Hydrogen Hybrid Internal Combustion Engine Transit Bus

Cold Weather Demonstration in Winnipeg, Manitoba, Canada

Overview

Manitoba was the natural choice to be the demonstration site for the first hydrogen engine-powered bus to be tested on-road in Canada, given its climate advantage, bus manufacturing experience and leadership in hydrogen.

The Hydrogen Hybrid Internal Combustion Engine, or HHICE, transit bus uses compressed hydrogen gas as its fuel, similar to vehicles now running on propane or natural gas. This advanced technology offers all of hydrogen's environmental benefits, including clean exhaust and reduced greenhouse gas emissions, at a cost that is relatively affordable today.

The hydrogen-fuelled bus was test-driven in Winnipeg during February and March 2005 – the ideal time to find out how the HHICE technology would perform in cold weather conditions. The trial also involved a temporary refuelling system, which produced compressed hydrogen gas using electricity and water.

Travelling on a regular Winnipeg Transit system route, the bus performed well, carrying more than 1,000 passengers and logging more than 500 kilometres (300 miles). The bus was able to keep passengers sufficiently warm during operation, and was noticeably quieter than conventional diesel buses.

The successful demonstration of the HHICE bus was made possible by a team effort involving a dozen organizations and agencies. (See *Cold Weather Demonstration Partners* - page 4)

Project Details

The HHICE bus is an innovative technology that uses hydrogen as a clean-burning fuel. The 40-foot, low-floor bus was built in Winnipeg by New Flyer Industries, the leading manufacturer of transit buses in Canada and the United States. ISE Corporation of California designed and installed the hybrid drive system. It consists of an internal combustion engine adapted to run on hydrogen, an electrical generator to power the wheel motors, and regenerative brakes with electrical storage to recover and reuse energy. This advanced system is ideal for buses that are involved in stop-and-go driving.

The Province of Manitoba leased the HHICE bus, which is owned by SunLine Transit Agency. The bus was operated briefly in route service in California before coming to Manitoba. The Winnipeg demonstration involved cold-weather operational testing of the HHICE bus in actual, for-fare service.

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HHICE Bus Tested in Winnipeg Winter

The bus operated periodically in February and March 2005 on Route 19, running from Red River College's Notre Dame campus through downtown to Windsor Park and back. The Province of Manitoba sub-leased the bus to the City of Winnipeg's Transit Department and arranged for a temporary refueling infrastructure, set up at Red River College. (See photo at top of this page.) The infrastructure included a mobile electrolysis trailer unit leased from Stuart Energy (to produce compressed hydrogen using water and electricity), and a high-pressure hydrogen dispenser from Winnipeg-based Kraus Global (to fuel the bus). A suitable facility was also leased for overnight storage of the bus and maintenance.

The water vapour exhaust from the bus was clearly visible in cold weather.

DEMONSTRATION RESULTS

Benefits of the demonstration included experience in safe handling of hydrogen, knowledge about the technologies, and enhanced profiles for the technologies and partners involved.

Overall, the bus performed well during the test, proving that the HHICE bus technology works in cold climates. The bus carried an estimated 1,000 passengers and travelled more than 500 kilometres (300 miles).

Further test cycles over a longer period would be useful to verify the long-term durability of the technology in a cold climate. Although outside temperatures during operation averaged -13 C (8° F) and dipped as low as -27 C (-1° F), the bus stayed warm enough for passengers throughout the demonstration. It was also noticeably quieter than conventional diesel buses.

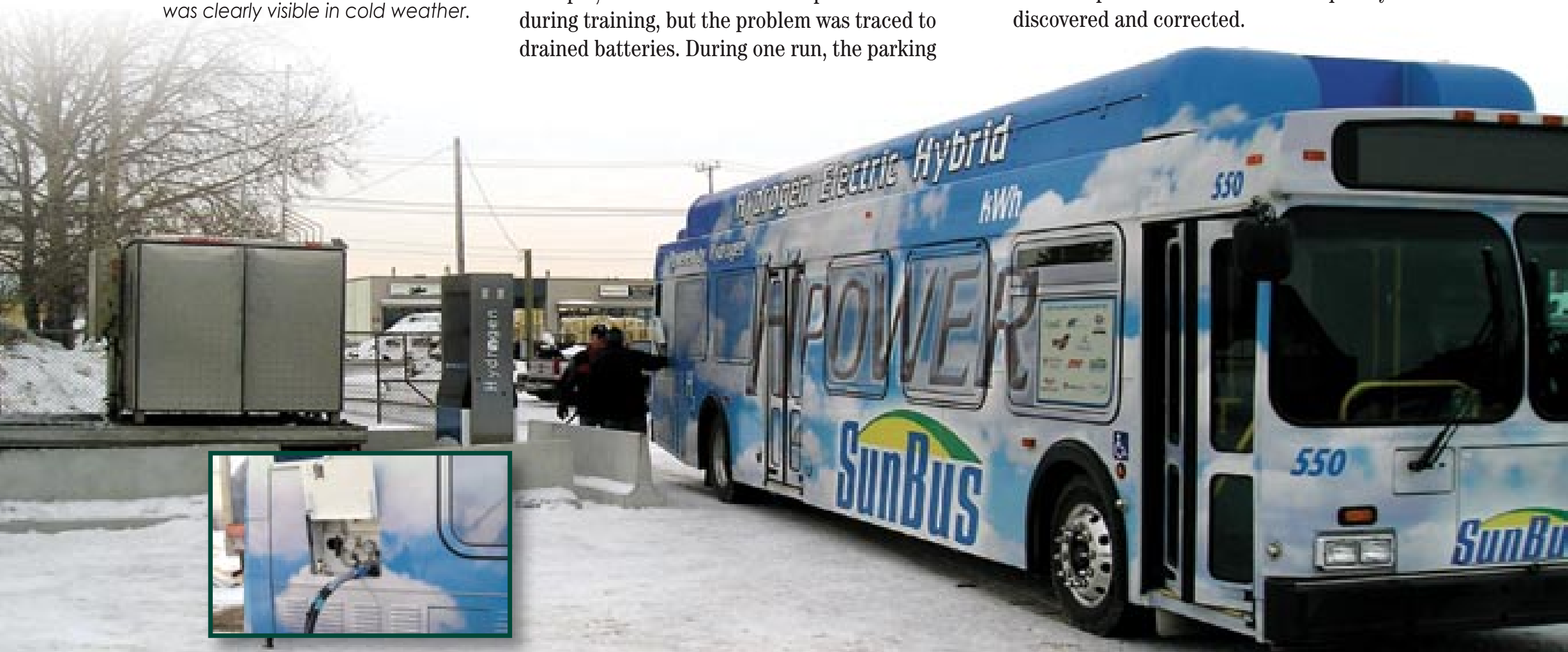
During the demonstration, the University of Manitoba Transport Institute conducted a survey of passengers, drivers and others involved with the bus project, on behalf of the Vehicle Technology Centre. Overall, the bus was well-received, dispelling negative perceptions often associated with the safety of hydrogen use.

The bus operation encountered several challenges; however, these were unrelated to hydrogen, and were, for the most part, quickly resolved. For example, there were some startup difficulties during training, but the problem was traced to drained batteries. During one run, the parking brake did not function properly, but it was determined this was due to computer sequencing and interlock settings. Finally, one of four, on-board, hydrogen sensors persistently indicated intermittent traces of hydrogen. Investigations confirmed there was no hydrogen present, but couldn't determine what caused the yellow indicator light to flash. The team concluded it was most likely related to cold conditions.

Since a suitable cold-weather test cell was not available, cold-weather emissions testing was not done.

The temporary refuelling infrastructure was used on 14 occasions, dispensing more than 110 kg (240 pounds) of hydrogen in total. The cold weather in which the system operated was a challenge, initially, due to excess water vapour in the produced hydrogen gas. As a result, the gas lines on the refuelling system froze. The problem was resolved, achieving a dew point of -68 C (-90ºF) referenced to atmospheric conditions.

Other issues surrounding the cold-weather infrastructure included the initial freeze-up of the water feed to the trailer, resolved by increasing the insulation on the heat-traced line; the unintended release of hydrogen gas from factory-preset, pressure relief valves on the hydrogen storage bank, resolved by heat-tracing these devices; and ongoing false hydrogen indications from the leak detector on the dispenser, not fully resolved but simply addressed by manual reset. A miscalibration of the dispenser read-out was also quickly discovered and corrected.



Project Success Stories

Hydrogen effective in cold weather

The operation of the bus and infrastructure in cold weather was an important success, for it showed hydrogen can be realistically used in cold climates. It also highlighted Manitoba's natural advantage for vehicle testing in both cold-weather and hot-weather conditions. Winnipeg likely possesses the coldest conditions in the world in which a hydrogen bus has been used in regular transit service, and hydrogen production and dispensing systems have been operated in a free-standing manner.

Co-operation helped drive complex project

The demonstration involved a dozen organizations working within two co-ordinated project teams – one addressing bus conversion and operation, the other addressing support infrastructure. This division of responsibilities was necessary due to the complexity of the project and the need to access co-funding through two separate Government of Canada programs.

For the long term, it would be beneficial to have a sole source administrative structure for testing in place, however open communications throughout the project helped the partners work together in a goal-oriented manner. Collaboration proved particularly important in safety training. Three separate, safety-training modules were prepared, covering the bus, refuelling operations and the hydrogen production system. This work included providing safety presentations to more than 50 participants, developing standard, safe-work procedures and creating response plans for emergencies. Local fire services staff also received briefings on the specific nature of the bus and the temporary infrastructure.

College involvement invaluable

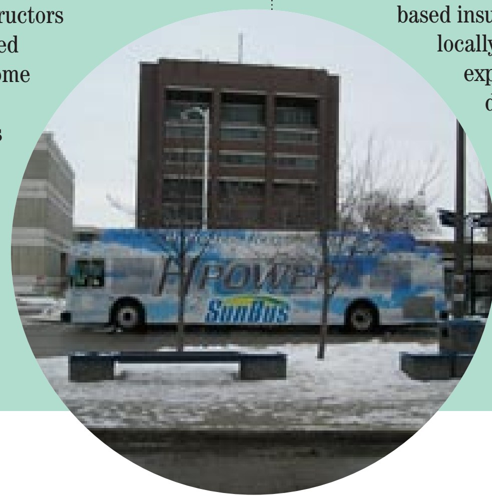
An important factor in the success of the trial was the flexibility of Red River College as a project partner. The college was helpful in accommodating temporary infrastructure, and in providing staff resources and knowledge to help with operations and troubleshooting. At the same time, staff and students benefited from direct exposure to technologies of the future. This is the first time a Canadian college has taken part in a major hydrogen vehicle and refuelling demonstration.

Roughly a dozen instructors and staff were involved with the project to some degree, with about half a dozen students assisting with minor bus maintenance under supervision. More than 50 college students were exposed to the technologies used in the project. University of Manitoba engineering students were also exposed to the innovative technology.

A key recommendation was made to increase the involvement of Red River College in particular, and colleges and other educational institutions in general, for future hydrogen projects.

Collaboratively addressing risks through insurance

Public exposure to hydrogen is increasing as hydrogen becomes more commonly used as a transportation fuel. Technical safety systems and codes for the safe design and implementation of hydrogen equipment still remain the dominant public safety issues. However, the areas of risk and insurance management are gaining in importance. Although improvements in insurance delivery are needed to reduce costs, the ability to insure all partners in this trial was critical to the project's success. The project-based insurance was co-ordinated locally, and insurers gained both exposure and experience in dealing with hydrogen.



Red River College in Winnipeg, Manitoba was the hub for the demonstration.

Lessons Learned and Needs Identified

The bus ran on compressed hydrogen gas produced with a mobile refuelling system. The engine was modified to burn pure hydrogen gas, powering an electric generator which powered motors at the drive wheels.

Simplify administration

Opportunities in the near future for hydrogen vehicles will focus primarily on demonstrations and testing, an area requiring speedy response and turnaround. While the countless arrangements necessary for this project ultimately worked, the project's planning time frame was exceptionally long, due to the number and complexity of interactions.

Creating a single, all-encompassing entity would simplify project administration and contract issues. Such an organization would need sufficient funding, resources and authority to promote and carry out short- and long-term demonstrations of hydrogen and possibly other alternative fuels. It could also co-ordinate funding and administration of hydrogen-related permanent facilities (discussed below). In Manitoba this organization could be a Crown corporation, a Special Operating Agency (SOA) or a stand-alone, non-profit corporation. It could serve as a model for similar organizations, in other jurisdictions, to implement demonstrations and expand hydrogen infrastructure networks in a co-ordinated manner.

Develop permanent hydrogen facilities

This project showcased Manitoba's potential in the field of cold-weather testing. Becoming an important test site for hydrogen would require three permanent but flexible facilities. The first would provide a suitable storage and maintenance space that meets all necessary codes. The second would have the capacity to produce and dispense hydrogen fuel, and the third would accommodate emissions testing. The latter is particularly important because there's no suitable, large-scale facility of this kind in Western Canada. Implementing a permanent hydrogen refuelling station has already been identified as a priority by the Manitoba government. Consolidating all three facilities at one location would be the best way to capture future testing opportunities, especially if combined with other alternative fuels.

Reduce insurance costs

Project-based insurance addressed risk issues for this trial, representing a useful model for other jurisdictions doing similar tests. The cost, however, was fairly high, with premiums making up about seven per cent of the overall budget. Deductibles and co-insurance represented more potential cost if a claim occurred.

There are several possible solutions to reduce this cost. One approach is to have a dedicated, one-stop, hydrogen demonstration organization (described earlier) with ongoing insurance and funding for deductibles and co-insurance. Forming an ongoing relationship with insurers would reduce costs associated with each project. Alternative solutions for reducing costs within Manitoba include using a public insurance corporation for this purpose, or having the provincial government provide the risk backstop, effectively through self-insurance.

Develop hydrogen-safety training programs

Training requirements were met successfully, but each component involved a unique effort, particularly to ensure safety training fulfilled legislated, safe-work requirements. Through experience gained from this project, Manitoba has an opportunity to become a leader in practical, hydrogen-safety training, particularly as hydrogen use becomes more widespread. Additional resources would be needed to create the necessary theoretical and practical curriculum.

Improve systems to measure and control water vapour

The tolerable content of water vapour in any gaseous stream – as expressed by the dew point – depends only on temperature, not pressure. The dew point is typically measured at atmospheric pressure conditions, and water vapour removal (drying) operations are typically conducted at lower pressures. However, when gas pressure is then increased to the high levels required for vehicle operation – for example, 5,000 psig (pounds per square inch gauge) – the partial pressure of the water vapour is magnified. Unfortunately, the higher pressure results in a much higher, effective dew point than would be experienced at atmospheric pressure. This means that water vapour in the hydrogen gas begins to freeze as ice at higher temperatures than would be expected.

While this problem of excess water vapour leading to ice formation and blockage was ultimately resolved, it emphasizes the need to develop practical, low-cost ways to measure water vapour content in high-pressure, hydrogen gas flows, and to control water vapour (as required) to very low levels in cold weather. Both provide opportunities for further technology development.

Reconsider hydrogen fuel specifications

Hydrogen fuel specifications are currently under general review. This project emphasized the need to reconsider appropriate levels for both water vapour and oxygen gas.

While a simplistic approach – requiring that water vapour not be condensed – may be practical while only a few hydrogen stations exist, it won't work once hydrogen use becomes more widespread. An unintended consequence is that effective specifications are different throughout the continent, depending on temperature. Therefore, water vapour limits need to be addressed more systematically.

A higher oxygen gas level, rising above one or even two per cent, does not represent a concern for ICE applications – it could even be an advantage. Attempting to keep oxygen content at a low level is potentially detrimental, as this is typically accomplished by catalytic conversion of oxygen with some of the hydrogen to produce water vapour. However, as noted above, water vapour itself is a significant problem. Therefore, introducing or producing water vapour should be avoided.

Next Steps

Further hydrogen vehicle demonstrations should be done in Manitoba, particularly to capitalize on cold-weather advantages.

Longer duration testing of hydrogen vehicles in general, and the HHICE bus in particular, should be carried out in Manitoba to confirm the long-term suitability of the technology.

Approaches to simplify project administration (including insurance and risk management) and to enhance infrastructure (including permanent vehicle storage, refuelling and emissions testing facilities) should be pursued.

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Partnership Key to Demonstration Success

Many partners contributed to this demonstration project. The Government of Canada played a significant role in providing financial support. The Province of Manitoba led the demonstration with the support of Manitoba Energy, Science and Technology and Manitoba Transportation and Government Services. This project supports the province's vision for a cleaner energy economy, a commitment to greenhouse gas reduction and sustainable transportation. The Vehicle Technology Centre and nine other organizations also contributed to this project.

Cold Weather Demonstration Partners

Province of Manitoba
Government of Canada
Vehicle Technology Centre
Red River College
ISE Corporation
New Flyer Industries
Kraus Global
City of Winnipeg Transit Department
Stuart Energy
SunLine Transit Agency
University of Manitoba Transport Institute

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