.11	0.27	0.34	0.005	0.048	0.59
	SOFC	Propane	482.0						
	PEMFC	MeOH fossil - NG	675.3	0.06	0.24	0.16	0.007	0.077	0.15
	SOFC	MeOH fossil - NG	487.7	0.04	0.18	0.11	0.005	0.056	0.11
	PEMFC	Wind-hydrogen	0.0	0.00	0.00	0.00	0.000	0.000	0.00
Grid-connected power		<250kW							
	Engine	Diesel	704.6	0.18	9.8	1.5	0.11	0.49	1.7
		Gas	515.9	0.35	2.9	0.014	0.002	2.4	0.22
	Turbine	Gas	714.3	1.01	0.70	0.020	0.003	0.72	0.31
	PAFC	Gas	464.3	0.28	0.051	0.011	0.006	0.019	0.11
	PEMFC	Gas	488.8	0.37	0.068	0.014	0.008	0.033	0.14
	SOFC	Gas	337.7	0.23	0.033	0.007	0	0.007	0.080
	SOFC/GT	Gas	273.1	0.19	0.026	0.006	0	0.005	0.065
	PEMFC	Coal gas	1072.0	N/a					
	SOFC	Coal gas	927.0	N/a					
Commercial		<250kW							
	Engine	Diesel	704.6	0.18	9.8	1.5	0.11	0.49	1.7
		Gas	515.9	0.35	2.9	0.014	0.002	2.4	0.22
	Turbine	Gas	714.3	1.01	0.70	0.020	0.003	0.72	0.31
	PAFC	Gas	464.3	0.28	0.051	0.011	0.006	0.019	0.11
	SOFC	Gas	337.7	0.23	0.033	0.007	0	0.007	0.080
	SOFC	Diesel	680.1	0.11	0.27	0.34	0.005	0.048	0.59
Industrial		<1MW							
	Engine	Gas	515.9	0.35	2.9	0.014	0.002	2.4	0.22
	Turbine	Gas	619.1	0.88	0.60	0.017	0.003	0.63	0.27
	SOFC	Gas	337.7	0.23	0.033	0.007	0	0.007	0.080
	SOFC/GT	Gas	273.1	0.19	0.026	0.006	0	0.005	0.065

Table 11 : Fuel Chain Calculations and Comparisons

As can be seen, the emissions for fuel cell systems are generally lower than for conventional technologies, and often much lower.

To highlight the anticipated effect on global warming potential (GWP) of the systems discussed above, separate calculations have been performed to show the CO_2-equivalent emissions for CO_2 and methane emissions. The GWP was calculated as:

$$GWP(g/kWh) = CO_2 + (21xCH_4)$$

using the IPCC standard correction factor of 21 for the effect of methane release into the atmosphere. Other gases were neglected and have much less contribution in the case of this technology. The charts below indicate the GWP corresponding to the results above.

As can be seen, in the majority of cases there is a clear and significant GHG emissions benefit derived from the implementation of fuel cell technology solutions, though this is not universally the case. In general, if the fuel provided to the fuel cell comes from a heavy hydrocarbon source without carbon sequestration, then the emissions are likely to rise in comparison with conventional technology solutions. In other cases, the emissions are likely to fall.

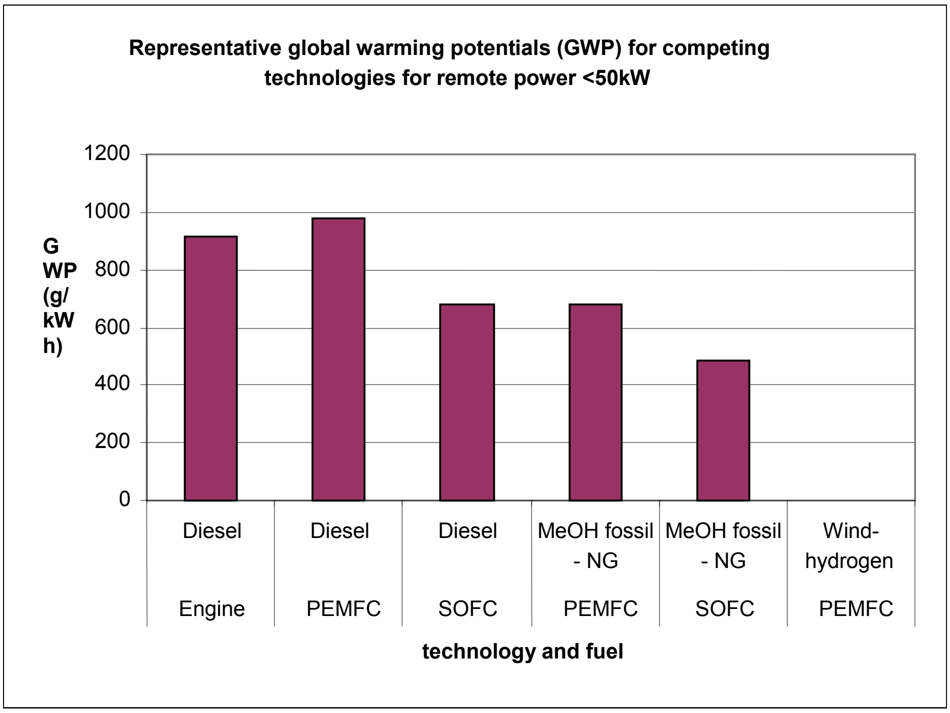


Figure 20 Representative GWP for Remote Power <50 kW

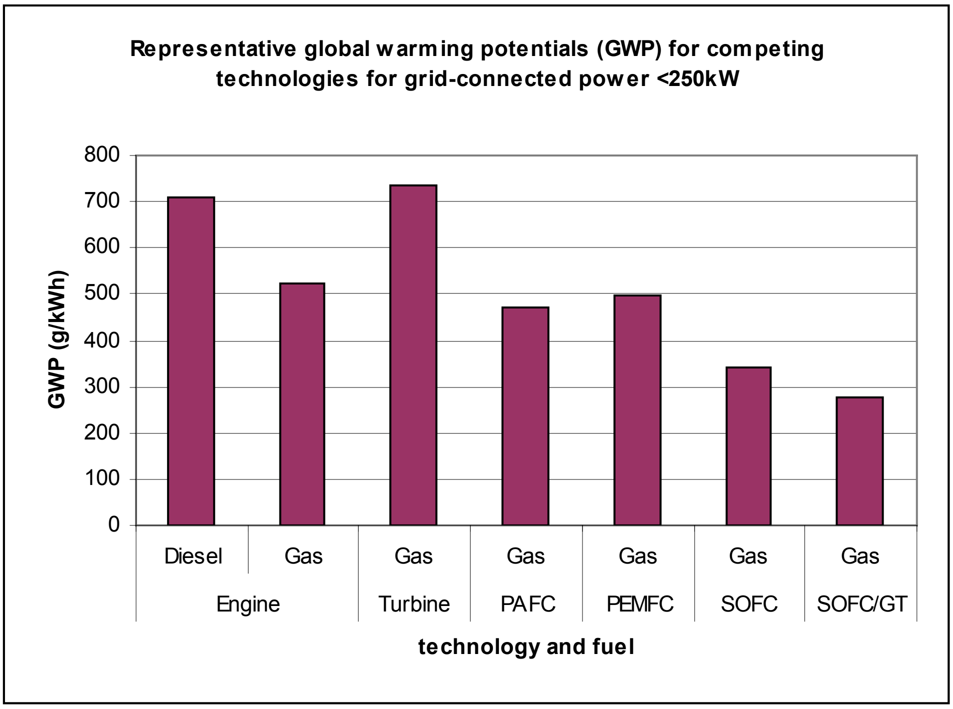


Figure 21: Representative GWP for Grid Connected Power <250 kW

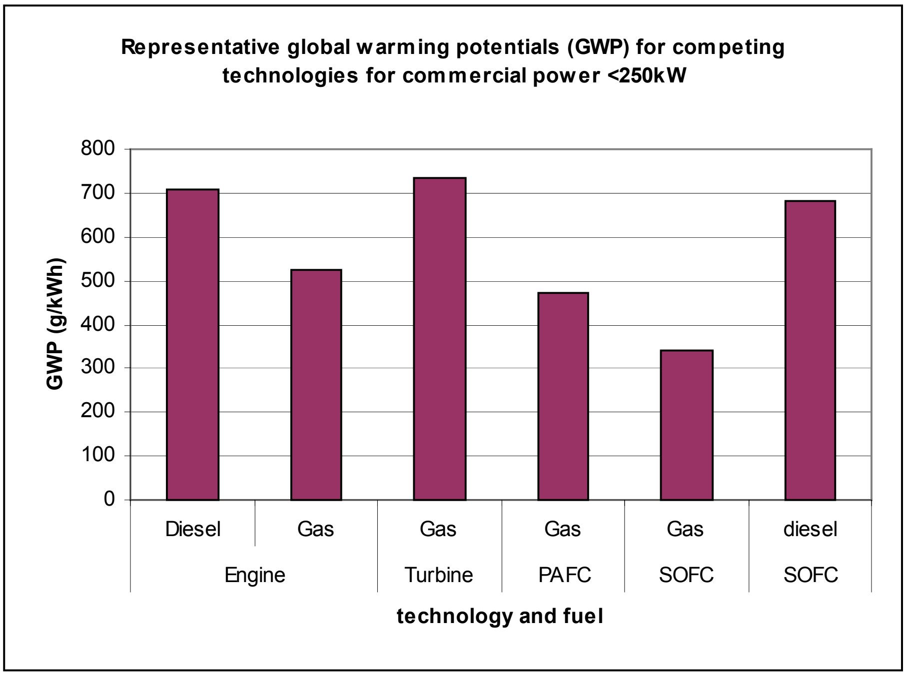
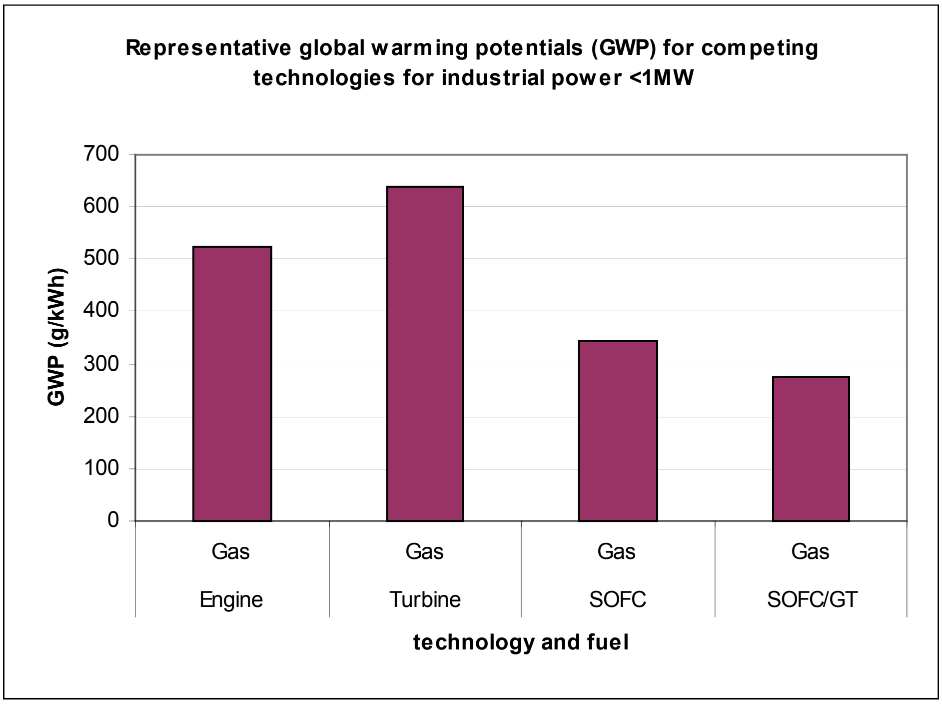


Figure 22: Representative GWP for Commercial Power <250 kW

Figure 23: Representative GWP for Industrial Power <1 MW



6.13 Potential impacts on global CO_2 emissions

The outcomes of the FCDG market assessment provide a basis for estimating the environmental benefits that may derive from fuel cell introduction into stationary applications, compared to the generating mix projected in the IEA World Energy Model Reference Case. The benefit of operating fuel cells in combined heat and power (CHP) applications is accounted for in the analysis. To perform the environmental analysis assumptions have been made regarding both the electrical efficiency and heat to power ratio of fuel cell systems (Table 12). It has been assumed that 50% of the installed capacity is operating in combined heat and power mode. Also, assumptions have been made with respect to the fuels used in fuel cell operation. Indicative CO_2 emissions calculations have been performed assuming a split of fuel cell fuels of 80% natural gas and 20% carbon 'neutral' fuels (renewable energy in the form of biomass fuels or hydrogen produced from either electrolysis using renewable power and/or fossil fuels with carbon sequestration). Figure 24 and Figure 25 show the resulting global absolute reductions in CO_2 emissions, and the reductions relative to projected emissions (IEA World Energy Model Reference Case) associated with FCDG introduction using the fuels above. Figure 26 estimates the potential monetary benefits of avoided CO_2 emissions from the introduction of FCDG to the year 2020. Calculations are based on a CO_2 damage cost estimate of \$37/tCO_2.

Table 12: Assumptions on efficiency and heat to power ratios

	El. Efficiency	H:P ratio
1-100kW	40%	1
100kW-1MW	50%	0.6
1-10MW	60%	0.3

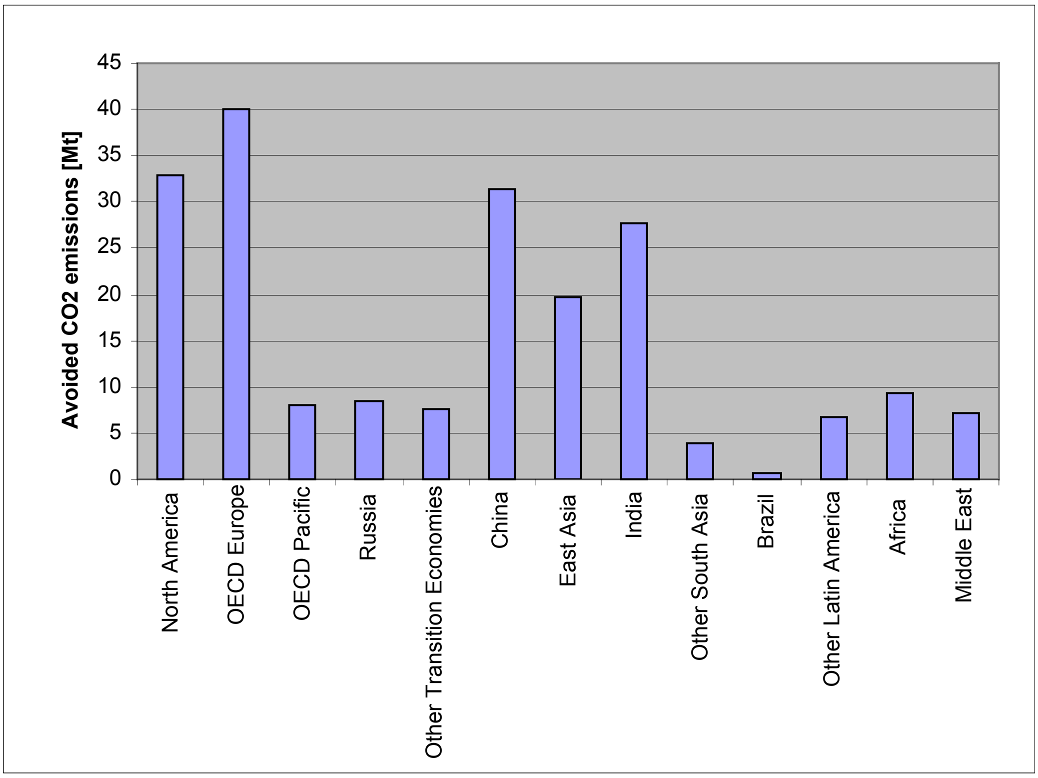


Figure 24: Potential avoided CO_2 emissions to 2020 from introduction of FCDG

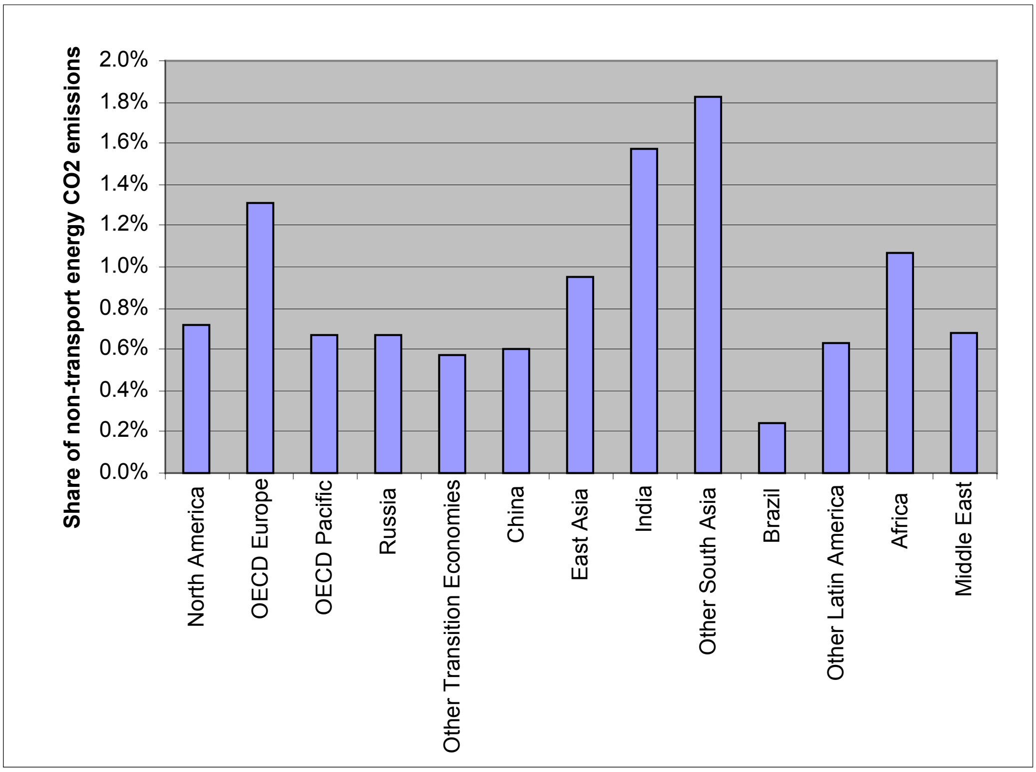


Figure 25: Estimated avoided CO_2 emissions to 2020 from introduction of FCDG (as a share of Reference Case emissions)

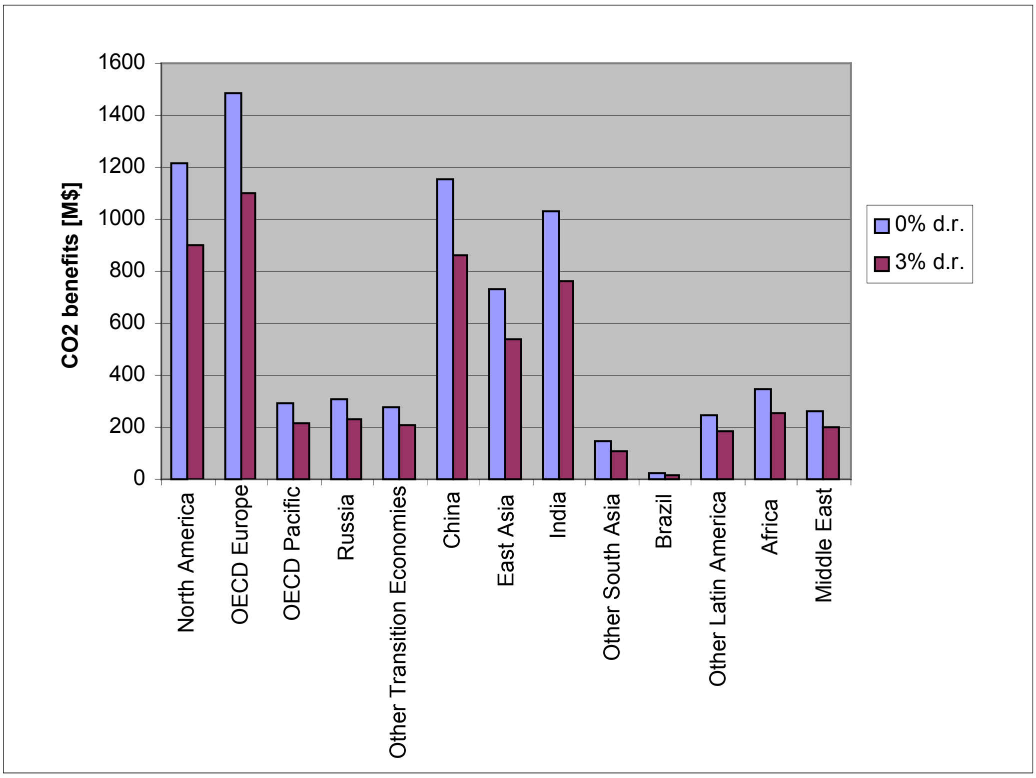


Figure 26: Estimated monetary benefits of avoided CO_2 emissions using damage cost estimates of \$37/tCO_2

6.14 Conclusion

The global fuel cell decentralised generation market assessment presented takes into account a variety of projections and information relating to future generating capacity and potential growth in decentralised generation. Fuel cell system cost projections and associated demand curves have been used to estimate the fuel cell decentralised generation market to 2020. Total installed FCDG capacity could grow from about 110MW in the year 2005 to about 95GW by 2020, representing 50% of DG and 3% of total installed capacity. The introduction of fuel cell systems could lead to significant avoided CO_2 emissions with potentially large social benefits, in addition to low levels of regulated emissions and noise, and a move towards the use of low-carbon fuels.

6.15 Economic Analysis of Avoided and Incremental Costs

An economic analysis has been conducted to show the cost of generation at the sub transmission level for six representative fuel cell systems, compared with the avoided cost of generation and transmission in that system. The purpose was not to predict winning or losing fuel cell technologies, but rather to portray an approximate current level of relative competitiveness subject to future technical innovation and cost reduction accomplishments. It must be remembered that real fuel cell system costs are not yet known with any degree of certainty, and the analysis can only be indicative at this stage. Two analyses have therefore been conducted. The first contains the expected cost and performance parameters for the FC technology prior to mass production. The second section assumes that volumes are sufficient to achieve mass production economies and reduced unit costs.

6.15.1 Economic Analysis for 'Initial Commercial Units, 2002-2005, (Upper Bandwidth)

At any expected level of near term capital and fixed O&M costs, the FC system remains far too expensive for deployment, even with generous grants from the GEF and others. Therefore, an alternative approach will be used.

- The multi-lateral institutions are assumed to provide a subsidy of $1,000 per kWe for the equipment only.
- Participating manufacturers are required to cost share the capital cost up to the point at which the economic internal rate of return approaches the threshold of 10%, under base case installation and operating conditions.
- Project developers will be liable for the full cost of installation and project development.
- Fixed O&M charges will be based on manufacturers subsidies for replacement equipment.

Various measures of merit for the alternative FC systems have thus been calculated. These include:

- FC cycle generation cost,
- Rates of return,
- Fuel mix of the receiving system.

The simulation model used integrates the following elements of power plant economics:

- Avoided cost of generation,
- Generation expansion planning;
- Economic dispatch (marginal energy cost);
- Transmission and distribution tariffs;
- Power purchase agreement structures;
- Investment analysis, including alternative financing structures.

The model is used to determine how FC distributed generation (DG) facilities can be used in existing power systems to the greatest benefit, calculating a levelised cost of electricity from the plant and comparing it with conventional generation alternatives.

This simulation does not provide estimates of the benefits of enhanced reliability, though such a factor should be among the reasons to adopt FC technology. The economic analysis provides a quantitative basis for comparing various FC and central generating systems, but does not address the potentially large benefits to be gained from replacing other DG technologies such as diesel or gas gensets. However, a number of hard-to-quantify, yet critical considerations come to play in a complete economic analysis. These other factors may include one or more of the following:

- Reliability enhancement;
- Transactional costs of investment;
- Security of cash flows;
- Ability of local banks to finance such transactions.

Key Economic Results

Table 13below shows the key results from the calculation:

Table 13 Economic Rates of Return and Present Value of 100 kW Systems: Philippines Case

Rates of Return and Present Values for Three 100kWe FC Systems: Philippines						
	Economic Internal Rate of Return (EIRR, %)			Present Value of Net Benefits (US$)		
	PEM	MC	SO	PEM	MC	SO
Base	14.93	12.87	16.12	22,502	25,312	56,094
Pessimistic	-9.43	5.86	8.52	(77,628)	(24,494)	(9,207)
Optimistic	26.40	15.98	19.04	58,845	54,800	85,583

Note: simulations of the PEM technology were performed using the avoided cost and performance data in the South Korean electric power system. In that fully electrified nation, FC technology exhibited large economic losses, in excess of $200,000 in present value terms for a 100kWe PEM system in the Base case.

Ultimately, a GEF decision to go forward with trials of the FC technology will hinge on the expected future benefits in terms of reduced carbon emissions. As the following section on the economics of mature FC technology shows, there is also potential to compete effectively with central power stations in the context of distributed generation. There is not yet an economic case that might be made for the FC technology in the early commercial stage, given the magnitude of the required subsidies.

Table 14 Valuing Environmental Benefits from Fuel Cells

Valuing Environmental Benefits From Fuel Cells

One of the claims made for FC technology is the absence of emissions of hydrocarbons, CO, NOx, SOx and other compounds. The high efficiency of some of the processes, especially MC and SO, would seem to compare favourably with other distributed generation options, or with central station generators.

The magnitude of the environmental benefit depends largely on what is foregone in order to build the FC system.

Fuel Cells will show net environmental benefits if they

1. Replace coal, gasoline or heavy diesel power plants;
2. The fuel cycle has a lower overall energy loss than the central station fuel cycle
3. The conversion efficiency of the FC is greater than the conversion efficiency of a competing distributed generation technology

The value, if any, of the net environmental benefits of the FC option can be established only with respect to specific power system options and situations. In the case of the Philippines, whether the FC environmental benefits for reason #1 outweigh the FC environmental costs for reason #2 may depend largely on whether the FC plant is located in Luzon (gas-fired) or Cebu (coal-fired).

Financial Analysis of FC Unit Cases

To make investment in a fuel cell system not only economic, but also financially attractive, further analysis must be conducted. This section contains a short summary of the financial rates of return that correspond to the cases discussed for the economic analysis. The operating and cost parameters are the same for both cases. In addition, the FC stack owner would:

- Borrow 75% of the funds for the generating unit at 12.5% interest;
- Receive 2 percentage points interest rate subsidy;
- Pay corporate income taxes on profits; and
- Depreciate the unit over a period of 10 years.

The financial analysis leaves far less favourable results. Only under the very best (most highly subsidised) circumstances can the IRR even approach double digits. For example, to push the SO Base case (100 kWe) results into a financially feasible range, an additional $77,000 in subsidies must be used. These additional subsidies will bring the initial cost to the developer down to about $69,000, from $146,000. Such a reduction in initial costs raises the FIRR from 7,84% to 19,42% and the NPV increases to $61,991 from *minus* $24,274, a net change of more than $86,000.

Table 15 Financial IRR and NPV for Philippines Case

Rates of Return and Present Values for Three FC Systems: Philippines

	Financial Internal Rate of Return (IRR, %)			**Present Value of Net Benefits (k US$)**		
	PEM	**MC**	**SO**	**PEM**	**MC**	**SO**
Base	9.13	5.91	7.84	(5,029)	(44,282)	(24,274)
Pessimistic	-6.61	2.01	3.70	(107,490)	(60,685)	(49,119)
Optimistic	16.26	7.86	9.65	28,120	(24,009)	(4,000)

Note: simulations of the PEM technology were performed using the avoided cost and performance data in the South Korean electric power system. In that fully electrified nation, FC technology exhibited large financial losses, in excess of $175,000 in present value terms for a 100kWe PEM system in the Base case.

Using the same cost, subsidy and performance parameters as the economic case, the financial rates of return are generally worse for each set of assumptions about initial cost, performance, subsidies, O&M costs, and avoided costs. As was discussed above, the financial analysis must cope with additional costs not in the economic analysis: interest, depreciation, taxes. To accommodate such additional costs, the subsidies that make the economic analysis acceptable will still generally leave the financial returns insufficient to attract investment. In just one example, a PEM system that shows acceptable *economic* returns (14.9%, NPV=$22k) is unattractive from a *financial* standpoint (FIRR=9%, NPV= -$22k). The other cases show similar disparities. Further incentives may therefore be required to put FC systems into use by private investors.

In the short term, however, investors motivated by other criteria – such as public organisations – may invest in these technologies. In addition, there may be scope for fuel cells to displace what would otherwise be new DG capacity at small scale, e.g. in the Philippines rural electrification programme.

6.15.2 Economic Analysis for 'Sustained Commercial Availability', 2004-2007, (Lower Bandwidth)

The three fuel cell technologies were examined in two distinct cost environments. In the first instance, most of the future expansion in the electric power system is based on liquid fuels and the average cost of those fuels is high. In the second instance, the system expansion was based largely on solid fuels, with gas available by pipeline.

Two countries that exemplify these polar cases, Philippines and South Africa, respectively, were chosen for a more detailed analysis. In both cases, the FC plant was “located” at the interface of the transmission and distribution systems. Many of the results can be extrapolated to similar receiving systems, including India, as an example of a solid fuel-dominated system.

The same economic model that was used to assess the early stage FC systems was also used in somewhat greater detail to analyse the costs and returns of more mature FC technology.

6.15.2.1 Assumptions

The economic analysis pinpoints the estimated incremental cost of FC technology at the sub transmission level vis-à-vis the costs of generation from conventional central plant sources. If the proposed FC plant is economic on its own merits, relative to the avoided costs of the receiving system, no need exists to involve outside agencies in the financing of the FC plant. However, if the incremental costs of the FC unit exceed those from central generation, then such excess incremental costs can be financed by the GEF or possibly by purchasers of GHG emissions reductions, according to policies adopted in recent years for estimating these costs. To derive the incremental cost, the GEF eligible project is compared to the alternatives.

EIRR (Economic Internal Rate of Return) is the basic indicator to which the World Bank and others look to reflect the cost-effectiveness of the proposed project. The calculation of EIRR is based on the cash flow analysis, and the EIRR on the fuel cell systems will be based upon the total costs of the project. The benefits side of the project will be estimated from either the output benefits (increased electricity generation) or cost-savings benefits (reduced investment in generation & transmission and reduced fuel costs). For the financial analyses, the positive cash flows are valued at the level of some proposed power purchase agreement, plus the additional cost-savings of location in sub transmission.

It must always be borne in mind that the long-term levels of GHG emissions reduction will affect the final acceptance of a project from the GEF perspective. In the short term these benefits may not be obvious, but if the project can be justified as part of a long-term strategy to move towards lower carbon emissions then it will have some justification for attracting financing.

Key Economic Results

Using the assumptions and methods discussed above, the economic model was able to derive the key rate of return and present value calculations. The tables below shows the key results:

Table 16: Rate Of Return and Present Values for Three FC Systems: Philippines

Rates of Return and Present Values for Three FC Systems: Philippines						
	Economic Internal Rate of Return (EIRR, %)			Present Value of Net Benefits (US$)		
	PEM	MC	SO	PEM	MC	SO
Base	9.85	5.02	13.66	(3,600)	(72,900)	30,400
Pessimistic	1.20	-2.08	4.33	(90,000)	(126,000)	(56,100)
Optimistic	20.27	10.46	21.51	88,300	3,700	94,100
Base & GEF	15.59	11.94	11.28	37,300	14,900	4,800

Table 17: Rate of Return and Present Values for Three FC Systems: South Africa

Rates of Return and Present Values for Three FC Systems: South Africa						
	Economic Internal Rate of Return (EIRR, %)			Present Value of Net Benefits (US$)		
	PEM	MC	SO	PEM	MC	SO
Base	9.61	6.74	20.76	12,896	(49,600)	101,500
Pessimistic	-3.78	2.05	10.62	(113,737)	(130,200)	4,915
Optimistic	19.83	12.31	25.63	79,755	27,700	133,700
Base & GEF	12.06	14.41	12.63	29,531	38,100	30,191
Note: The SO case includes a GEF programme for the *Pessimistic* case, not the *Base* case as with the other two programmes.						

The subsidies necessary to achieve a minimally acceptable rate of return vary, unsurprisingly, from one technology and country to another. The table below shows the magnitude of the subsidies required to bring returns up to an acceptable level.

Table 18: Subsidies required to Achieve Economic Feasibility

Indicative Subsidies to Achieve Economic Feasibility ($/kWe)		
	Philippines	**South Africa**
PEM	**350/850**	**300/1,000**
MC	**750**	**750**
SO	**500**	**NA**

Note: For the PEM technology, the second figure represents the subsidy necessary to make the pessimistic case feasible.

These subsidies appear to be within the range of those currently used by GEF for some technologies. Once specific technologies and applications are proposed, the cost per tonne of CO_2 equivalent can be estimated for comparison with other mitigation strategies, though this should not be the only measure. It is noted that outcomes in terms of acceleration of the market place will need to be estimated and supported through long-term commitment to stay in the market and develop lasting partnerships.

Key Parameters for the Case Studies:

In order to establish the likely range of economic performance for the three FC technologies, a range of efficiencies, plant factors, fixed O&M costs and investment costs were estimated for each technology. There are differences between the two countries as regards the economic performance of the two systems. In general each system at each level of performance showed better returns in South Africa than in the Philippines. The lower total avoided cost of electricity in South Africa, generally in the range of $75/MWh at sub transmission using current oil prices, includes a higher investment component as a proportion of total costs than does the higher avoided cost of the Philippines, some $82-84/MWh.

As mentioned earlier, the benefits of DG can be significant when compared with grid-connected central generation alternatives. It is imperative, therefore, that the economics of the individual projects consider the *direct alternatives* to the fuel cell system proposed, such as extending the grid to outlying islands or installing and running diesel gensets. This can have a dramatic impact on both the comparative economics and, equally importantly, on the relative emissions of the unit.

Given the fuel efficiencies of the FC units considered in this case – compared with CCGT baseload – the FC units do better when they can save investment rather than fuel. In the case of the Philippines, the power plant fuel to be saved in the future is generally either natural gas used in a CCGT or imported coal used in a baseload generation plant. Only under the best of circumstances can the FC units compete with CCGT on a fuel efficiency basis. Thus in the Philippines the benefits of FC technology are generally limited to those directly attributable to distributed generation: savings in transmission system investment and power losses. In South Africa, the FC system can also conceivably help to defer high investments in baseload generating stations.

A final normal means of assessing the costs of a technology involves the comparison of the costs of generation from the current system with the costs of generation from the new technology. In the table below, it is clear that the levelised economic costs of generation are high, relative to central station power without consideration of the savings in transmission and energy losses. For some of the cases, notably the SO and PEM optimistic cases, the FC cost of generation compares favourably with almost any peak period generation technology.

Table 19: Levelised Costs of Generation

Levelised Costs of Generation ($/MWh)				
	Philippines		South Africa	
Case	**Economic**	**Financial**	**Economic**	**Financial**
MC				
Base	107.91	111.47	96.89	99.72
Pessimistic	138.29	139.72	121.14	122.02
Optimistic	89.89	95.01	78.88	83.40
PEM				
Base	92.37	96.98	87.00	92.41
Pessimistic	116.00	120.12	116.12	116.42
Optimistic	72.12	81.74	68.09	77.61
SO				
Base	84.66	91.36	63.40	72.15
Pessimistic	106.82	111.79	86.52	91.06
Optimistic	70.88	80.98	56.54	67.16
Note: The cost of a new CCGT generation plant in the Philippines is about $72.00/MWh using LNG and $51.00/MWh using pipeline gas on a levelised cost basis. Coal-fired baseload generation in South Africa will cost about $56/MWh for a new plant on a levelised basis.				

Other Economic Issues

Earlier in this section four important issues were listed, each with a potentially significant effect on the economics of distributed generation technologies and FC deployment. These four considerations were:

(i) Reliability enhancement;

(ii) Transactional costs of investment;

(iii) Security of cash flows;

(iv) Ability of local banks to finance such transactions.

Reliability enhancement: In a system that suffers from transmission system congestion during peak periods and where capacity in both the transmission and generation systems is not sufficient, there may well be added value for reliability improvement, with two main components. Reductions in peak period congestion losses can easily fall in the $15-25/MWh range during peak periods, while improved generation reliability can certainly be worth a similar amount if there is a means of rewarding these services.

Transactional costs of investment: In many countries with insufficient generation capacity, the ability to put together large IPP projects may be limited. As has been seen in India, some large transactions take many years to come to fruition. Other countries have been more successful at streamlining the permits and negotiation process for large IPPs. However, where the realistic alternative to FC technology is a diesel engine of some sort, there are potential improvements in cost and emissions from moving to FC investments.

Security of cash flows and ability of local banks to finance transactions: Where the process for approving large IPPs is difficult and slow, financial institutions may be loath to carry large exposures to that market. On the other hand, local financial institutions, especially those with experience in financing other self-generation technologies, may look at the FC option as a relatively "normal" extension of previous lending activities. Given the small generation unit size, a FC unit operator may well be able to collect the fees for electricity generation within an industrial or commercial complex with greater efficacy than can the national power company.

These issues should be investigated as a part of specific case studies for initiating lending.

Financial Analysis of FC Unit Cases

This section summarises the financial rates of return that correspond to the cases discussed for the economic analysis, using the same assumptions as before.

Key Findings: Philippines

- MC technology provides generally inadequate returns under any operational assumptions;
- PEM technology is almost acceptable in the Base case and clearly so with a GEF grant or with improved performance and efficiency
- SO may provide good returns even in its Base case if the technology performs as expected; and
- GHG benefits are positive for natural gas

Key Findings: South Africa

- Only the SO technology provides adequate returns without the GEF grant. Again, the proviso is that this technology will perform as expected.
- MC is acceptable only with the GEF grant. Even the Optimistic case provides subnormal returns
- PEM may be acceptable, provided its fuel efficiency remains above the minimum level. The combination of its lower capital costs and higher fuel consumption make PEM highly sensitive to fuel costs. Coal gas as a fuel for PEM would cause significant GHG emissions increases, not reductions.

Summary of Economic Findings

The key implications of the economic simulation results include the following:

- SO technology is feasible under most foreseeable conditions, even if the technology costs more and performs worse than is expected;
- MC technology is economically marginal, even under the best conditions and assumptions, requiring substantial subsidies to attract private investors;
- PEM technology, though inferior technically to both MC and SO, outperforms MC technology both economically and financially. In the base case, the EIRR is almost feasible in South Africa (9.61%) and clearly feasible (12.75%) in the Philippines.
- PEM technology can be made feasible with a far lower GEF grant than can MC technology, although GHG benefits are subject to full fuel cycle calculations.
- SO technology can be made feasible, even under the most pessimistic assumptions, with a grant of about half the size used to make the MC *Base* case feasible.

For the PEM technology in this scenario, fuel costs are relatively more important than for the other two technologies. With its lower conversion efficiencies, vis-à-vis MC and SO, any action that can reduce fuel prices is important to the financial viability of the project. Alternatively, it can be considered in areas where CCGT baseload is not the alternative, giving it a different baseline against which to compete.

In terms of emissions reductions, the value of FC technology will be greater; the more the current system relies on coal, heavy oil or diesel gensets, for example.

6.16 Indicative costs of abatement

A series of indicative calculations were conducted by E4tech and UNEP, using the Philippines as an example, to link the economic and greenhouse gas emissions results presented earlier in the report. The results are presented in Tables 20, 21, and 22.

Application	Capital cost (installed) $/kW	Efficiency %	Annualised capital cost $/kWh	Fuel and other O&M $/kWh	Energy Productioncost $/kWh	CO2 emissions g/kWh	CO2 abatement incremental cost $/tCO2				
Baseline											
Coal combustion	1150	33	0.024	0.037	0.061	1019					
Natural gas CCGT	750	48	0.015	0.051	0.067	372					
Diesel engine	500	30	0.010	0.087	0.097	907					
NG microturbine	800	25	0.016	0.073	0.089	742	*FC alternative compared to:*				
CCGT + gas boiler	467	62	0.010	0.039	0.048	316					
FC alternative							*Coal combustion*	*NG CCGT*	*Diesel engine*	*NG micro turbine*	*CCGT+ boiler*
Diesel PEMFC	1300	28	0.027	0.111	0.138	972	1638.6		---increased emissions		
Natural gas PEMFC	1100	38	0.023	0.066	0.089	489	53.1			-1.3	
Diesel SOFC	1200	40	0.025	0.079	0.104	680	126.2		30.3		
Natural gas SOFC	1000	55	0.021	0.047	0.068	338	10.1	32.2		-53.4	
H2 PEMFC	800	50	0.016	0.149	0.165	0	102.5	265.3	75.6	102.4	
Natural gas SOFC cogen	1100	85	0.023	0.036	0.058	219					101.5

Table 20: Illustrative CO_2 abatement costs for a range of technologies (source: E4tech/UNEP)

- CCGT + gas boiler: Reference systems for supply of electricity and heat (or cooling). Efficiency, cost and emission values represent weighted averages for the supply of electricity and heat (or cooling).
- The abatement costs calculated are based on fuel cell system costs (i.e. FC + reformer (where needed) + balance of plant equipment) estimates for the period 2010-2015.
- --- indicates cases where FC alternative results in higher GHG emissions or negative benefits

Table 21: Illustrative CO_2 abatement costs for a range of technologies (by E4tech and UNEP)

Notes:

CCGT + gas boiler: Reference systems for supply of electricity and heat (or cooling). Efficiency, cost and emission values represent weighted averages for the supply of electricity and heat (or cooling).

--- indicates cases where FC alternative results in higher GHG emissions or negative benefits

negative values indicate GHG reductions can be obtained in tandem with economic benefits (win-win situation)

Fuel costs:		
Coal	0.0076	$/kWh
Natural Gas	0.0180	$/kWh
Diesel	0.0258	$/kWh
Ren. H2	0.0650	$/kWh
T&D costs	0.013	$/kWh

Lifetime	20	yrs
Discount rate	12	%
Utilisation factor	6500	h/yr

Other O&M		
PEMFC	0.019	$/kWh
SOFC	0.0145	$/kWh
Other	5%	% of capital expenditure

Table 22: Economic assumptions used for illustrative examples

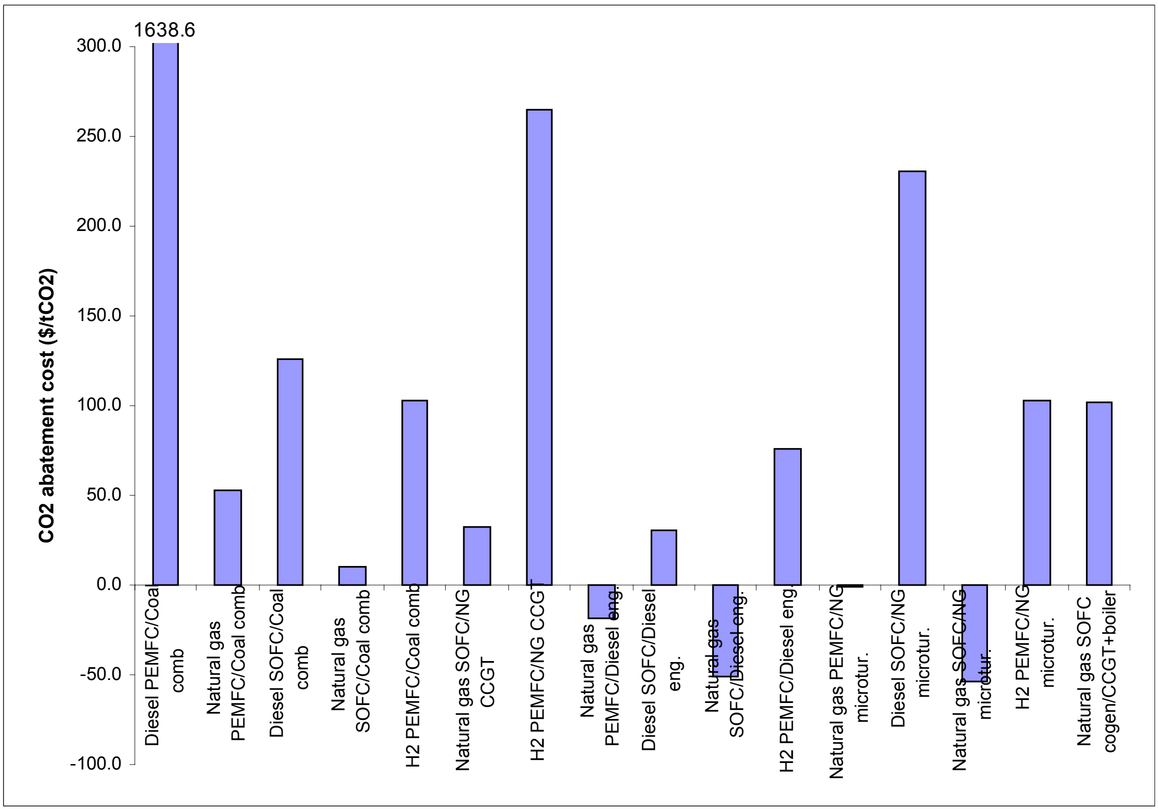


Figure 27: Illustrative examples of CO_2 abatement costs (by E4tech and UNEP)

The above examples provide an indication of CO_2 abatement costs associated with FC decentralised generation solutions compared to other centralised and decentralised power generation solutions. They are to be considered as illustrative, as a more precise assessment of the CO_2 abatement costs would require a more detailed study of the different options for each application. Cogeneration options are compared based on systems providing similar services and using the fuel cell heat to power ratio as a basis (i.e. a fuel cell based cogeneration system is compared to a system composed of electricity from a centralised CCGT plant and on-site boilers for the production of heat). A rigorous assessment of decentralised cogeneration solution would need to consider the heat to power ratios of different technologies and consider systems with the same heat and electricity outputs.

The illustrative examples show that the greatest benefits, amongst the options considered, are likely to be achieved when substituting natural gas fuelled fuel cells for gas microturbines. These cases could result in win-win situations where GHG emissions can be reduced in tandem with energy costs.

Since fuel switching provides a portion of the benefit of natural gas fuel cells versus diesel engines this case may be considered less valid but does result in win-win benefits.

SOFC examples are generally positive, even when no fuel switching is assumed. This is a result of their high efficiency. SOFCs used with more carbon intensive fuels results in less attractive example applications.

Fuel cell systems fuelled with renewable hydrogen are clearly the most effective with regard to CO_2 abatement, but the costs of hydrogen from renewables results in slightly higher abatement costs. Renewable H_2 is particularly interesting when compared to diesel engines in remote power applications.

In the case of electricity and heat generation, the example shows that reductions in CO_2 emissions could be obtained at a relatively low cost compared to a reference system based on centralised CCGT electricity and on-site heat production from gas boilers. The generally low emissions and noise of fuel cells are likely to result in advantages over other decentralised generation technologies in terms of siting.

The illustrative examples also show that in some cases the use of FC alternatives may result in higher GHG emissions, for example when replacing electricity from a diesel engine with electricity from a diesel fuelled PEMFC or when replacing electricity from CCGT with electricity from natural gas fuelled PEMFC. This depends strongly on local operating conditions and should be treated on a case-by-case basis.

6.17 Preferable Financing Modalities and Intervention Options

A wide range of financial modalities is available to the GEF for financing FC systems. The ideal package will depend on the individual circumstances of the country, project and technology under consideration.

Direct grants to manufacturers of fuel cells are unlikely given the financial strength of manufacturers and the general orientation of the proposed multi-lateral lending agencies' programme. Capital cost buydowns can be used but will be delivered through the purchase of fuel cells from the manufacturers.

Equity for fuel cell marketers and ESCOs can be provided as grants or concessional investments. The primary advantages of equity for ESCOs are that: (i) equity is risk capital and can be leveraged with available levels of debt; and (ii) equity contributes to start-up and establishment of new ESCOs.

Multi-lateral lending agencies' monies can be disbursed as grants to pay a portion of ESCO project costs. These can fully passed through to consumers, or returned to the ESCO as revenues generated by the project investments. This approach builds the long-term financial capacities of the ESCOs.

Equity for ESCOs can also be used made as concessional investments in the ESCOs. The terms of the concessional investments can take many forms, and even be deferred until the ESCO reaches some designated plateau of commercial viability. Returns could be paid out over time or the investment could be in the form of redeemable preferred shares, that are sold back to the ESCO or to new ESCO investors. Concessional equity investments could also include a grant component, even as an incentive for ESCO development objectives. Options and warrants in the investee FC company could be provided as part of the package of returns. As the ESCOs mature they will likely seek new equity investment from both new active partners and from financial investors. The multi-lateral lending agencies' concession investment structure could anticipate this development and be structured to attract this next stage of commercial finance.

Concessional equity investments for ESCOs can also be made via venture capital financial intermediaries (VC FI). A portion of the concessional element of the multi-lateral lending agencies' investment could accrue to the VC FI as an incentive.

International ESCO partners could contribute equity. IFC could complement the multi-lateral lending agencies-funded programme with direct investments in participating companies through either IFC investments or investments made through the IFC-sponsored Renewable Energy and Energy Efficiency Fund (RE/EEF). Facilitation of commercial equity investment for ESCOs can be a subject for the programme's technical assistance.

Several other key features of such loans which influence their development impact are: (i) the loan interest rate; (ii) whether the loans are provided on a recourse or non-recourse basis; and (iii) whether the loans are provided on a senior basis or a subordinated basis, and (iv) other risks assumed by the lender.

The partial guarantees provide leverage according to the guarantee percentage. Subordinated recovery guarantees, because they are more meaningful than parity guarantees, can use a lower guarantee percentage to achieve the same level of overall risk protection to an FI and therefore achieve greater leverage. Loss reserves can achieve even greater leverage.

Technical assistance programmes are essential to assist in organising the market, engaging various parties to participate in the fuel cell market, training and education, economic analysis, and preparation of projects for investment.

6.18 Types of Financing

Investments will be oriented toward reducing risk and providing financing not available in local markets.

Mechanisms to be used in this programme could include:

- **Incremental cost and risk reduction mechanisms** including a range of appropriate non-grant financing modalities such as:
  - partial guarantees for credit enhancement purposes;
  - technology performance backstop guarantees;
  - limited currency exchange cover for IPP agreements or other in-country financing;
  - use of multi-lateral lending agencies' funds as equity or quasi-equity;
  - contingent loans made using multi-lateral lending agencies' funds; or
  - reduced interest rates/extended loan terms on conventional IFC loans.
- **Capital cost buy-downs** to allow IFC financing of private sector projects compared to a baseline alternative.

These recommendations are designed to be similar to a fund with a mandate to invest in a specific sector, but one that pursues gains for sustainable dissemination of fuel cells rather than seeking to maximize financial returns for its investors. Recovery of investment funds is considered important, but less for the need to provide this financial return to multi-lateral lending agencies than for the commercial discipline it imposes on investee companies in operating their businesses as going concerns. Successful business models resulting from any proposed investments will demonstrate to financial institutions that companies can engage in successful fuel cell businesses and service their financial obligations including commercial debt.

6.19 Framework for Promoting Commercialisation of Fuel Cells for Stationary Power

A range of programme design and finance options for multi-lateral lending agencies exist. The ultimate goals are reduction of greenhouse gas (GHG) emissions, improved energy efficiency, and energy savings; these are to be achieved through expansion of a commercially sustainable fuel cell industry globally and initially in the target countries chosen for the programme.

The immediate objective of the multi-lateral lending agencies' programmes will be to support development and financing of fuel cell applications. The focus will be on getting fuel cell systems installed. Support will be provided primarily through various financial/investment methods to be determined, and through market-organising and technical assistance activities.

6.19.1 The Chain of Project Development and Financial Intermediation

The programme design must anticipate all steps required to get fuel cell projects developed, financed and installed. To assess programme design options and evaluate the most effective points for market intervention by the multi-lateral lending agencies' programmes, the full chain of project marketing, development and financial intermediation must be examined. This chain includes:

1. the distribution of roles, responsibilities and risk amongst the various parties involved in the overall fuel cell project value chain;
2. how fuel cell projects are developed and marketed;
3. how projects are financed; and
4. the economics of fuel cells in various applications.

6.19.1.1 Key Parties and Roles.

Key parties involved in developing, financing and implementing fuel cell projects are as follows:

1. fuel cell manufacturers, and their related component suppliers;
2. equipment distributors/vendors, who can include project developers and energy service companies, any party who directly markets fuel cells to the end-user;
3. service companies which provide after-sale operations and maintenance (O&M) services for installed equipment;
4. governments and power purchase regulators
5. electric utilities, which may have a special role as marketers or users;
6. fuel suppliers, of any suitable fuel;
7. financial institutions; and
8. the end-users themselves, which category may include organizations which act for and aggregate end-users for the purpose of project development and implementation.

In developing an effective programme, commercial partners must be recruited and organised so that all these necessary functions are performed. Some roles may overlap. The programme design for any given country and market must be based on a roles analysis and risk/credit analysis defining the interests of all parties to the transactions, the functions they perform and the complete distribution of project roles and risks between them. Where this analysis identifies a gap, the programme can seek to fill the gap through targeted financial support, credit enhancement, technical assistance, facilitative matchmaking, and organising skill. The programme will assist in achieving a distribution of project roles and risks that meets the objectives of all parties.

6.19.2 Multi-lateral lending agencies' Programme Design Criteria

The following strategic criteria are suggested for design of the multi-lateral lending agencies' fuel cells programme; the programme should:

a) target GHG benefit opportunities

b) address market barriers and fuel cell industry and market conditions,

c) build on existing capacities and engage quality players/partners at all levels in the chain of project development, marketing and financial intermediation;

d) mobilise commercial capital and achieve maximum leverage of multi-lateral lending agencies' monies;

e) be manageable and reasonably administrated with capacities available or able to be readily developed in chosen countries, and to use transparent and sound business practices in selecting and structuring relationships with programme partners;

f) be timed to coincide with industry near-commercial readiness so that the multi-lateral lending agencies' market intervention has best prospects for helping create a commercial industry

6.20 Transaction Structures & Market Aggregation Strategies Appropriate for Fuel Cell Projects

This report distinguishes between transaction structures, where fuel cell project investments are made and projects implemented; and finance programmes, i.e., the ways that fuel cell project development and financing can be promoted systematically by multi-lateral lending agencies working with the commercial actors. The transaction structure describes, at the commercial level, the contract and finance structure used to implement the project whereby the customer acquires use of the fuel cell. Finance programmes address the needs to make fuel cell projects happen: the missing pieces, gaps and barriers in the value chain.

Transaction structures appropriate for implementing and financing fuel cells projects are similar to those used for other small on-site power, distributed generation and energy efficiency projects. Each transaction structure must be defined from the points of view of each of the key parties including the customer, the fuel cell marketer and the financial institution. Several common business models are:

1. cash sales,
2. equipment finance, loans & leases to end-users, with financing provided through the equipment vendor or by a financial institution (FI) directly,
3. ESCO (energy services company) models, using a variety of energy services agreements.

GHG emissions reduction purchases would entail additional overheads for project set up and monitoring.

6.20.1 Energy Service Company (ESCO) Transaction Models

ESCOs offer turnkey solutions for energy services projects, and can additionally provide needed services, including consulting to end-user facility staff on improving plant/facility efficiency, or procurement and sale of energy, for example. The ESCO transaction model has been used extensively for on-site generation and EE projects and is judged very relevant for fuel cell projects with the full range of end-user sectors.

6.20.1.1 Mechanics of ESCO Structure and Energy Service Agreements (ESAs)

An ESCO project is implemented pursuant to an Energy Services Agreement (ESA) between the ESCO and the end-user. Main provisions of the ESA define the project scope, the equipment being installed, all the technical and interconnection specifications, the estimated operating plan for the system, the division of operating and maintenance responsibilities between the ESCO and the end-user, warranties on equipment performance, the formula for customer payments, project financing, fuel supply, ownership of equipment, contract term and termination, disposition of equipment at the end of the original term, and other legal details such as risk of loss and damage, insurance, default and remedies.

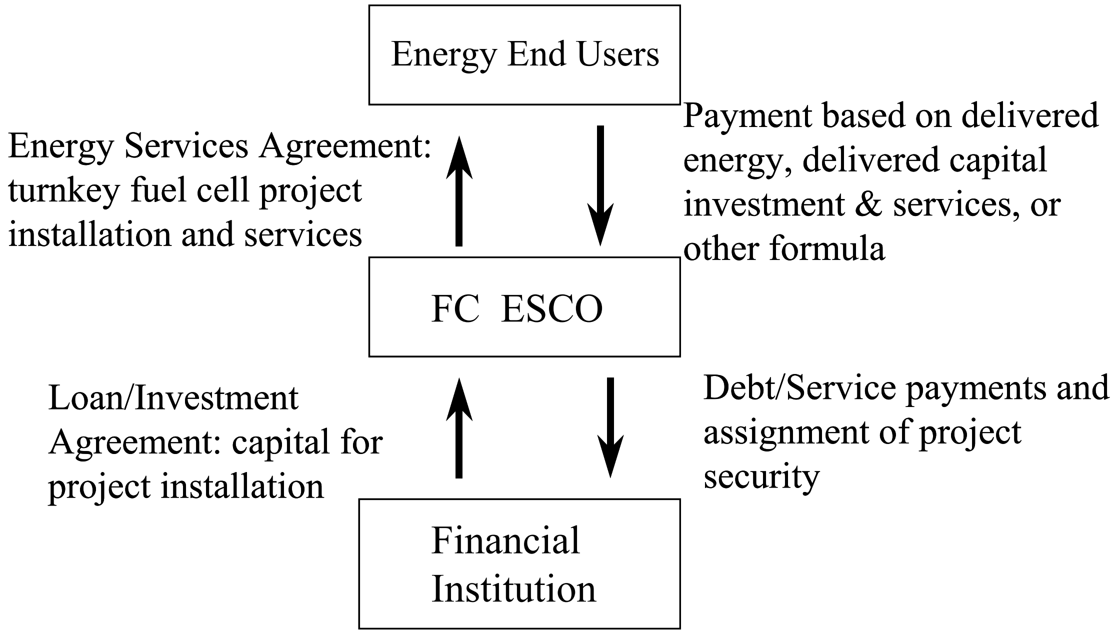
6.20.1.2 Financing ESCO Projects: Structure & FI Perspectives

Under the ESA structure, the ESCO provides financing for the project. The ESCO must mobilise the financing, and will do so typically through a combination of debt and equity. Debt facilities to ESCOs can usually cover 60-80% of project costs. Project debt provided to the ESCO would be matched to terms of, and secured primarily by, the end-user payment obligation.

The loan facility would be designed anticipating a target business volume over a stated period. The larger and more assured the volume, the more attractive the lending opportunity. A minimum size for each individual project or for each credit facility disbursements may be defined. If project sizes are very small, the ESCO can fund installation of groups of projects, or assemble mini-portfolios for takeout financing under the loan facility.

Figure 28 provides a simple depiction of the typical ESCO transaction structure. Table 40 provides a summary presentation of advantages and disadvantages of these two basic transaction structures, end-user as borrower and ESCO as borrower. Many hybrids of transaction structures can be developed, but they all must address these basic project elements.

Figure 28: Typical ESCO Transaction Structure



6.20.2 Strategies for Market Aggregation and Organising Project Delivery Capacities

Primary challenges for organising and delivering fuel cell project financing will stem from the large number of small projects, which will initially characterise most of this market. These challenges can best be met by project aggregation, grouped typically by end-use sector. A programmatic approach, not a project-by-project approach, to project marketing, development and financing is recommended; this can be accomplished by developing financing relationships with market actors who can develop multiple projects with sets of end-users in their target sector. These parties include utilities, fuel suppliers, FC equipment manufacturers, existing ESCOs, and specialised financial intermediaries.

Aggregation of projects needs to occur at the level of project development. FC financing strategies should be integrated with FC project development strategies, and should be combined with other project and business development assistance.

Three special types of market actors with strong potential relevance for fuel cell project development, implementation and financing are (i) electric utilities, (ii) fuel suppliers, (iii) manufacturers; each of these can play a key role in market aggregation strategies, including sponsoring ESCOs and equipment financing.

6.20.3 Electric Utility-Based Programmes and ESCOs

Electric utilities may be motivated to establish a fuel cell ESCO business in order to develop the utility system benefits associated with DG, to improve customer service and/or as a new profitable line of business.

Electric utilities can offer several important natural advantages, which may include:

1. existing customer relationships, credibility and marketing capacities throughout their service area, and, consequently, market organising and aggregation capacities;
2. strong financial resources;
3. technical engineering resources, including access to customer energy data;
4. an ability to comprehend, develop and capture utility system benefits of DG;
5. billing and collections systems;
6. and, in some cases, fuel supply capacities.

Utilities can be an ideal vehicle to perform the project pooling or aggregation functions needed to achieve broad scale fuel cell market penetration, aggregate capital demand and manage transaction costs.

6.20.3.1 Utility-Based Super-ESCO Programmes

A "super-ESCO" programme is one where the utility acts as the ESCO from the customer's perspective, but, to deliver the fuel cell projects and services, qualifies and organises a network of fuel cell project partners to co-market and deliver the projects.

6.20.4 Fuel supplier sponsored ESCOs.

Fuel and gas suppliers with motivation to build load for their fuel business can also be natural sponsors for fuel cell projects and ESCOs. Natural gas utilities will have many of the advantages and capacities described above with respect to electric utilities for undertaking fuel cell programmes and ESCO activities including existing customer relationships, marketing capacities, financial resources, and billing and collections systems. Equally, LPG, methanol, biomass and other fuel suppliers may seek opportunities to expand their markets.

Further, fuel suppliers can combine their fuel product with the fuel cell equipment to offer an economic power generation alternative to customers. Given the importance of fuel infrastructure to expansion of fuel cell applications, fuel suppliers can be natural partners with fuel cell companies.

6.20.5 Manufacturer Sponsored Finance Programmes and ESCOs

In other EE and energy services industries, equipment manufacturers have commonly also undertaken turnkey installation and finance programmes and sponsored ESCOs as a means to promote sales of their equipment.

The first requirement is local vendor network. Some fuel cell companies have their own established network of subsidiaries and distributors for other product lines, which can possibly be deployed for fuel cell marketing. Other fuel cell companies will be seeking local partners to gain market access and equipment sales capability. Equipment sales will also need to be married with application engineering, installation, after-sale service, fuel supply, financing and other capacities.

6.20.5.1 Vendor Finance Programmes

Manufacturers frequently have superior financial resources as compared to their local equipment vendors. Manufacturers can assist their local vendors to establish vendor finance programmes, as described above. Support is needed to develop and arrange the programme, as well as provide, potentially, credit support.

6.20.5.2 Manufacturer-Sponsored ESCOs

Manufacturers may also consider sponsoring ESCOs in conjunction with local partners as a means to deliver their systems in a way that meets customer needs in both urban/grid-connected and off-grid markets.

6.20.6 Building on Existing Capacities

In designing the programme, it will be important to build on existing commercial capacities and promote their adaptation to the fuel cell industry and project marketing, implementation and financing challenges. Existing capacities for distribution, installation, fuel supply, marketing and finance can potentially be tapped for the cause of fuel cell commercialisation; auto leasing and dealerships provide one example, LPG fuel business another.

6.21 Assessment of Fuel Cell Industry Commercial Practices & Market Barriers

The industry is in a pre-commercial to near-commercial stage. Fuel cell systems remain for the most part economically uncompetitive due to high capital costs. A few commercial sales have occurred in specialised premium power applications. Other units that have been procured and installed are mostly part of test and demonstration programmes.

Fuel cell companies have formed many alliances with large multi-national companies from auto, oil and gas firms, electric and gas utility, chemical, electronics and specialised materials technology industries. Manufacturing technologies from other industries are being adapted to fuel cells. Tremendous investment in product development is underway and many firms are predicting their ability to hit the $1200-1500/kW fuel cell unit price target in the 2003-2004 timeframe, partly through production facilities to be built in the next 1-3 years.

In general, equipment distribution and marketing channels remain to be developed; many firms have identified this need and are beginning to establish marketing partnerships, distributor networks. Partnerships have been formed, anticipating development of marketing and equipment distribution capacities.

Similarly, the approach to warranties, both standard and extended, varies considerably. The majority of firms anticipate offering some type of warranty with respect to longevity. Interest and willingness to provide turnkey installations of and after-sale service for systems varies widely. Some firms actively conceive of taking an energy services approach, such as ZeTek, which has begun to establish a network of systems integrators who can act as both sales agents and turnkey installations and service companies. Joint ventures with electric and gas utilities and fuel suppliers have been formed in anticipation of marketing to existing customers and bundling fuel cell sales with fuel supply.

6.21.1 Barriers Assessment

The multi-lateral lending agencies' programmes must be based on an analysis of market barriers to commercialisation of fuel cells. Near term, the primary barrier is price: fuel cells remain economically uncompetitive for most all applications. Fuel cell performance also needs to be proven in almost every case. The industry is making rapid strides to reduce equipment prices. The multi-lateral lending agencies' programmes is intended to accelerate this process, intervening with market launching orders and capital cost subsidies strategically timed and sized. This assumes that the technical capacity has been developed and that an appropriate policy environment, power purchase arrangements and public acceptance have been achieved through technical assistance activities.

6.22 Private sector role in sharing risk in multi-lateral lending agency programme countries

There will be numerous situations where the private sector will need to share in the risk during the "cradle to the grave" of a fuel cell product. Except for the possible demonstrations discussed herein, the private sector is expected to bear – and is currently bearing – virtually the entire burden of research, development and demonstration. In addition, the private sector will bear the burden of capitalising the manufacturing facilities, marketing and distribution networks and the after-market service and sales.

The fuel cell vendors involved thus far in this project have shown willingness to share and shoulder the risk through the R,D&D process, but would seek assistance in the credit and market development areas within developing countries. They have indicated limited interested in sharing risk through extended warranty rather than after-market O&M agreements. While manufacturing capacity is constrained and premium power markets are offering price-tolerant customers, there is limited interest by the fuel cell industry to potentially overextend itself into the more difficult developing country markets. The environmental benefits of fuel cell technology will not be globalised in the near or mid term unless there is a market intervention strategy and programme that brings forward, aggregates and manages the significant developing country market in a commercially financeable fashion. In relative terms, the possible multi-lateral intervention funding of $50-100 M, even when leveraged, is not a significant sum when compared to the several billion dollar annual investments in the fuel cell industry. However, that same sum of money is significant in the timing and conditioning of a market that would otherwise go unattended for a period of ten to fifteen years without a multi-lateral strategy and intervention, and the greenhouse gas benefits attainable by bringing forward the introduction of fuel cells in these markets can be very large.

7 CHALLENGES TO FUEL CELL COMMERCIALISATION

7.1 Challenges Common to New Technologies

Commercialisation barriers exist for the widespread use of fuel cell technology. Some of these barriers are the same as for other new energy technologies, especially renewable energy technologies, namely:

- *Undervaluation of environmental and other societal benefits*. The public health and other impacts of air pollution are not factored into cost assessments, nor are environmental costs of resource extraction and depletion.
- *Continued availability of cheap fossil energy*. Highly efficient technologies such as fuel cells are disadvantaged when fuel prices are low. This is exacerbated by the fact that fuel prices in many countries are subsidized either directly (especially diesel for cargo and public transport) or indirectly (through import policies, military support, etc).
- *Limited global demand for clean technologies*. In face of other pressing development needs in many countries, resources to meet clean development objectives are scarce.
- *Inability to achieve economies of mass production.* Even for technologies with good prospects for long-term competitiveness, low demand poses the classic "chicken and egg" problem, wherein conventional technologies are locked-in despite being inferior to new technologies that have not yet established markets.

7.2 Challenges Unique to Fuel Cells

Fuel cell technologies have their own unique set of challenges related to their relative technological newness and their need for hydrogen as a fuel. Some of the more prominent issues include:

- *Continuing development of fuel cell design and manufacturing technology.* Developers are still in the process of designing complete systems, with fully tested power electronics, thermal, air and water management, fuel storage and processing. Manufacturing processes are still under development, and significant cost reduction must still be realized in order to make large-scale commercialisation feasible.
- *Inadequate hydrogen infrastructure*. The existing fuel supply infrastructure is oriented to the delivery of liquid fuels
- *Hydrogen availability.* There is not yet a cost-effective hydrogen route for vehicles
- *Regulatory framework.* There is currently a lack of widely accepted safety codes and performance standards for hydrogen energy infrastructure, handling, and storage
- *Perception*. In the public at large, there is a generally negative perception of hydrogen, and uncertainty about the performance of fuel-cell vehicles.

7.3 Challenges for Fuel Cell Buses

For most developing countries, where there are not research and development activities in fuel-cell technology, the above challenges and barriers are further exacerbated. The introduction of FCBs to urban fleets faces a number of specific barriers that dominate their consideration:

- *Costs.* FCBs have not achieved cost reductions that make them competitive with diesel buses, the conventional alternative in most countries;
- *Technical Capacity.* A small number of ongoing demonstration notwithstanding, there is little technical, institutional, and policy capacity related to the introduction, operation and maintenance of FCBs;

- *Awareness.* There is a lack of awareness and acceptance of FCB technology among policy makers, potential private sector investors, and the general public.

7.4 Challenges for Fuel Cell Distributed Generation

A number of challenges already raised for FCBs are similar for FCDG technology, while other more specific ones also exist:

- *Costs.* FCDG has not achieved cost reductions that make it competitive with diesel gensets, gas engines or turbines, the conventional alternatives in most countries;
- *Institutional framework.* There is a general absence of the framework in which FCDG could maximise its advantages of high efficiency, low noise and low emissions. The state of the power and energy markets in many regions do not allow incentives for these attributes to be put in place;
- *Regulatory framework.* Electricity distribution, even in highly liberalised electricity systems, remains at best a quasi monopoly, and competitive prices have proved to be difficult to achieve. In addition, regulations often disfavour the entry of new, small-scale technologies on the system. Related to this, addressable issues, such as voltage control and quality of supply, remain unaddressed.
- *Technical Capacity.* A small number of ongoing demonstration notwithstanding, there is little technical, institutional, and policy capacity related to the introduction, operation and maintenance of FCDG;
- *Standards and norms.* There are few standards already developed for the installation and use of FCDG, and development of standards will take several years.
- *Awareness.* There is a lack of awareness and acceptance of FCDG technology among policy makers, potential private sector investors, and the general public.

In the next section, a range of policy options are explored that address these barriers and challenges. Effective policies to meet these assorted challenges and barriers will benefit from effective coordination between industrialised and developing nations. Such activities can facilitate adequate levels of information exchange, technology transfer, capacity building, and private/public partnerships.

7.5 Policy Options for Action

A wide range of polices can be applied to encourage either the adoption of FCBs, or FCDG in industrialised and developing countries:

- *Research, Development, and Demonstration.* This policy category aims to foster breakthroughs in fuel cell technology and applications. Specific policies include: ***1)*** funding for research and development, ***2)*** demonstration projects, and ***3)*** public-private partnerships. For developing countries, opportunities for production of balance of system components or even fuel cells should be a priority.
- *Government Mandates.* This policy category aims to exert control over technology performance through governmental regulatory actions to ensure that the fuel cell technologies are considered an attractive option relative to conventional technologies. Specific policies include: ***4)*** emissions standards and technology controls, ***5)*** licensing and certification requirements, and ***6)*** procurement targets.
- *Fiscal Incentives*. This type of policy category is designed to influence decisions by organizations and individuals through changes in prices or costs. Specific policies include ***7)*** taxes, and ***8)*** subsidies.
- *Awareness Building*. This category of policies focuses on a range of measures to educate the public at large on the merits of transitioning to a hydrogen economy and the use of fuel cell technology. Potential policies include ***9)*** public education and ***10)*** targeted training for key stakeholders.

- *Regulatory reforms in support of distributed generation as a whole.* As discussed, a range of barriers to distributed generation technologies exists in many regions. Policies to open markets for such systems would enable technologies to compete on a more level basis.

Most of the above policy options types can be applied either as a singular intervention, or in combination with other policies. For example, a government mandate for a certain percentage of urban buses to be FCBs could be coupled with a fiscal incentive in which part of the incremental capital cost is offset through a subsidy. In the following subsections, we classify a potentially promising set of 10 specific policies that fall within the above broad categories that could help to promote an accelerated transition to FCBs.

7.6 Applicability of Policies to IEA's "Bus Technology Ladder" Concept

Much of the discussion to this point has been highly focused on policies that can promote the penetration of FCBs in transit bus systems. In many contexts, these policies could also have a significant impact in promoting a transition to the use of other types of cleaner and more efficient energy. For example, a standard requiring that air pollutant emissions be below a certain threshold could mean the purchase of buses having certain emission control technologies, and could be monitored through a fleet inspection and maintenance programme.

The International Energy Association has developed a ladder for cleaner bus technologies and is actively developing projects and strategies within this framework. Any GEF intervention should be carefully targeted to fit in with other multilateral programs such as this. The 'ladder' consists of the following six rungs, with an additional 'rung' added as a suggestion:

- *Better Bus Maintenance.* This corresponds to regulations for addressing inspection and maintenance operations of transit bus fleets.
- *Diesel Water Emulsions* - Low-emission diesel fuel/water blends to reduce two of the critical emissions from compression ignition engines -- nitrogen oxides (NOx) and particulates (PM). The fuel can be used in both older and newer diesel engines.
- *Low sulphur diesel with Catalytic Filter* This involves using low sulphur diesel to reduce SOx emissions combined with a catalytic filter to reduce particulates and NOx. These technologies can be applied to existing diesel buses.
- *Alternative fuels* – Compressed natural gas (CNG), di-methyl ether (DME) and liquefied petroleum gas (LPG) can be used to fuel transit buses to lower particulate and NOx emissions. Existing engines can be converted to use one of these fuels or new buses can be built with engines designed specifically for the alternative fuel.
- *Hybrid Electric* This technology combines a combustion engine with energy storage. This lowers emissions through increased fuel economy.
- *Fuel Cell Buses.* FCBs represent a vanguard technology holding promise for emission reductions greater than achieved in the previous rungs.
- *Hydrogen Infrastructure.* The last step in the ladder could be development of a more extensive infrastructure for producing, storing and delivering hydrogen fuel, to be used both in FCBs and, where appropriate, in ICE buses.

A detailed qualitative assessment of different policy options and their relevance to the rungs of the 'ladder' discussed above are shown in Table 23.

Several polices could promote action at all levels of the ladder, depending on the design and level of the policy and the conditions of the host country. Others will only be applicable to a few specific technologies. Consideration of these issues could assist the IEA in the development of robust strategies for achieving the goals set out in its initiative, while the GEF should perhaps focus on areas with policies that will assist in FCB demonstrations.

	Better Bus Maintenance	Diesel Water Emulsions	Low Sulphur Diesel with Catalytic Filter	Alternative Fuels – CNG, DME, LPG	Hybrid Electric	Fuel Cell
RD&D						
Research & Development	Low	Low	Medium	Medium	High	High
Demonstration	Low	Medium	Medium	High	High	High
Government Mandates						
Emissions Standards and Technology Controls	Medium	Medium	High	Medium	Medium	High
Licensing And Certification Requirements	High	High	Medium	High	High	High
Procurement Targets	NA	NA	Low	High	High	High
Fiscal Incentives						
Taxes	NA	NA	Low	Medium	High	High
Subsidies	NA	Medium	Medium	High	High	High
Awareness Building						
Public Education	High	High	High	High	High	High
Training	High	High	High	High	High	High

Table 23: Qualitative assessment for the bus technology ladder of the potential impacts of policy

7.7 Can GEF Make a Difference?

Helping stimulate demand for, and investment in, technologies that will prove beneficial in the long-run fight against accelerated climate change is part of the rationale for the continued work of GEF in the climate change focal area. This strategic approach has been codified under both OP7 and OP11. With this approach, GEF can be seen to invest in an area with positive global externalities – not just in reducing future GHG concentrations in the atmosphere, but in helping accelerate the commercialisation of a technology that can then be used throughout the world. Some have persuasively argued that this role in helping foment and commercialise new, cleaner technologies is the most important one that GEF can play in the interest of reducing the risks of climate change.[7] In general, the rationale for GEF support to the development of these newly-emerging energy technologies is clear: in doing so, GEF is pursuing positive global externalities by helping make key climate-friendly technologies widely available and affordable.

Turning more specifically to FCBs, there are several reasons for GEF to support FCBs in its programme countries. By targeting larger markets for urban transit buses in developing countries, GEF will be helping to open the largest bus markets in the world to a new technology with both global and

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[7] President's Committee of Advisors on Science and Technology (PCAST), June 1999, *Powerful Partnerships: the Federal Role in International Cooperation on Energy Innovation*, a report from the Panel on International Cooperation in Energy Research, Development, Demonstration, and Deployment of the PCAST, Executive Office of the President, Washington, DC. Available through homepage of the Office of Science and Technology Policy: http://www.whitehouse.gov/WH/EOP/OSTP/html/OSTP_Home.html

local environmental benefits. Urban areas in developing countries rely heavily on transit buses as a critical element of their transport systems, and far more urban transit buses are in operation in the GEF programme countries than in Annex II countries.

It is thought that approximately 1.9 million buses operate in developing or GEF programme countries. Thus, GEF can help open the largest bus markets in the world to FCBs. The annual number of old buses replaced in these countries is 126,000 to 190,000 buses. Expansion (at 3% per year) would add another 55,000 to 60,000 buses. Thus, the total annual market for new buses in non-Annex II countries is 180,000 to 250,000. The rapid growth in bus fleets in GEF countries reflects rapid growth in the transportation sectors more generally. This growth will require increasingly significant investments in new fuel supply infrastructure. If non-Annex II countries begin to make substantial investments in conventional energy infrastructures, making the switch to clean infrastructure for FCB will only become more difficult and expensive. By investing in FCBs early on, GEF countries will be better prepared for future transitions to cleaner and more efficient fuel-supply systems, including hydrogen.

GEF can accomplish several things by supporting the demonstration and development of FCBs in developing or GEF programme countries.

- First, it is helping open the largest bus markets in the world to a new technology with both global and local environmental benefits.

- Second, it is providing an important avenue for new partnerships between technology developers, largely in Annex II countries, and the technology users, largely in GEF eligible countries.

- Third, in supporting FCBs, GEF is helping developing countries make incipient steps toward the **hydrogen economy**.

GEF support can make a difference in both the time taken to commercialise the fuel-cell technology in its application to buses and the time needed for this technology to disseminate widely around the world.

7.8 Strategy for FCDG

Regarding FCDG, there are equally good reasons for GEF support in its programme countries. Growth in energy use – and in fossil fuel use and greenhouse gas emissions – is certain. Bringing new technologies into the market earlier than they would otherwise penetrate can clearly bring forward the time at which they will make up a significant proportion of the generating capacity. The benefits from preparing markets early on may thus be much greater than waiting until fuel cell costs have dropped from their initial very high levels. Diesel gensets are currently the generator of choice for local small-scale power production in many developing countries, bringing with them significant pollution and noise problems, and by enabling cleaner alternatives a number of benefits can be brought about. Enabling high-volume markets in developing countries, and using local labour skills, should also bring down the cost of fuel cells for developed country markets and enable a virtuous circle of development and cost reduction.

By clearly stating a requirement for fuel cell projects in developing countries to show long-term greenhouse gas reductions and an evolution to hydrogen energy, the GEF can provide leverage for renewable energy technologies such as solar and biomass generation. Applications with poor to negative GHG benefits in the longer term can be avoided without restricting the eligible applications to any great extent. In tandem with fuel cell systems, these technologies can be used to produce hydrogen for energy storage. This increases not only the useful energy that can be produced from the system because of load matching, but also enables alternative uses for renewable resources – such as hydrogen in transport. The economics and the operation of the systems can be greatly enhanced, while increased use of local resources should encourage reduced energy imports and increased living standards.

By investing early on, GEF can make a substantive difference to the direction that FCDG projects may be developed. By encouraging low greenhouse gas emissions as a key criterion, projects that might otherwise be developed without this measure may be refocused. Early investment in this area, and the development of policy and other support frameworks, should also encourage development of other cleaner and more efficient energy supply systems, including – but not limited to – hydrogen. In contrast, delayed investment in this rapidly developing area is more likely to allow lock-in of environmentally inferior technologies, making future investment more complex and less successful.

GEF can accomplish several things by supporting the demonstration and development of FCDG in developing or GEF programme countries.

- First, it is helping open the fastest-growing energy markets in the world to a new technology with both global and local environmental benefits.

- Second, it is providing an important avenue for new partnerships between technology developers, largely in Annex II countries, and technology users in GEF eligible countries.

- Third, in supporting FCDG, GEF is helping developing countries make incipient steps toward the **hydrogen economy**.

GEF support can make a difference in both the time taken to commercialise fuel cell technology in its application to distributed generation and the time needed for this technology to disseminate widely around the world.

7.9 How Can GEF Play a Role?

If the goal of the GEF is to support the process of commercialisation of FCBs and FCDG in GEF eligible countries, then it must play several roles in order to achieve that goal:

- The GEF should help fund the incremental costs of the FCB and FCDG demonstration(s) in its programme countries.

- The GEF should join with other multilateral organizations like the IEA and serve a role as facilitator to the process of FCB and FCDG commercialisation in developing countries. The GEF can act both as a convenor, and as a financial facilitator.

- The GEF should act as an agent for information exchange. Lessons drawn from one demonstration should be shared with activities being carried on in another.

7.9.1 GEF strategy considerations for encouraging FCDG

As part of the underlying strategy it will be important for GEF to ensure that the goal for any intervention is clear. GHG emissions reductions can be achieved through the increased efficiency of FCDG in many cases, while fuel switching to lower carbon fuels such as natural gas will be important in others, and an eventual move towards hydrogen produced from renewable resources will enable the most significant reduction in GHG emissions. A set of basic principles should be applied:

- GEF cannot – and should not – buy down the costs of fuel cells across the board, but should target specific areas in which it can make a difference
- Countries and regions should be selected based on favourable policy frameworks, technical capacity and infrastructure
- Suitable levels of leverage for GEF funds should be set and pursued; additional funds may be available for local air quality or development criteria, in particular

- Rather than prescribe a specific fuel cell technology for any situation, GEF should be technology-neutral and set the framework in which projects can be implemented
- The level of GHG emissions reduction for a project should be assessed, but both long term and short term criteria must be considered in evaluating the project. A project with no immediate substantial emissions reduction but excellent future prospects based on a clear strategy may be superior to a one-off short-term gain
- Potential synergies between FCB and FCDG projects (common infrastructure, training, awareness-raising, local production facilities) should be assessed in case they can be used to improve specific projects
- A holistic approach to projects is important in the early stages. Not only may initial technology cost reductions be essential, but concurrent training, education, infrastructure development and other issues must be kept in mind.

GEF Strategy Options

7.10 Fuel, environmental and economic issues

Fuels derived from renewable resources need great consideration in the development of a strategy. Also, the economic and environmental impacts of **hybrid renewable and fuel cell systems** deserve closer attention. FC systems will generally produce very low emissions (water vapour is the only emission from a system operating on hydrogen). Use of renewable fuels should result in the greatest environmental benefit, with near-zero GHG emissions. The use of fossil fuel reforming, or conversion of natural gas to methanol would incur energy penalties and be reflected in higher GHG emissions, though these are still likely to be lower than conventional technologies. The expected immediate and potential future GHG benefits should hence be carefully assessed across the total fuel chain. The key point is to what extent a GEF strategy aimed at supporting fuel cells can be linked to options with potentially the greatest long-term benefits, i.e. integrated with renewables. Consideration should also be given to the economic value to the developing countries of the early deployment of these options.

However, due consideration must be given to the issues related to the use of non-conventional fuels in fuel cells in the development of a strategy aimed at supporting the introduction of fuel cells. This is an area where significant synergies may exist between stationary and transport applications.

7.11 An outline strategy for FCDG

Fuel cells offer a range of potentially large benefits when compared with conventional power generation technologies:

- They hold the promise of achieving high electrical efficiencies of around 60%, and 75-80% in colder climates when operated in a combined-heat-and-power mode.
- When used as a decentralised source of electric power, they avoid the losses (typically 20%) and the high capital costs (typically $1000/kW) of transmission and distribution associated with centralised forms of generation in developing countries.
- They can use natural gas as a feedstock, the least carbon intensive of fossil fuels.
- Hydrogen, however, is the ideal fuel, derived from renewable energy sources, in which case there are no emissions of CO_2 to the atmosphere. In this respect fuel cells are also seen as an element in the solution of the ‘intermittency’ problem associated with solar and wind energy.
- They are modular, capable of meeting electricity demands ranging from 1-5kW at the household and single village level, to 5-250kW for small industries and commerce, to 10s of MW for large industrial users and bulk electricity suppliers.

They are also a proven technology, having long been used in the aerospace and defence industries, and more recently for backup supplies in remote locations, as an alternative to diesel generators.

However, FCDG technology faces a number of barriers to its introduction. These include:

- High technology costs and low availability
- Policy and structural barriers in energy markets
- Lack of infrastructure, both for fuel supply and support
- Environmental externalities are not costed
- CO_2 sequestration is unproven on a wide scale
- Renewable energy technologies for hybrid systems are also expensive

GEF must address all of these in its strategy development.

7.11.1 Addressing the right opportunities

To assess the opportunities that may arise for FCDG projects in developing countries it will be important to establish a set of criteria by which each project may be judged. These will include not only the potential GHG benefits of the project and of possible future FCDG commercialisation in the area, but also criteria evaluating the likelihood of project success. These will include:

- Expected level of emissions reduction of immediate project, relative to the most likely alternative
- Possible level of emissions reduction of subsequent project stages or expansion
- Potential for move towards renewably-produced hydrogen
- Cost of project and availability of leverage from other funding sources
- Policy framework in local region and local level of enthusiasm
- Quality and dependability of fuel cell supplier or consortium
- Existence of local ‘champion’ and support infrastructure
- Synergies with other projects – e.g. fuel cell buses
- Size of potential market

The individual projects should fit within a suitable strategic framework, to ensure that maximum benefit is derived from the use of GEF finances. A small number of targeted high-profile projects, properly managed, will provide much greater benefit than a wider range of small but unfocused developments. Ideally, sufficient regional spread should be introduced to enable markets in all of the major geographies to be encouraged.

A preliminary strategy is suggested, in brief, below:

1. Preparation of initial projects should be carried out as soon as possible. Although the technology and project organisation will take time, preparation of the specific areas in which markets may be viable can be done immediately.
2. Preparation of these possible market areas should be the first phase of any project. Developing local policy support, education and training programmes, and facilitating local buy-in will be essential to a successful demonstration.
3. Development of a pilot programme of ~$2-3 million of GEF resources in each of three countries would permit, depending on costs and the extent of co-finance, 500-1000kW of small scale projects in each country. This might represent one hundred fuel cells in the range 1-5kW, plus ten to twenty larger fuel cells for commercial uses and embedded generation in the 10s and 100s of kW range. This would provide much needed operational experience in a diverse range of situations.
4. A defined fraction of the above resources would be needed in addition, to go to technical assistance, local training and the analysis of local policies that would support DG in the context of the reform of the electric power sector.

5. A programme should be started to monitor the operational performance of the projects from a technical and economic perspective. Feedback from the programme should be incorporated into development of the wider strategy for further GEF intervention.

Development and implementation of these projects is likely to take three years, by which time significant further operating experience will have been gained in the OECD countries, and cost structures and emissions profiles will be known with much greater certainty.

Since GEF resources for subsidies are limited, the subsidy program itself may begin only after FC industry efforts in the OECD market have enabled fuel cell system prices to drop to approximately $2000/kW range, so that the GEF subsidy is in the range of 25-50% of capital costs or approximately $1000 per kW. Capital subsidies can be designed to be phased out as FC project economics improve and as commercial practice is established.

Direct assistance programs are needed for market preparation and capacity building. The ability of the FC industry to meet the price targets indicated above will affect the timing of the GEF capital subsidy intervention and is expected beginning in the 2003-2005 timeframe. Prior to that, technical assistance activities can begin immediately to organise and prepare the FC markets and build delivery capacities. A direct assistance program will help ensure that markets are ready for the follow-on program elements of capital subsidies, near-commercial co-finance and strategic programs, which may include:

(i) activities to address policy and utility barriers, standards, permitting & siting, and end-user awareness;

(ii) capacity building and training of market actors in all phases of the project cycle including application engineering, installation, operations and maintenance and servicing; and

(iii) project identification and economic feasibility analysis of specific applications and markets, including cost/benefit analysis for utilities. Direct assistance in the early stages of the program may include demonstration projects that involve greater levels of capital subsidies, justified for their demonstration value.

7.11.2 Transportation Strategy

Since the formulation of the Operational Strategy in 1995, GEF has offered support for fuel-cell buses (FCBs), initially under Operational Programme 7, Reducing Long-Term Costs of Low GHG-emitting Energy Technologies; and more recently, under Operation Programme 11, Sustainable Transport. The GEF's interest in FCBs is justified on the dramatic reductions in system-wide air pollution and GHG emissions that FCBs offer over conventional diesel buses. Furthermore, the current GEF strategy is consistent with the H_2 FCV strategy discussed above.

Once fully commercialised, H_2 FCVs can play an important role in the stabilisation of GHGs by the year 2100, as intended in IPCC scenarios. The potential cumulative CO_2 reduction through 2100 for all H_2 fuel cell systems is calculated from the SRES scenario outputs to be 85 Gt C in the A1B scenario and 270 Gt C in the A1T scenario assuming that all the hydrogen is produced from renewables, nuclear or fossil fuels with CO_2 sequestration. These values represent a 5% and a 25% reduction of cumulative emissions for the A1B and A1T scenarios, respectively. The emission reduction for H_2 FCVs would be a significant portion of this total, and the GEF programmatic support of FCBs in developing countries can be a significant contributor to the achievement of the total long-term GHG emission reduction.

Given the technology transfer barriers discussed in the TAR, GEF support to FCBs will likely require a phased approach consisting of preparatory activities, demonstration projects, and commercialisation efforts. GEF support for demonstration activities in Brazil, Egypt, Mexico, India, and China should proceed and the results evaluated. In the meantime, preparatory activities should be commenced in additional countries so that additional demonstration activities can be started as needed to support meeting the cumulative H_2 FCV targets discussed above.

GEF activities will complement the significant public and private sector FCV commercialisation efforts currently underway. Practically all the major car companies (Ford, General Motors, Daimler-

Chrysler, BMW, Volkswagen, Fiat, Honda, Toyota, Nissan, Mitsubishi, Mazda, Hyundai and others) are working on FCVs. In addition, a variety of FCB demonstration projects have been funded or are under development in industrialised countries, including the California FC initiative, demonstrations in over 10 Europe cities by Daimler-Chrysler, MAN and others, and a proposed demonstration in Australia. GEF does not support cars, but this market will dominate cost reduction of the technology and is important for developing a sustainable pool of technical capacity.

By supporting deployment of FCBs in GEF programme countries, GEF is fulfilling its role as an important agent of technology transfer in support of the UNFCCC. By encouraging the early adoption of these buses in a process of "technological leapfrogging", GEF is helping developing countries gain experience with the FCB early in its product cycle. GEF programme countries can then develop partnerships with technology developers, thereby increasing technological competence and adapting the technology to local needs. GEF Programme countries will also benefit from reduced local air pollution, new export opportunities attributable to local manufacturing, and improved quality of public transit service. Finally, because FCBs are hydrogen fuelled, the GEF can also assist developing countries in preparing for a future transition to newer, cleaner and more efficient fuel-supply systems.

7.11.3 Distributed Energy Sector

In the IPCC SRES A1B and A1T scenario, hydrogen fuel cells provide very significant amounts of energy services in the energy sector for commercial and residential applications by 2100. In the A1B scenario, NG fuel cells seem to play a transition technology role (equal outputs for H_2 and NG fuel cells in 2050, with no NG fuel cells in 2100). However, in the A1T scenario NG fuel cells do not appear to play this transition role (or the transition occurs much sooner than 2050). Given the GEF mission relative to climate change, a long-term strategy should seek to minimize the cumulative atmospheric build-up of GHGs. In this vein, the following outlines a possible strategy for distributed energy applications that is consistent with that goal and also provides potentially beneficial interactions with the strategy in the transport sector.

The strategy is based on the premise that in many developing countries, the commercial and urban residential sectors use high carbon fuels with low end-use efficiency and high levels of air pollution. A variety of fuel cell technologies could provide air pollution and GHG reduction benefits through switching to lower-carbon fuels and through higher end-use efficiency. However, fuel cells using carbon-based fuels directly do not seem to provide a pathway to long-term GHG emission reductions beyond their efficiency improvement benefits. The use of H_2 from a variety of sources would offer significantly greater potential for GHG reductions because the H_2 can eventually be produced from renewable energy or fossil fuels with CO_2 sequestration.

Distributed H_2 fuel cell systems might have higher value if they co-produced hydrogen for H_2 FCVs in addition to electricity and heat for commercial and residential applications. This added capability in the distributed H_2 fuel cell system could create interesting (and potentially beneficial) synergies between these two fuel cell markets, but should not be overplayed.

Distributed H_2 fuel cell systems for large commercial and urban residential buildings could be an attractive market around which to build a long-term GEF fuel cell strategy. The systems could both provide the efficiency, fuel switching and air pollution benefits discussed earlier in this section and provide a distributed source of H_2 to expand the fleet vehicle options that are at the core of the H_2 FCV strategy discussed in the previous section. These distributed H_2 sources could also provide the basis for development of a H_2 distribution network involving interconnection of the distributed sources into small H_2 grids initially. Once demand has increased sufficiently, these small distribution grids could be connected into a larger network with the addition of a centralised H_2 supply system that could incorporate H_2 production using renewable energy or fossil fuels with CO_2 sequestration. Because of more favourable economics in large-scale production facilities, the smaller distributed hydrogen production systems would eventually be phased out.

By helping to create a pathway to CO_2-free H_2 production and use, this strategy could lead to significantly greater GHG emission reductions compared to a more generalised strategy that only captures the efficiency benefits of fuel cells. OP 7 and 11 GEF interventions should include a path to attainment of maximum GHG benefits. Since GEF resources are a minor contributor to overall costs, selection of more promising opportunities is warranted. Efficiency gains are important, but pathways enabling these are likely to become viable earlier than renewable hydrogen pathways, and so GEF resources can justifiably be shifted to barrier removal activities.

7.12 Intervention options for multilateral agencies

Inherent in a successful programme design for the GEF is a three-fold strategy supporting the fuel cells industry to:

(i) set the framework, in policy and market support terms, to enable support of fuel cell technology in GEF-eligible markets,

(ii) achieve manufacturing scale economies for fuel cells and balance of plant needed to hit a competitive price target, and

(iii) develop commercial delivery systems for getting fuel cell projects adopted, installed, financed, operated efficiently and maintained properly.

These strategies go hand-in-hand. Financing, including capital cost buydowns, is necessary but alone not sufficient. Any market launch must be coupled with sales capacity. The programme must consider the full project cycle and value chain and support development of commercial capacities to deliver and finance fuel cell systems. Each programme must have a marketer, the party who is motivated to make contact and sales with the customers, and capable of developing and preparing projects for investment in a creditworthy, bankable structure. The pathway to full commercialisation – how subsidies will be phased out, how commercial capacities will be built – must be envisioned and aided as part of the programme design.

Because fuel cells are currently uneconomic, some form of subsidy is likely needed to make them economic to the customer; capital cost buydown is the most likely and direct, but not the only, method for delivering a subsidy. The subsidy must be delivered in a way that directly reduces the end-customers' fuel cell system cost and delivered cost per kWh. Capital cost subsidies by themselves are not sufficient and must be coupled with development of commercial delivery and financing capacities. Capital cost buydowns deal with the distinct barrier of as yet uneconomic equipment.

The capital cost subsidy is designed to bridge the gap between (a) the manufacturers' cost and sales price, given current technology and the manufacturing volumes which will be stimulated by the programme, and (b) the end-user's target price point which makes the system economically attractive. Given the dynamic industry developments underway, it is recommended that the industry achieve a price point in the $2000/kw range as a pre-condition of the programme start. This will reduce the cost gap to a level that can justify multi-lateral lending agencies' funding, and keep the required subsidy in the range of 25-40% of capital costs.

The subsidy should be delivered in a way that makes the project economics attractive for the end-user. Subsidies can be delivered so as to influence other key variables of the customer's project economics. Other methods may include: fuel supply support & cost buydowns, increased utility buyback rates and improved terms of commercial financing

A primary programme strategy is to organise and provide financial support to bulk purchases of fuel cells as a means to procure lower unit prices. Because of the need and potential to lower prices through increasing manufacturing and sales volumes, market aggregation strategies are likely to be a part of the programme.

The multi-lateral lending agencies' selection criteria could include: on commercial arrangements, exerting maximum leverage from multi-lateral lending agencies' monies; multi-lateral lending agencies' expenditure or support for kW of installed systems; or multi-lateral lending agencies' expenditure per ton carbon emissions reduction achieved.

Financing, including a capital cost buy-down component, is necessary but not sufficient on its own and must be coupled with programmes that build sales and project delivery capacities. A programme delivering subsidies should consider: (i) capital subsidies, or other forms of targeted subsidies, reflecting the fact that fuel cells will not be economic; and (ii) concessional co-financing, which uses commercial methods and is tied to building commercial capacity as it can be instrumental in mobilising market actors and commercial capital. Use of GEF funds for non-grant financing could be structured to share foreign exchange risk, reduce the cost of borrowing, extend the term of available loans, and share commercial and end-user risk. Because GEF resources are limited, its funding should be leveraged by providing it through energy service delivery companies and financial intermediaries either at the individual project level or as lines of credit at a corporate level for use in a portfolio of fuel cell projects.

Direct grants to manufacturers of fuel cells are unlikely given the financial strength of manufacturers and the general orientation of the proposed multi-lateral lending agencies' programme towards a market-pull strategy to engage manufacturers; to supporting applications of the technology; and to building commercial capacities to deliver installed projects. Capital cost buydowns can be used but will be delivered through the purchase of fuel cells from the manufacturers.

Multi-lateral lending agencies' monies can be used (a) as loans to FIs for on-lending to end-users and fuel cell ESCOs for project costs, or (b) as loans direct to ESCOs. The multi-lateral lending agencies' monies would be combined with other FI resources and/or other ESCO resources. The percentage share of co-financing provided by the multi-lateral lending agencies' monies would typically be in the range of 30-40% of total investment amount. This relatively low leverage ratio makes debt co-financing less attractive generally than other forms of co-financing.

Multi-lateral lending agencies' monies can be used like a revolving loan fund. Reflows can be deployed for further loans within the lifetime of the programme, which may be considered as:

(i) the availability period during which new loans can be originated, and

(ii) the total loan term, which would continue until the last loan had matured or been retired.

Guarantees support FI lending by sharing in the credit risk of FC project financings and ESCO debt facilities, which the FIs provide with their own resources. They are appropriate to use when financial resources are available in the market, but need an incentive to be deployed, and can help bridge gaps between perceived credit risks in developing markets – as reflected in credit underwriting practices – and actual credit risks.

Several types of guarantee instruments exist, including subordinated recovery guarantees and loss reserves. These allow the multi-lateral lending agencies' monies to be used as reserves against guarantee liabilities.

It is considered good practice to make partial guarantees (<100%), to assure that the FI remains at risk for at least a portion of its lending, as a means to assure sound credit practices. Further, the FI typically retains responsible for exercising remedies and taking collection actions in events of default, as the FI is typically better equipped to do so.

Concessional co-financing using near commercial methods can be instrumental in mobilising market actors and commercial capital. Options for using GEF funds as such will include equity investments for fuel cell-based energy service delivery companies, businesses and projects; senior and subordinated debt provided as co-financing for a project, and – more and more in later years – guarantees for sharing commercial and end-user risk. Such use is likely to leverage GEF funding better and mobilise commercial financing.

Multi-lateral lending agencies' funds can also be used to create loss reserves. These would be applied to cover an FI's losses on a portfolio of FC loans made with its own resources. The loss reserve would typically be established as a percentage of the overall portfolio value, typically 5-20%.

Technical assistance programmes are also recommended for consideration, to assist in organising the market, engaging various parties to participate, in training and education, economic analysis, and preparation of projects for investment.

8 CONCLUSIONS AND RECOMMENDATIONS

A strategic programmatic framework has been developed to focus and govern the GEF support in the area of FCBs and FCDG, by anticipating and managing the risks involved. This section lays out the goals and stages for the proposed GEF programmatic framework for the development of FCBs and FCDG in developing countries.

It is anticipated that the GEF programmatic intervention will extend beyond a single project or set of projects, and will encompass several stages of support: (I) Preparatory Phase; (II) Demonstration Phase, and (III) Commercialisation Phase. The GEF should monitor progress carefully and may decide to increase or decrease its participation in the programme, depending upon changing circumstances and conditions.

8.1 Programmatic Framework for GEF Intervention for FC projects

The development objective for support of FCBs and FCDG is the reduction of long-term GHG emissions from the transport and stationary power sectors of GEF programme countries by providing support to the commercialisation of FC systems. The programmatic objectives would not be reached within a single project timeframe. Rather, they will take a longer period of between ten and twenty years. Additionally, GEF support is directed specifically to the process of commercialisation of FCBs and FCDG. By supporting the process of commercialisation of this technology, it is expected that the costs will decline, and a much larger portion of the world's markets will be able to afford to purchase and use fuel cells. Finally, a precondition is that the GEF is interested in supporting meaningful participation in the process of commercialisation of fuel cells by GEF programme countries. While much effort toward commercialisation can be expected to take place in Annex II countries, all countries are expected to benefit. Information sharing, both among developing country initiatives, and between Annex II and GEF programme countries, becomes an important part of the programme.

The programme can then be broken down into three stages, each with its own set of objectives, indicators, assumptions and input requirements. The first stage, or Preparatory Phase, focuses on the evaluation of whether the conditions for a successful programme exist in a proposed context. The second stage, or Demonstration Phase, establishes that fuel cells can operate successfully in a developing country context. The third stage, or Commercialisation Phase, involves increasing demand for fuel cells sufficiently to enable the cost to fall to where they are fully competitive with conventional technologies in GEF programme countries. Each of these objectives defines a stage. GEF has important roles to play in all of these stages, and they are discussed in greater detail below.

A number of outcomes from the GEF programmatic intervention can be identified. First, a vibrant, growing market for fuel cell systems in GEF programme countries can be expected to emerge, and much of that demand will be satisfied from production in these countries (generally non-stack production). Second, while the cost of fuel cells is expected to fall, their performance is expected to rise, reducing their overall lifecycle costs in comparison with conventional technologies. Third, hydrogen will become available on commercial terms in a variety of countries. Finally, if the programme is successful, the growth rate in sectoral emissions from participating developing countries will begin to decline.

The total quantity of GEF resources necessary to achieve these outputs cannot be clearly specified *a priori*. It will depend upon the progress made in the commercialisation of the technology, the investment that flows into its production, and the decisions about continued relevance and support. It will be essential for the GEF Implementing Agencies, Secretariat, and Council to keep abreast of progress in this field. An alternative approach to financing allocation is described below.

To monitor progress and make careful decisions about continued GEF support, indicators from different sources will have to be followed. Industry demand data, project reports and research, and industrial statistics from the automotive, stationary power and fuel cell industries should be monitored to yield information on demand, costs, prices and fuel availability. Progress toward commercialisation in developing countries will be the primary determinant of continued GEF involvement in this programmatic effort.

8.1.1 Stage I: Preparatory Phase

The preparatory phase is intended to evaluate the conditions for successful FCB operation and commercialisation in key developing countries. It focuses on establishing whether local markets are strong enough to justify GEF support for fuel cell development. Seeking to verify strong local/national political and financial support; robust market conditions; availability of appropriate fuel supplies; sufficient technical capacity; and the existence of significant GHG benefits; this stage involves feasibility studies and information gathering to prepare a plan and proposal for further GEF support for commercialisation of FCBs or FCDG. The outcomes of this phase include: a feasibility study and proposal that documents that all of the conditions for successful implementation of fuel cell demonstration exist. These conditions extend to verification of strong local support; an assessment of the local market; an assessment of fuel supplies; an evaluation showing that local industry is capable of handling the technology (including maintenance, efficiency and safety aspects); potential for national/regional production of related components; and, an assessment of system-wide GHG benefits in both the demonstration and commercialisation stages.

Even at Stage I of the process, certain assumptions and risks regarding external conditions influencing the operation should be highlighted. One of these is technical in nature, dealing with design elements of the fuel cell system, and the other two are more methodological in character, dealing with assumptions underlying the assessment. For the methodological assumptions, they basically run to the validity of the assessments being undertaken—can the strength of local support and the capabilities and plausibility of proposed projects be accurately gauged? These are critical assumptions to this stage and are especially important in the context of the decision to move from the Preparatory Phase to the Demonstration Phase. Although more is said about controlling for these factors below, in the discussion of the criteria to be used for Stage II project approval, initial indicators can be taken as proposal quality and significant local financial support from national and local sources.

8.1.2 Stage II: Demonstration Phase

Criteria for Evaluating Stage II Projects for Work Programme Entry – In similar fashion to the preliminary assessment of fuel cell projects, it has been suggested that five criteria be utilised in evaluating the demonstration phase proposals. Only if the proposals meet these criteria should the demonstration proposals be submitted to GEF Council for Work Programme inclusion. These criteria are presented and discussed below.

1) ***Climate Change Impact:*** As the primary objective of GEF activities is to reduce GHG emissions, all projects must demonstrate a favourable GHG balance on a system-wide basis. The entire system should demonstrate GHG benefits, or the potential for GHG benefits to be developed in the long term – coupled with a strong strategic vision of how this may be accomplished.
2) ***Replication Potential:*** Proposals should include preliminary “action plans” for follow-up deployment of fuel cells, and should present clearly how multilateral and GEF concessional funding will influence follow-on private sector investments.
3) ***Cost Sharing:*** Effective cost-sharing is important as an indication of support or commitment on behalf of all parties. Without this support, the project will be unlikely to succeed, both at the demonstration phase and at the subsequent commercialisation phase.

4) ***Clarity of Indicators to be Used to Measure Success:*** Another important criterion will be the clarity of indicators proposed for measuring the success and failure of the project. These will be monitored throughout implementation and will provide the key as to whether the initiative merits further support.

5) ***Geographic Diversity:*** The GEF programmatic intervention will target only the major markets of the world. It will seek to avoid duplication in choosing countries, so each proposal will have to demonstrate that not only does it target a significant market, but that it is the centre of a regional or sub-regional manufacturing industry.

Phasing of the projects during Stage II may help keep the fuel cell initiatives in transport and power generation from dominating GEF support for the transport sector under OP11. During Stage III, phasing will become increasingly important, as this stage will involve a greater number of systems, more funding, and increased public attention.

Nature of Stage II Demonstration Phase - The Demonstration Phase is intended to provide significant operational experience with fuel cell systems, in order for the decision-makers in the targeted developing country markets to make an informed decision about the viability of and interest in future expanded deployment of fuel cells. The objective for this stage is to demonstrate the operational viability of fuel cell systems in major developing country markets. Immediate outcomes of the demonstration phase focus on gaining significant real-life experience of operating fuel cells in developing countries; providing feedback to manufacturers to improve FC system specifications based upon that experience; evaluating the selected fuel supply facilities under operational conditions; establishing the minimum requirements for fuel quality; providing training; sharing of lessons between projects worldwide; increasing awareness and support for commercialisation; and evaluating and revising of plans for Stage III commercialisation activities. Stage II is critical to the future commercialisation of the technology in developing countries. It will provide the basis for any decisions to be made by local stakeholders on the future wide-scale deployment of the technology. It will also provide the GEF with an indication as to whether future support for the technology is justified.

The outcomes of the demonstration phase are the results of the individual demonstration projects. The most important of these is the gaining of significant experience of fuel cell systems operating under real-world conditions service. This experience is the basis for feedback to be provided to FC producers. Other outcomes are the establishment of a fuel supply system that is both reliable and cost-effective. In each demonstration country, an outcome will also be a significant cadre of operators, maintenance staff, and technicians who will be trained, and a large shared knowledge of fuel cell system operation and commercialisation that will be developed. If the operations are successful, increased local awareness and support for fuel cell commercialisation would be another outcome that would be linked to strengthened plans for Stage III of the commercialisation process. The final outcome of this Stage would be the sharing of experiences and lessons-learned between the various projects.

While interest, assumptions, and resource requirements are expected to be sufficient to justify GEF support to FCB and FCDG commercialisation at least through a demonstration phase (Stage II), support for a Commercialisation Phase (Stage III) will require careful consideration. However, the incremental costs at Stage III will be proportionally lower than Stage II, and the industry interest and participation in the programme must be higher as well. Nevertheless, any discussion of a possible Stage III strategy can only be tentative at this time.

8.1.3 Stage III: Commercialisation Phase

The purpose of the commercialisation phase of the proposed GEF Programmatic Initiative for FCBs and FCDG is to finish the process of “buy-down” or the paying of the incremental developmental costs of the technology in order to ensure that the technology matures to become commercially competitive at the global level. Formally stated, the objective of Stage III is to increase the demand for and production of FCBs and FCDG components in developing countries to a point where they become cost-competitive, on a life-cycle basis, with conventional technologies – perhaps with GHG benefits taken into consideration. This can only be achieved if there is support from other public-sector and multilateral agencies and if there is coordination with developed country activities. It is only through the pursuit of this final stage that GEF support can achieve the overall programmatic objective.

Although both demonstration Stage II and commercialisation Stage III can be viewed as part of the "buy-down" period, their focus is inherently different. In Stage II, the technology is still expensive and still undergoing technological progress. In addition to gaining experience working with the technology and taking the initial, expensive steps down the technology learning curve, Stage II is intended to provide information to decision-makers about whether the technology merits a more ambitious role in the country's future plans. If Stage III is reached, it signifies that sufficient progress has been made in the technological performance of the fuel cell systems to enable decision-makers to undertake a more serious commitment to the technology. However, the lifecycle costs of the technology will still be higher than that of conventional technologies. Some form of concessional financing will likely still be required.

The first objective of the Commercialisation Phase is to increase the demand for, and production of, a significant number of fuel cell systems – buses or stationary power generators – for use in developing countries to the point where they are considered cost-competitive with conventional technologies. The output will be the fuel cell systems in operation.

The second outcome of this Phase is that much of the fuel cell equipment used in developing countries will also be produced there.

The third outcome is that the country teams are able to operate the systems with sufficient efficiency to enable the fuel cells to operate satisfactorily, and to reduce greenhouse gas emissions.

The commercialisation phase will focus on reducing the growth rate of GHG emissions from the urban transport and stationary power sectors in participating developing countries. However, even a large number of fuel cell systems deployed will likely influence only the growth rate of sectoral emissions initially. Reducing the actual overall emissions of this sector will require more time and continued expansion of fuel cell systems beyond the initial target countries.

The objectives of the commercialisation phase correspond with the final goals of the GEF strategic programme. It is the objective of this GEF intervention that the cost of fuel cell systems falls to a level whereby the new technology can be affordable and can therefore begin earning market share from the conventional alternative. Ideally, hydrogen begins to be successfully (and economically) utilised as a fuel for these applications. The growth of GHG emissions begins to abate. However, this phase would appear to be several years into the future. Much can happen in the intervening time period. Therefore, it is important that GEF maintain a watching brief and be actively involved in continually re-evaluating its participation in this strategic intervention.

An approach to financing allocation under constrained GEF finance could be to identify an amount for FCB cost buydown of perhaps US$100M over ten years, and then to set a target for GHG benefit cost at, for example, 100 $/tonne of carbon dioxide equivalent from direct impacts of the project and attributable outcomes over a period of ten years. A 50% subsidy could be set. Project proponents would initially compete with proposals to meet this target, but the target could be relaxed in accordance with additional criteria used to ensure regional balance, renewable energy technology integration, and technology provider competitiveness. This is elaborated further in the next section.

8.2 Distributed generation

The great merit of modular technologies is that they can be tested and demonstrated on a small scale. Fuel cell technology for distributed power generation has already reached the point where a

demonstration programme can begin in developing countries; something that is ongoing in OECD countries. In the course of this study, the market actors confirmed that there would be minimal developing country penetration in the near to medium term without significant GEF intervention.

Ideally, the GEF should now consider a three-phase programme of financial support to significantly contribute to future greenhouse gas reductions, through encouraging market penetration of fuel cells in emerging markets. The proposed Project Concept would require ~$165M of GEF support, and consists of three phases, the first of which would start in 2002-2004. The start date will depend upon a number of variables.

8.2.1 Phase I stage I

Phase I would span the period 2002-2006 and have two stages.

The **first stage** would have up to three commercial demonstration projects of stationary fuel cell technologies. Each commercial demonstrator is expected to require no more than $3M of GEF funds, for up to 50% of the project costs, to be used for capital cost buy downs and to mitigate risks.

These projects will be used to provide operational experience and to demonstrate project transactions using fuel cells in developing countries. They are intended to inform the design of a larger financing initiative to follow. The demonstrators should include representation from the fuel cell industry, local utilities and local operators and system integrators, to ensure that some technological and intellectual transfer takes place. This will include learning-by-doing, the integration of commercial, technical and any specific local considerations into the deal structure, the development of best practice, and the demonstration of benefits for all stakeholders. In partnership with this backing, additional funds of ~$5M would enable specific World Bank/UNDP initiatives to undertake support and market conditioning activities.

The potential for greater penetration of FCDG into developing country markets, and enhanced infrastructure development should enable the mobilisation of a **second stage** in Phase I deploying ~$50M in GEF funds in 2004-2006. These second stage funds would focus on financing close-to-commercial projects. The structure of this phase would be developed using the knowledge gained from the stage I demonstrations, specifically to drive meaningful regional market penetration, and including both cost reductions and performance enhancements in comparison with stage I. It is anticipated that GEF funding in the order of $1000/kW would be required in the second stage of Phase I to finance 33%-50% of the project costs, though this would depend upon variables such as technology type, unit capacity, fuel availability and location. Therefore, a minimum of 50 MW of fuel cells would be deployed in this stage.

Phase I could involve 3-5 major fuel cell suppliers, competitively selected for the opportunity to participate. The industry would be expected to create partnerships between manufacturers and energy service providers/project developers; identify the key market barriers; assume some technical risk through warranty and performance guarantees; and share in the commercial risk. The role of IFC and other implementing and executing agencies would be to assist with project preparation (especially on the commercial and deal structuring aspects, including leveraging of GEF funds), to obtain and provide concessional GEF financing, facilitate host country government support, and provide commercial funding on their own account where possible. GEF-funded activities for stationary fuel cell applications designed and implemented by the IFC would incorporate related experience in renewable energy and energy efficiency programs being implemented by IFC currently. The projects will also coordinate, as relevant, with any policy interventions taken by the World Bank and support infrastructure development (primarily training of the service workforce) undertaken by the World Bank and/or UNDP.

Phase II would be a second $50M GEF support package, requested in 2005-2006 to support ~100MW of new fuel cell installations over the period 2006-2010. In this phase, based on continued expectations of cost reduction within the fuel cell industry, up to $500/kW of subsidy would be provided, ensuring that more fuel cell capacity was installed for a similar level of GEF support. The programme itself would benefit from the experiences of Phase I, and should be more geo-politically diverse. Ideally, a specific monitoring system would also be implemented during this phase to gather information on system performance and ensure that technical and economic expectations can be met.

Phase III would be contingent on success in Phases I and II, and would consist of a further $50M in GEF support. This would be requested in 2009-2010, to subsidise up to 200MW of fuel cell installations in the period 2010-2013. The subsidy would be further reduced to $250/kW.

Two considerations are important in all Phases. Local education, awareness-raising, and policy support will be essential for all stages of technology introduction, but especially early on. Activities in this area should be initiated well in advance of technology introduction. In addition, it may be possible to identify synergies between different projects, e.g. using fuel supply infrastructure for both buses and stationary applications. If this is the case they should be identified and valued, but not overplayed. Regional balance and widespread participation within potential markets should be maintained.

In addition, a number of criteria are suggested to enable continuing focus on the longer-term greenhouse gas reduction objectives of the programme:

- Project merit may be partially assessed based on an estimated cost of CO_2 reduction. Low efficiency fuel cells using fuels such as diesel and coal gas should not be considered even if the impacts of the likely alternative are greater.
- Renewable energy technology could be given additional credit in view of synergies with other OP7 technologies
- Ideally, a mix of technologies, fuels and regions would provide balance to each tranche of funding

The programme described above could also be enhanced by the integration of the regional development banks, with the potential for the deployment of $200-250M (GEF and cofiance) through this route.

Table 24 summarises the proposed GEF funding support for stationary fuel cell applications as well as transport. The ten year programme for stationary applications alone would cost approximately $170M, and would deploy over 350 MW of fuel cells over a declining incremental cost of global benefit. Fuel cells demonstrate enhanced fuel efficiency, reduced GHG emissions and negligible pollutant emissions in comparison with competing technologies. GEF support is expected to enable developing country markets for fuel cells 7-10 years earlier than would be the case without intervention. This could forestall the installation of significant numbers of environmentally inferior alternatives that would otherwise have a 2-30 year lifetime.

GEF Programmatic Framework for Fuel Cells under OP 7, 11, 5, 6

Intervention/ Stage	Agencies	Application	Region or Country	Anticipated project timing	Nominal Range of GEF finance M$	Mitigation Cost Target
Strategy development	UNEP	FCB and Stationary power		2001	1	
FCB demo	UNDP	FCB /Electrolysis/hydro	Brazil	2001	12	
		FCB/ NG	Egypt	2001	12	
		FCB/ NG reforming	Mexico	2001	12	
		FCB	China	2001	12	
		FCB	India	2001	12	
FC power demos	UNEP	remote RET electrolysis		2003	1-3	150
	EBRD	cogen SOFC/ NG	Eastern Europe	2002	2-5	120
	IFC,other DBs	?/RET or NG	Asia, Latin America	2003	4-8	120
	UNDP	landfill	Jordan / Central Asia	2002	1-4	120
FC Power subsidy 1	IFC	dist power	Philippines, Bangladesh, Trinidad/Tobago	2003	22-45	100
	RDBs	cogen	2 country projects	2003	7-15	100
FCV demo	UNEP	2-3 wheelers	China	2003	1-3	
FC Power subsidy 2	IFC	any	6 country projects	2006	25-50	60
	RDBs	any	4 country projects	2006	10-20	60
FCB subsidy 1	WB		3 countries from demos	2005	30-60	75

	RDBs		1 country	2005	10-25	75
FC Power subsidy 3	IFC		20 country projects	2010	15-30	25
	RDBs		8 country projects	2010	7-15	25
FCB subsidy 2	WB		3 more countries/projects	2010	30-70	25
	RDBs		1 country	2010	15-30	25
FC Power Barrier removal	all		remainder as regional projects	2007	10-20	10
CO2 sequestration study	UNEP	coal gas/ FC	South Africa, India, China	2005	2-5	
Total					200-500 M$	

Table 24: Nominal funding possibilities for FCDG through GEF, 2001-2015

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