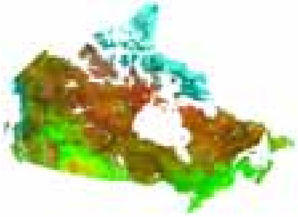
Natural Resources Canada | Ressources naturelles Canada



TRANSFORMING THE FUTURE:
MOVING TOWARD FUEL CELL-POWERED FLEETS IN CANADIAN URBAN TRANSIT SYSTEMS

STUDY SUMMARY
JANUARY 2005

BC Transit | MARCON-DDM | Canada

ACKNOWLEDGEMENTS

This study was commissioned and funded by the Government of Canada through the Canadian Transportation Fuel Cell Alliance, a program administered by Natural Resources Canada. Contract management was provided by BC Transit. The study was conducted by MARCON-DDM HIT of Montreal, Canada.

This study would not have been possible without the extraordinary cooperation of Canadian urban transit system management teams, as well as the expert contribution of numerous technology providers, academics, bus manufacturers, demonstration site managers and industry experts.

Thank you to all participants for your time and support.

Note: The detailed report can be accessed at:
http://www.nrcan.gc.ca/es/etb/ctfca/Publications_e.html.

M38-24/1-2005
0-662-68749-3

THE FUTURE

The world is on the verge of a dramatic change in the energy economy toward hydrogen. At the centre of this transformation is the hydrogen fuel cell, the most efficient way to turn a variety of fuels into useable power with greatly reduced emissions.

In Canada, our urban transit systems could lead the way in creating the future with transit fleets that produce no smog and emit no greenhouse gases.

Hydrogen Fuel Cell-Powered Transit Buses:

- *No smog-creating emissions*
- *No greenhouse gas emissions*
- *Quieter than conventional buses*
- *Can be twice as efficient as internal combustion engines*
- *Cheaper to maintain and operate than internal combustion engine vehicles*
- *Multiple fuel feedstocks, including renewables*

TABLE OF CONTENTS

BACKGROUND

In the year 2000, Canada, as part of a world community concerned about the environmental, social and economic consequences of increasing greenhouse gas emissions, announced its Action Plan 2000 on Climate Change.

As part of the plan, the Government of Canada committed to work with industry and other levels of government to develop and demonstrate hydrogen-based technologies that would enable Canada to reduce greenhouse gas emissions while enhancing its innovative economy. A major part of this initiative is a focus on hydrogen applications in transportation.

In June 2001, Ottawa announced the creation of the Canadian Transportation Fuel Cell Alliance (CTFCA), a program to support the demonstration and evaluation of different processes for the production and delivery of hydrogen to fuel cell vehicles.

Urban transit systems, currently operating bus fleets powered almost exclusively by diesel, are a natural early adopter of hydrogen fuel cell technology that can reduce greenhouse gas emissions and urban air pollutants to zero.

Canadian urban transit systems are an ideal sector to engage because:

- There are over 2.42 billion riders per year;
- The number of vehicles – approximately 12,000 across Canada – is a sizeable market;
- UTSs consume over 360 million litres of diesel and 17 million cubic meters of natural gas per year;
- The transit application is visible to a public sympathetic to improving air quality;
- Transit properties have a centralized infrastructure that can be adapted to hydrogen; and
- Urban transit applications have global market relevance.

The societal benefits of hydrogen fuel cell-powered transit buses include:

- The health-related impacts of deploying zero-emission transport in inner city and other urban neighbourhoods;
- Significant reductions in noise pollution levels by replacing internal combustion engines with electric drive systems;
- Reduction of greenhouse gas emissions to zero; and
- The potential use of renewable sources of energy, e.g., solar, wind, geothermal and hydropower, to produce hydrogen fuel.

In 2003,The CTFCA decided to study the issues that face Canada's urban transit systems in making the transition from the diesel-powered fleets of today to the hydrogen fuel cell-powered fleets of the future.

The need for this study was identified through the CTFCA's Heavy Duty Vehicle Demonstration Working Group, comprised of representatives from transit operations, bus manufacturers, equipment and technology providers, fuel suppliers and governments.

The group noted that, in addition to providing information to urban transit systems, the study would provide a knowledge base for industry to assist them in targeting business opportunities with regard to hydrogen fuel cell-powered transit systems.

In short, Canada's urban transit systems represent:

- An attractive market for the emerging fuel cell industry as it commercializes product;
- An opportunity for governments to meet a significant portion of their green house gas reduction commitments; and
- An opportunity for Canada to be a world leader in the transition to fuel cell-powered transportation.

METHODOLOGY

The findings presented in this report were derived from information gathered through visits to 16 urban transit systems across the country, including environmentally sensitive sites. As well, personal and telephone interviews were conducted with:

- bus manufacturers;
- hydrogen technology suppliers;
- technical training institutions;
- hydrogen industry experts;
- codes and standards developers;
- government agencies both in Canada and abroad; and
- fuel cell bus demonstration projects.

The findings were supplemented with secondary data obtained from a variety of sources, including industry associations, government agencies and industry analysts.

For the detailed methodology, see Appendix 1 of the detailed report, which can be accessed at: **http://www.nrcan.gc.ca/es/etb/ctfca/Publications_e.html**.

OBJECTIVES OF STUDY

This study was conducted to determine the challenges and the way forward for Canadian urban transit systems to make the transition to fuel cell-powered bus[1] fleets.

Specifically, it examines the following areas:

- The development of transit bus fuel cell technology in Canada and abroad;
- Canadian regulatory issues at all levels of government, in concert with the U.S. regulatory environment;
- Risk analysis compared to other technologies used in transit operations;
- Specifications for fuel cell-powered transit buses;
- The impact on operations and maintenance facilities;
- The impact on maintenance practices;
- The impact on operations and training budgets;
- Fuelling infrastructure and technology;
- Supply chain impacts; and
- The need for external communications.

[1] *"Fuel cell-powered bus" defines all types of buses powered in whole or in part by a fuel cell on board the bus. The two major categories of fuel cell-powered buses discussed in this report are the fuel cell bus (a bus powered by a fuel cell only) and the fuel cell hybrid bus (a bus powered by a fuel cell and one or more other power sources).*

KEY FINDINGS

The transition to fuel cell-powered transit fleets involves changes to buses, transit facilities, fuelling infrastructure and the regulatory environment. Major transition costs for urban transit systems (UTSs) include the capital cost of fuel cell-powered buses and the conversion of existing facilities or the building of new ones. Following is a summary of key findings on the implications of making the transition to fuel cell-powered fleets:

FUEL CELL-POWERED BUSES

- Technology suppliers and bus manufacturers do not expect fuel cell-powered buses to be commercially available before 2015.
- In the transition period, it is anticipated that fuel cell-powered transit bus demonstrations will increase in size and scope.
- The type of fuel cell used for transit buses is expected to be the direct hydrogen proton exchange membrane (PEM) fuel cell.
- On-board hydrogen fuel will be stored in high-pressure cylinders at 350 bar or higher.
- Commercial fuel cell-powered buses are expected to equal or surpass existing operational requirements for diesel buses.
- The reliability of commercially available fuel cell-powered buses is expected to be equal to or better than conventional diesel buses.
- Fuel cell hybrid systems – combining a hydrogen fuel cell of smaller capacity, a system that recuperates energy from the brakes, and an efficient electric power storage system – are a promising technological development that reduces the consumption of hydrogen without increasing the cost of the power system.
- Fuel cell hybrid buses currently being developed may enter the transit marketplace first.

URBAN TRANSIT SYSTEMS

- The planning of routes and bus allocations will be the same for fuel cell-powered buses as for diesel buses; no additional spare buses will be required.
- Maintenance operations of fuel cell-powered buses will differ substantially from current practices in areas such as power plant maintenance but will remain identical for the majority of current procedures relating to body, frame, suspension, chassis, wheels and brakes.
- The skills base required to maintain fuel cell-powered buses will not differ significantly from that currently in place, but the mix of skills will change in favour of more electrical and electronics training. By 2015, it is anticipated that UTS workforce demographics will have changed to reflect the skill set required for fuel cell technologies.
- UTSs will need to add additional tools and equipment to their maintenance facilities (e.g., hydrogen sensors and fuel cell diagnostics) and replace some current tools with specialized tools (e.g., non-sparking hand tools).

- The degree of change required for existing facilities will vary. If a garage currently services a compressed natural gas (CNG) bus fleet, changes will be minimal. If a garage services a diesel fleet, changes to safety, ventilation, lighting, monitoring and fire suppression systems will be required. Changes may also be required to the facility's electrical system.
- A fuel cell-powered bus fleet will use the same amount of garage and maintenance space as a diesel-powered fleet.
- All UTS personnel will require hydrogen fuel safety training at the same level as their current safety training for diesel fuel.
- It is anticipated that individual UTSs will require a period of approximately three years to prepare for the transition to commercial fuel cell-powered buses.
- Technology and transit experts report that the use of hydrogen fuel in internal combustion engines may represent an intermediate phase prior to the introduction of fuel cell-powered buses. This could provide an opportunity for UTSs to transition to hydrogen fuelling prior to adopting fuel cell-powered buses.

FUELLING INFRASTRUCTURE

- While hydrogen is currently classified as a hazardous material, its emerging use as a fuel has created a demand for it to be classified as a fuel. This reclassification is expected to occur before fuel cell-powered buses are marketed.
- The handling and storage of hydrogen in the UTS facilities will involve procedures similar to practices for fuels like CNG.
- UTSs may have sites that are not suited to on-site hydrogen production, either because of their location or the lack of space.
- The choice of a hydrogen supply strategy for a UTS will depend on several factors but particularly on the cost of the feedstock – electricity in the case of water electrolysis and natural gas in the case of methane reforming.
- Hydrogen fuelling procedures will not change noticeably from diesel fuelling procedures, nor will additional personnel be required.

REGULATORY ENVIRONMENT

- In the absence of standards set specifically for fuel cell-powered buses or components thereof, fuel cell-powered vehicles currently on the road are permitted to use CNG bus standards as a reference.
- It is expected that specific codes and standards for hydrogen and fuel cells will be available prior to the commercial availability of fuel cell-powered buses.
- A major effort is underway in Canada, the United States and internationally to develop a sound scientific basis for standards development. Preliminary results indicate that acceptable clearance distance standards will be developed within the next few years for fuelling stations and on-site storage – in time for significant growth of the fuel cell-powered bus option in UTSs.

COSTS

Buses

- Fuel cell-powered buses are expected to cost approximately $1 million[2] when they make their market entry in 2015.
- The purchase cost of fuel cell-powered buses will be over two-thirds more than their diesel counterparts.
- The purchase cost of fuel cell buses will be approximately the same as that of fuel cell hybrid buses.
- The lifecycle cost of a fuel cell bus will be comparable to that of its diesel counterpart, while a fuel cell hybrid bus will cost approximately 10% less.
- The annual maintenance costs of fuel cell buses and fuel cell hybrid buses will be approximately 15% and 21% less expensive, respectively, than those of diesel urban transit buses.

Fuel

- Scenarios comparing the cost of fuels indicate that hydrogen technologies are expected to be more price-competitive than diesel, particularly in the case of fuel cell hybrid buses.
- Hydrogen fuel prices are sensitive to the price of feedstock, e.g., methanol, natural gas, electricity.
- On-site reforming of natural gas is likely the most economical source of hydrogen for UTSs where the site can accommodate the equipment required. In hydroelectric-rich provinces like Québec, Manitoba and British Columbia, electrolysis will be price-competitive.

Facilities & Operations

- If existing facilities have been built to the standards for diesel bus operation, the incremental cost of conversion to hydrogen standards will range from $2.1 million to $4.2 million for a 250-bus depot (depending on the configuration of the building). This compares to an incremental cost (i.e., the cost exceeding that of building diesel bus facilities) of $1.4 to $2.8 million to build new facilities for the same needs.
- Facility maintenance operating costs are estimated to increase by $2.70/m^2/annum to accommodate the maintenance of hydrogen-related safety equipment such as sensors and heating and ventilation systems. This amounts to $250 per bus per year (less than 0.6% of total maintenance costs).
- Retraining of personnel can be undertaken within the regular training budget.
- The cost of developing and implementing new procedures that are hydrogen-compatible can be accommodated within the regular operational budget.
- The cost of communications related to the introduction of fuel-cell technology can be accommodated within the regular public relations budget.

[2] *All currency figures presented in this report are in Canadian dollars. Dollar figures quoted for 2015 are expressed in 2015 dollars.*

KEY CHALLENGES

Numerous technical, economic, political and administrative challenges have to be resolved before fuel cell-powered buses can be made commercially available and before urban transit systems (UTSs) can begin to acquire fuel cell-powered buses. All stakeholders will need to address these challenges as soon as possible in this pre-transition phase if Canadian UTSs are going to make an accelerated transition to fuel-cell powered fleets.

TECHNICAL CHALLENGES

- Ensuring that the performance parameters and reliability of current diesel buses are equalled or bettered;
- Adapting current demonstration-type technologies to the standards required by transit operators;
- Improving the efficiency of electrolyzers as well as their capacity to deliver larger quantities of hydrogen at a competitive cost;
- Reducing the size of on-site reformer units while adding carbon sequestration to the process;
- Developing a competitive supply chain for UTSs wishing to source their fuel off-site;
- Introducing large capacity, on-site reservoirs of high-pressure gaseous hydrogen to the market at a competitive price;
- Finalizing hydrogen-specific standards and codes; and
- Developing training programs for technical personnel.

ECONOMIC CHALLENGES

- Decreasing the current price of fuel cell systems[3] by 90%;
- Decreasing the cost of delivering hydrogen to transit buses by reducing the capital costs of hydrogen production systems; and
- For UTSs, addressing a shift in cost from operating to capital by developing new partnership agreements with fund providers.

PUBLIC POLICY CHALLENGES

- Achieving multi-level government cooperation in support of UTSs as a means of realizing collective environmental goals; and
- Finding and securing the financial resources to support the introduction of hydrogen technologies in UTSs over a period of several years.

ADMINISTRATIVE CHALLENGES

- Preparing UTSs, in all aspects of their operations, for the transition to fuel cell-powered buses;
- Securing the cooperation of key stakeholders; and
- Ensuring effective communication with all stakeholders.

[3] *In addition to fuel cell modules, fuel cell systems include components that form the balance of the plant. These are: the interface module and piping network, the inverter for converting DC into a 3-phase alternating current, the fuel cell control device, the air supply sub-system and the cooling sub-system.*

CONCLUSION

Fuel cell-powered buses, expected to be commercially available by 2015, are a viable technology for use in Canada's urban transit fleets.

Fuel cell-powered buses are expected to be able to carry out urban transit duties with performance and reliability that are comparable to or better than their diesel counterparts. Although the acquisition cost of a fuel cell-powered bus will be more than that of a diesel-powered bus, the lifecycle cost, including the cost of acquisition, maintenance and fuel, will be comparable.

Closing the gap between the current reality and what can be possible in 2015 is feasible only if all stakeholders focus on the opportunity that presents itself at this juncture in Canadian transit history.

For the fuel cell and related equipment industry, the Canadian transit fleet represents a critical target market and an ideal first large-scale market segment, as well as a stepping stone to other markets.

A crucial part of closing the gap in the next ten years will be the support of government, at all levels, in accelerating the introduction of fuel cell-powered transit vehicles and acting as a catalyst for increased cooperation among stakeholders.

The introduction of fuel cell-powered buses into transit fleets cannot be achieved without increased government intervention, particularly with regard to transition costs. While fuel cell-powered buses are expected to be cost-competitive on a lifecycle basis, the cost of acquisition (anticipated to exceed that of a diesel bus by two-thirds) is more than most urban transit systems can afford. As well, the one-time cost of adapting facilities, tooling, and equipment is outside the normal scope of transit system budgets. While this transition is feasible, it will require new arrangements with funding partners to ensure that additional support for capital costs is available.[4]

[4] *In Canada, there is no federal funding support for the purchase of transit buses. By contrast, in the U.S., the Department of Transportation's Federal Transit Administration (FTA) can fund up to 80% of the capital cost of transit buses. In Canada, individual UTSs fund new bus purchases through their funding partners, i.e., the province and/or local municipal entities. (Source: Manitoba Energy Development Initiative)*

In the final analysis, it will be governments, with their financial incentives, policies, legislation, and regulatory standards that will be the most critical players in accelerating the transition to fuel cell-powered bus fleets in Canada's urban transit systems.

If this goal is achieved in a timely manner, Canada could become a world leader and innovator in sustainable energy technology and expertise. In turn, Canadian stakeholders in the hydrogen and fuel cell industry would have a sustainable competitive advantage in the global marketplace.

RECOMMENDATIONS

A significant collaborative effort involving all stakeholder groups is imperative if there is to be a successful transition to fuel cell-powered bus fleets in Canadian UTSs.

All stakeholders – UTSs, bus manufacturers, fuel cell system suppliers, fuel storage system suppliers, fuel and fuelling station providers, training institutions, and governments – have a critical role to play. Following is a list of recommended activities by stakeholder group:

FOR THE CANADIAN UTS INDUSTRY

It will be important for UTSs to work collaboratively in the development of fuel cell-powered transit bus technology. In advance of fuel cell-powered buses being commercially available, there are a number of activities UTSs can undertake to ensure that fuel cell technology will meet their operational requirements. These are:

1. Clearly determine current operations and maintenance costs to use as a baseline when considering a transition to fuel cell technology;
2. Determine the current skills profile of their maintenance workforce to use when planning for the changes in competencies required to maintain a fuel cell-powered bus fleet;
3. When hydrogen codes and standards are available, examine the changes that will be required to existing facilities to accommodate and operate fuel cell-powered buses;
4. Within the context of individual UTS strategic plans, determine if the transition to fuel cell technology needs to be addressed by building new facilities at a green-field site; if so, identify potential sites within the service area;
5. Assess the impact of gaseous hydrogen use on current occupational health and safety programs in the UTS environment;
6. Review emergency response plans to adapt them to hydrogen;
7. Identify opportunities for shared fuelling facilities, i.e., small UTSs and city fleets;
8. Enlist the Canadian Urban Transit Association (CUTA) to be a clearing house for the sharing of information and experience related to hydrogen and fuel cell-powered buses;
9. Using CUTA as a reference base, establish a centre of knowledge and expertise for UTSs with regard to alternative fuel technologies and particularly hydrogen fuel cell technology developments;
10. Keep UTS governing boards informed of fuel cell technology developments relevant to urban transit;
11. Sponsor the development of a transition cost model that UTSs can readily use to assess their specific situation when considering fuel cell-powered buses; and
12. Continue participation in cost-shared demonstration programs.

FOR BUS MANUFACTURERS

It is recommended that bus manufacturers take a more proactive role in the technical integration of fuel cells in urban transit buses. In particular, it is recommended that they:

13. Work in collaboration with fuel cell system suppliers;
14. Develop bus design guidelines for fuel cell system suppliers; and

15. Continue participation in cost-shared demonstration programs.

FOR FUEL CELL SYSTEM SUPPLIERS

In addition to resolving technical challenges and focusing on cost reduction, it is recommended that fuel cell system suppliers:

16. Cooperate with all industry stakeholders to advance the anticipated date of market readiness;
17. Ensure continued cooperation with bus manufacturers to facilitate the smooth integration of fuel cells in new bus design and optimal manufacturability;
18. Develop field training programs for UTS maintenance and operations personnel;
19. Consider developing "stack rebuilding" services, procedures and pricing;
20. Continue participation in cost-shared demonstration programs;
21. Consider cross-application designs to standardize parts requirements; and
22. Study the possibility of balance-of-plant standardization throughout the fuel cell industry in an effort to simplify maintenance for UTSs and decrease costs for fuel cell suppliers.

FOR HYDROGEN FUEL STORAGE SYSTEM SUPPLIERS

The major challenge facing storage system suppliers is reducing the weight of on-board storage cylinders. It is recommended that they also:

23. Continue development of 700-bar storage and dispensing systems;
24. Develop larger units for fixed on-site storage and transportable systems for hydrogen fuel suppliers;
25. Work with bus manufacturers on the design of on-board storage; and
26. Continue participation in cost-shared demonstration programs.

FOR HYDROGEN FUEL AND FUELLING SYSTEM PROVIDERS

In addition to resolving technical challenges, it is recommended that fuel and fuelling system providers:

27. Evaluate future demand for hydrogen in urban transit applications, and plan for the expansion of centralized production units to meet the anticipated increase in demand from UTSs;
28. Identify opportunities for pipeline delivery and additional by-product recovery;
29. Identify opportunities for shared fuelling facilities (i.e., small UTSs and city fleets);
30. Provide information to the Canadian Association of Motive Power Educators (CAMPE) on the integration of hydrogen-related training into existing apprenticeship and licensing programs;
31. Continue participation in the development of hydrogen-specific standards and codes;
32. Continue participation in cost-shared demonstration programs; and
33. Acquire, review and share performance data from demonstration projects.

FOR TRAINING INSTITUTIONS

Training institutions will be faced with many tasks in the coming years. It is recommended that they:

34. Coordinate with provincial and inter-provincial apprenticeship programs regarding hydrogen and fuel cell-related trades training; for example, through the Canadian Association of Motive Power Educators (CAMPE);
35. Use a centralized training and certification body for hydrogen and fuel cell-related training and certification;
36. Integrate hydrogen and fuel cell-related training into existing apprenticeship and licensing programs rather than creating new training programs;
37. Revise hazardous material technician training under provincial fire marshal programs;
38. Cooperate with the United States in creating standardized hydrogen-related fire safety programs throughout North America; and
39. Prepare hydrogen and fuel cell-related emergency response training.

FOR GOVERNMENTS

Governments have a crucial role to play in the future of both the fuel cell and urban transit industries. It is recommended that they:

40. Consider changing or enacting legislation to encourage commercial application of fuel cell technologies;
41. Continue to develop appropriate funding strategies to support the transition to hydrogen fuel cell–powered applications through:
    - incentives for bus acquisition,
    - incentives for facilities building or conversion (including fuelling stations), and
    - incentives for education to facilitate adoption of hydrogen and fuel cell technologies;
42. Continue participation in cost-shared demonstration programs;
43. Complete the assessment of the overall cost-benefit comparison of fuel cell-powered buses to diesel buses by taking into account social costs such as air pollution, noise, and greenhouse gas emissions;
44. Develop regulations and processes regarding fuel cell-powered bus registration;
45. Continue to develop regulatory standards for vehicles, operating facilities and fuelling systems based on hydrogen and fuel-cell technology;
46. Survey health and safety regulations in the various provinces and territories to determine the implications of introducing hydrogen in the workplace;
47. Increase the quantity and level of information for various publics in order to improve their awareness, e.g., citizens, media, insurance companies and labour groups;
48. Gauge Canadian public support for the use of fuel cell technology in urban transit systems and continue monitoring over time;
49. Articulate a national strategy for providing incentives to accelerate the commercialization of fuel cell-powered heavy duty vehicles in Canada; and
50. Target environmentally sensitive areas and smaller UTSs with clear and definitive policies to encourage the early adoption of fuel cell-powered bus fleets.

APPENDIX I

FUEL CELL TECHNOLOGY

HOW A FUEL CELL WORKS

The following is a non-technical explanation of how a PEM fuel cell works.

THE PROTON EXCHANGE MEMBRANE FUEL CELL (PEMFC)

The PEMFC operates at a relatively low temperature, which means it warms up quickly and does not require expensive containment structures. Platinum is typically used as a catalyst in this type of fuel cell. Constant improvements in engineering and material used in the PEMFC have increased the power density to a level where a device about the size of a small piece of luggage can power a car. Cyclibility adds to the advantages of PEMFCs. They are the leading fuel cell technology for use in transportation applications

HOW A FUEL CELL WORKS

A fuel cell is a device that converts chemical energy into electrical energy. Hydrogen (which can be obtained from a variety of carbon-based fuels, including methanol, natural gas and petroleum or renewables), is combined with oxygen (obtained from the air) with a fuel cell to electrochemically produce electricity, water and heat.

The heart of the fuel cell generally consists of three primary parts: an anode, a cathode and an electrolyte. The electrical current flows from the cathode to the anode. The materials from which the fuel cell is composed determine the way in which the fuel cell produces electricity.

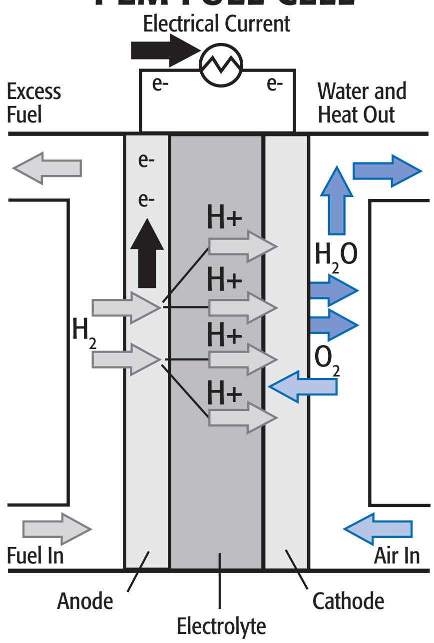
Cells

A basic Proton Exchange Membrane Fuel Cell (PEMFC) has hydrogen protons migrating from the anode through the electrolyte to the cathode. A platinum coating at the anode acts as a catalyst and helps to split the hydrogen molecules into positively charged protons and negatively charged electrons. The electrolyte membrane allows only the protons to pass through it to the cathode. The electrons cannot pass through this membrane and as a result, they flow (in the form of an electrical current) through an external circuit to get to the cathode, thus creating electricity. Oxygen supplied at the cathode then combines with the protons to form water.

Stacks

Individual fuel cells are typically combined into a fuel cell "stack". The number of fuel cells in the stack determines the total voltage. The surface area of each cell determines the total current. Multiplying the voltage by the current yields the total electrical power generated, typically measured in kilowatts (kW).

PEM FUEL CELL



Anode reaction: $H_2O = 2H^+ + 2e^-$

Cathode reaction: $O_2 + 4H^+ + 4e^- = 2H_2O$

Balance of Plant

Producing usable electrical power from a fuel cell requires more than just a fuel cell stack. In addition to the stack, a fuel cell system includes many components for functions such as: injecting fuel gases, managing a critical water balance, conditioning the power output and monitoring and controlling all the required system parameters (e.g., temperature and pressure). Without this supportive operating system, the fuel cell stack cannot produce usable power.

APPENDIX II

BUS LIFECYCLE COSTS

Table 1: Bus Lifecycle Costs in 2015 Dollars

LIFECYCLE COST COMPONENTS		250 BUSES OVER 18 YEARS
Bus Acquisition Cost	Diesel	$150,096,770
	Fuel cell	$250,300,279
	Fuel cell hybrid	$251,403,664
Operations Cost		
Maintenance Cost		
	Diesel	$236,704,005
	Fuel cell	$200,714,570
	Fuel cell hybrid	$186,199,881
Fuel Cost		
(Diesel @ $1,05/l)	Diesel	$155,521,825
(Hydrogen @ $3.47/kg)	Fuel cell	$91,672,162
(Hydrogen @ $3.47/kg)	Fuel cell hybrid	$60,503,627
Total Cost		
	Diesel	**$542,332,600**
	Fuel cell	**$542,687,012**
	Fuel cell hybrid	**$498,107,172**

The lifecycle cost of each bus is therefore:

- Diesel bus $2,169,290
- Fuel cell-powered bus $2,170,748
- Electric/fuel cell hybrid bus $1,992,429

All of the cost forecasts above pertain to a reference case of a 250-bus garage. Costs for larger or smaller facilities will vary accordingly, but will be the same proportionately. No facilities costs are factored into the lifecycle costs.

All costs are expressed in 2015 dollars.

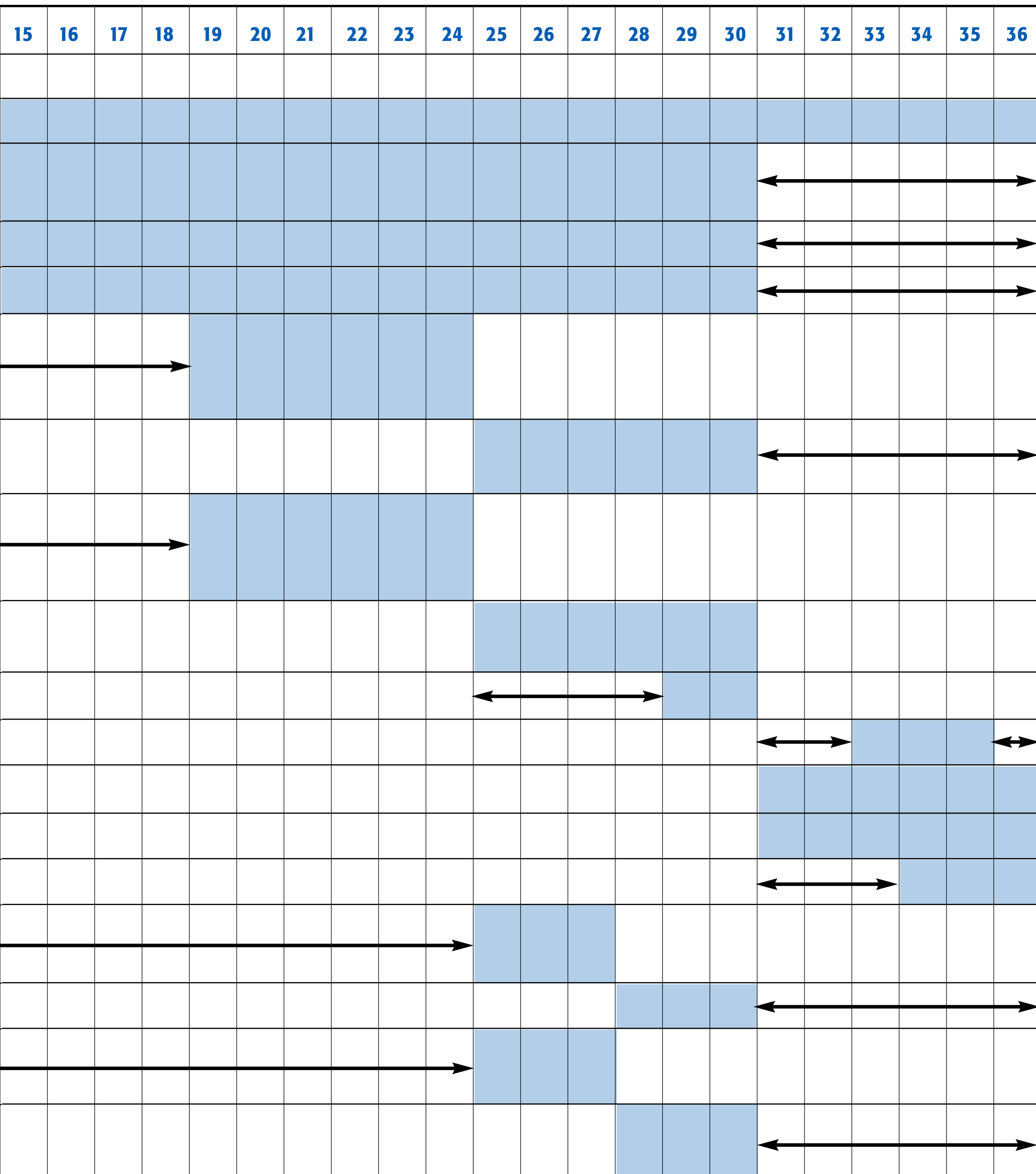
The lifecycle cost of all types of buses is dependent on the cost of the fuel used. In the above table, estimated 2015 average fuel costs are indicated. For a more detailed discussion of possible fuel costs, see the detailed report, Section 5-7: Summary of Costs. The report can be accessed at: **http://www.nrcan.gc.ca/es/etb/ctfca/Publications_e.html**.

APPENDIX III

TRANSITION PROCESS TIMETABLE

Table 2: Transition Process Timetable

MONTH:	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Definition of requirements and project approval process														
Contract award and delivery of buses														
Facilities modification design, contract award and construction														
Fuel station design, contract award and construction														
New facility design, contract award and construction														
Negotiations with bargaining unit representatives, as appropriate, to deal with any dislocation issues affecting employees														
Development of technical training program for employees														
Development and writing of corporate health, safety and environment policy applicable to the hydrogen/fuel cell environment														
Development of health, safety and environment training program														
Training the trainer program														
Training for supervisory and management personnel														
Technician training														
Facility maintenance staff training														
Service staff training														
Internal stakeholder education and communication program development														
Internal stakeholder education and communication														
External stakeholder education and communication program development														
External stakeholder education and communication														



Note: The arrows indicate the flexibility in scheduling the named activity, identifying the earliest start time and the latest completion time. Where there is no arrow preceding or following the activity bar, the activity should not commence or continue later than the time shown. The above time estimates will vary, depending on the unique circumstances of each urban transit system and the readiness to make the change to the hydrogen environment. For smaller systems, the above-stated time periods may be reduced significantly. The sequence of each activity can also vary by transit system. All activities, however, will have to be completed prior to fuel cell-powered buses entering into revenue service. All training programs will include the necessary health, safety and environment components applicable to the level of the person receiving the training.

NOTES

NOTES

NOTES