Hydrogen Hybrid Internal Combustion Engine Bus Demonstration:

Customer Acceptance Study

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1. Introduction[1]

Developments of alternative fuels for use in transportation have been by the twin goals of reducing greenhouse gases and reducing dependence on fossil fuels. Development efforts have primarily focused on bio-fuels, such as methanol, ethanol and bio-diesel and the development of hydrogen technologies. At the fuel production stage bio-fuels and hydrogen can be developed from renewable sources. The former, though the refinement of products such as grains and oilseeds, and the latter through harnessing wind energy for electrolysis. While both groups of fuels provide for a reduction in greenhouse gas emissions, hydrogen is often considered the gold standard, as the sole combustion by-products are water and nitrous oxide. This paper focuses on hydrogen as a fuel source in a public transit demonstration.

Hydrogen technologies in order to become the choice for the future, must first overcome several obstacles. First, the fuel must be price competitive with other fuel sources. Second, there must be sufficient infrastructure (vehicles and fuelling) in place and third, it must be acceptable to the consumer overcoming negative public perceptions.

Price competitiveness depends on the cost of producing hydrogen in the future compared with the costs of bio-fuels or fossil fuel alternatives. Given the future cost paths of these technologies are largely unknown, as is the price of oil, the price competitiveness issue is not currently resolvable.

The second obstacle has been studied by many authors, who have outline the steps needed to move toward a hydrogen based economy. Johnston, Mayo and Khare[1] and McDowall and Eames[2], provide a succinct description of the challenges related to adopting hydrogen as well as the future pathways for hydrogen adoption

[1] Funding for this study was provided by the Vehicle Technology Centre. The City of Winnipeg Transit Department provided resources and support to the project.

The published literature with respect to the last obstacle, public perception, is relatively small compared to the former two. With respect to the use of hydrogen in public transit, several studies are available, none of which have been published in pier reviewed journals. The earliest published work was Altman and Graesel[3]'s three part study carried out in 1997 and 1998. O'Garra[4] recently published a study of bus rider attitudes toward hydrogen as part of the Accept H2 project. This study considered the public perceptions of bus riders in five regions; Berlin, London, Luxembourg, Oakland and Perth before and after the introduction of hydrogen fuel cell bus test projects in the respective region. In addition to obtaining descriptive details of rider's attitudes, the data was used to determine the willingness of riders to pay for a change to hydrogen fuel cell buses. Samples sizes varied from 301 to 263. Oakland only participated in the first survey. ECTOS[5] performed a survey of bus riders as part of the hydrogen fuelled cell bus in Reykjavik in March 2004. Details of this study have not been published.

The research presented in this paper also focuses on the public acceptability of hydrogen for use in public transit. The study was conducted as part of the hydrogen hybrid internal combustion engine (HHICE) bus project undertaken in Winnipeg during the winter of 2005.

2. Study Approach

The Winnipeg HHICE bus demonstration was described in the 2005 CTRF proceedings.[6] The demonstration was designed to test the operation of the bus in actual service. In addition to testing the technology of the bus and related fuelling infrastructure, a customer acceptance study was also conducted.

A survey instrument was designed and a customer intercept approach used. Using a standardized script, interviewers approached riders on the bus with regard to their willingness to participate in the survey. Those that were willing were then screened in order to eliminate prior

respondents. Those who were not prior respondents were provided a survey to fill out, which was collected by the interviewers upon completion. Respondents were provided a small incentive to complete the survey.

In total 369 surveys were collected yielding an overall error rate of 5.1% at a 95% confidence level.

Optional demographic questions related to age and gender were included to test the representativeness of the survey group to the entire population[7]. Based on comparisons of the sample to the population, overall younger riders were overrepresented in the survey. As well males were underrepresented. These were expected because:

- The route selected terminated at Red River College, and consequently it is expected the ridership population would be younger than the norm.
- Generally more females ride buses than males.

Members of the survey group tended to be frequent bus riders, with 41% indicating they rode a bus more than 10 times per week, followed by 39% who responded they rode a bus 5 to 10 times per week. The remaining 20% indicated they rode a bus less than 5 times per week.

Results of the survey were classified into results reflective of the bus itself, where the respondent was asked to compare characteristics of the HHICE bus to a regular diesel public transit bus and those related to the use of hydrogen as a fuel.

3. Customer Acceptance - The HHICE Bus

The study focused on customer acceptance related to the following attributes of the bus in comparison with a regular transit bus:

- Ride comfort.
- Temperature comfort.
- Smoothness of stopping.
- Smoothness of acceleration.
- Noise level.

Ride Comfort

Table 1 provides a summary of the results related to ride comfort of the bus.

Table 1. Ride Comfort of the HHICE Bus: By Ridership Frequency[2]

	Frequency of Ridership (Weekly)			
Rating	Up to 4 times	5-10 times	Over 10 times	All Frequencies
Much Better	40%	36%	46%	41%
Somewhat Better	41%	40%	33%	38%
Neither Better Nor Worse	17%	22%	21%	20%
Somewhat Worse	2%	2%	0%	2%
Much Worse	0%	0%	0%	0%
No Opinion/ Not Stated	0%	1%	0%	0%

In terms of ride comfort, the majority of respondents (79%) felt that the comfort level on the HHICE bus was either "much better" or "somewhat better" than a regular transit bus. Comfort level responses did not vary significantly based on frequency of ridership.

[2] Totals and comparisons between tables may vary slightly due to rounding.

When the data was segregated by age and gender similar results emerged as shown in Table 2.

Table 2. Ride Comfort of the HHICE Bus: By Age and Sex

	Age		Gender	
Rating	Up to 34	35 and over	Male	Female
Much Better	43%	38%	41%	41%
Somewhat Better	33%	42%	40%	36 %
Neither Better Nor Worse	23%	18%	18%	23%
Somewhat Worse	0%	1%	0%	1%
Much Worse	0%	.0%	0%	0%
No Opinion/ Not Stated	0%	1%	1%	0%

There was little variation in the results on an age or gender basis.

Temperature Comfort

Tables 3 and 4 show the temperature comfort rating of the HHICE bus. This was an important test criteria since the bus did not have an auxiliary heater, which is commonly used in diesel transit buses operating in cold climates such as Winnipeg.

Overall the survey results indicate that the temperature comfort was superior to that of a regular transit bus, with 73% of respondents indicating the temperature comfort was either “much better” or “somewhat better”. Few respondents found the temperature comfort worse than a typical bus.

Table 3. Temperature Comfort of the HHICE Bus: By Ridership Frequency

	Frequency of Ridership (Weekly)			
Rating	Up to 4 times	5-10 times	Over 10 times	All Frequencies
Much Better	40%	31%	37%	36%
Somewhat Better	36%	38%	36%	37%
Neither Better Nor Worse	19%	28%	26%	24%
Somewhat Worse	3%	1%	0.0%	1%
Much Worse	0%	0%	0%	0%
No Opinion/ Not Stated	2%	2%	2%	2%

Across age and gender, those who were 34 or younger were also positive towards temperature comfort with 35 % of this category responding with “much better” and “somewhat better” respectively. 35 % of the 35 and older age category thought the temperature to be “much better” and 39 % felt it somewhat more comfortable.

Female respondents indicated a slightly more positive response than males, with almost 40% of females considering the temperature to be “much better”, compared with only 30% of males who chose this ranking. Further, a lower percentage of females suggested that the bus was "neither better nor worse" than a comparative bus.

Table 4. Temperature Comfort of the HHICE Bus: By Age and Sex

	Age		Gender	
Rating	Up to 34	35 and over	Male	Female
Much Better	35%	35%	30%	40%
Somewhat Better	35%	39%	40%	33%
Neither Better Nor Worse	27%	23%	27%	24%
Somewhat Worse	2%	1%	2%	1%
Much Worse	0%	0%	0%	0%
No Opinion/ Not Stated	1%	2%	1%	2%

Smoothness of Stopping

Given the hybrid systems on board the bus, where braking energy is recaptured for subsequent acceleration, the study also considered the smoothness of stopping and acceleration.

Table 5. Smooth Stopping of HHICE Bus: By Ridership Frequency

	Frequency of Ridership (Weekly)			
Rating	Up to 4 times	5-10 times	Over 10 times	All Frequencies
Much Better	51%	43%	39%	44%
Somewhat Better	35%	33%	40%	36%
Neither Better Nor Worse	12%	22%	18%	17%
Somewhat Worse	2%	1%	2%	2%
Much Worse	0%	1%	0%	0%
No Opinion/ Not Stated	0%	0%	1%	0%

As shown in Table 5, similar to the results for ride comfort and temperature, respondents also had a favourable opinion with respect to the smoothness of stopping. Across bus frequency categories, 44 % of respondents on average found the smoothness of stopping to be "much better." 51% of the respondents who rode the bus less than 4 times per week provided a "much better" rating while for those riding over 10 times only 39% provided a "much better" rating.

The views related to the smoothness of stopping did not vary significantly by age and gender of respondents, as shown in Table 6.

Table 6: Smooth Stopping of the HHICE Bus: By Age and Sex

	Age		Gender	
Rating	Up to 34	35 and over	Male	Female
Much Better	41%	46%	41%	44%
Somewhat Better	39%	33%	33 %	39%
Neither Better Nor Worse	19%	18%	25%	13%
Somewhat Worse	1%	2%	0%	3%
Much Worse	0%	1%	0%	1%
No Opinion/ Not Stated	0%	1%	0%	1%

Smoothness of Acceleration

Consumer response to the smoothness of acceleration was also positive as shown in Table 7. 84% of respondents indicated that the smoothness of acceleration was either somewhat better or much better than a typical transit bus. 47% indicated that the smoothness was much better. Only 15% indicated that the smoothness of acceleration was neither better nor worse. Negative indicators were minimal.

Table 7. Smooth Acceleration of HHICE Bus: By Ridership Frequency

	Frequency of Ridership (Weekly)			
Rating	Up to 4 times	5-10 times	Over 10 times	All Frequencies
Much Better	49%	40%	51%	47%
Somewhat Better	35%	43%	32%	37%
Neither Better Nor Worse	15%	15%	15%	15%
Somewhat Worse	1%	1%	1%	1%
Much Worse	0%	1%	0%	0%
No Opinion/ Not Stated	0%	0%	1%	0%

When the data was stratified by age and gender, results were much the same. Much better ratings dominated the frequency results. 45% of respondents who were 34 and younger indicated the bus was "much better". 49% of the respondents who were 35 and older provided a "much better" response. Males and females also had similar favourable perceptions towards the smoothness of acceleration with 48 % of males and 46 % of females finding the acceleration "much better".

Table 8: Smooth Acceleration of the HHICE Bus: By Age and Sex

	Age		Gender	
Rating	Up to 34	35 and over	Male	Female
Much Better	45%	49%	48%	46 %
Somewhat Better	38%	35%	31 %	41%
Neither Better Nor Worse	16%	15%	20%	12%
Somewhat Worse	2%	0%	1%	1%
Much Worse	1%	0%	0%	1%
No Opinion/ Not Stated	0%	1%	0%	1%

Noise Level

With respect to noise level, rider response was also favourable (Table 9). 48% of respondents who rode the bus over 10 times per week thought the bus noise level was "much better". Those who rode up to 4 times also thought the noise level to be "much better", with 41% falling in that category. 37% of riders who used the bus 5 to 10 per week gave the HHICE bus a much better rating with respect to noise levels.

Unlike the previous characteristics, there was a small group of negative responses; with 7% of respondents indicating the noise level was either "somewhat worse" or "much worse".

Table 9. Noise Level of HHICE Bus: By Ridership Frequency

	Frequency of Ridership (Weekly)			
Rating	Up to 4 times	5-10 times	Over 10 times	All Frequencies
Much Better	41%	37%	48%	42%
Somewhat Better	32%	33%	28%	31%
Neither Better Nor Worse	15%	23%	19%	19%
Somewhat Worse	7%	6%	4%	6%
Much Worse	2%	1%	1%	1%
No Opinion/ Not Stated	3%	0%	1%	1%

When the data was split on an age and gender basis the contents of the group providing the negative rating appears to be respondents who were 34 or younger and male. As shown in Table 10, 9% of respondents under the age of 35 provided either a "somewhat worse" or "much worse" ranking. 8% of males fell into the same strata.

Table 10: Noise Level of the HHICE Bus: By Age and Sex

	Age		Gender	
Rating	Up to 34	35 and over	Male	Female
Much Better	38%	49%	43%	42%
Somewhat Better	32%	29%	28%	32%
Neither Better Nor Worse	21%	18%	20%	20%
Somewhat Worse	8%	2%	7%	3%
Much Worse	1%	2%	1%	1%
No Opinion/ Not Stated	2%	1%	1%	2%

4. Customer Acceptance- Hydrogen as a Motive Fuel

As shown in Table 11, hydrogen as a fuel source had a very high level of acceptance across ridership frequencies. Overall 93% of respondents rated hydrogen fuel as either a good or very good idea. No respondent rated it as a poor or very poor idea. About 6% of respondents did not offer an opinion or were unwilling to state their opinion. Potential negative respondents are imbedded in that group.

Table 11. Rating of Hydrogen as a Fuel: By Ridership Frequency

	Frequency of Ridership (Weekly)			
Rating	Up to 4 times	5-10 times	Over 10 times	All Frequencies
Very Good Idea	47%	72%	65%	61%
Good Idea	43%	25%	27%	32%
Neither Good Nor Bad Idea	2%	1%	2%	2%
Poor Idea	0%	0%	0%	0%
Very Poor Idea	0%	0%	0%	0%
No Opinion/Not Stated	8%	2%	6%	6%

Generally, as ridership frequency increases the level of positive ratings also increased. 72 % of respondents who rode the bus between 5 and 10 times per week found hydrogen to be a "very good idea," while 65% who rode over 10 times per week had the same opinion. 43% of respondents who rode under 4 times per week found hydrogen to be a "good idea."

On an age and gender basis the results were similar as shown in Table 12.

Table 12.Rating of Hydrogen as a Fuel: By Age and Sex

	Age		Gender	
Rating	Up to 34	35 and over	Male	Female
Very Good Idea	66%	62%	75%	55%
Good Idea	30%	29%	20%	37%
Neither Good Nor Bad Idea	2%	2%	2%	2%
Poor Idea	0%	0%	0%	0%
Very Poor Idea	0%	0%	0%	0%
No Opinion/ Not Stated	3%	8%	4%	7%

66% of respondents who were 34 or younger thought that hydrogen fuel was a "very good idea," Respondents who were 35 or older had a slightly lower frequency of responding in similar manner. About 30% in each of these age bands consider hydrogen a "good idea".

Overall 95% of males had a positive rating ("very good idea" or "good idea") for hydrogen. Females were similar at 92%; however the strength of the positive response was lower for females than males. Males had a higher percentage in the "very good idea" category, at 75%, compared to females at 55%. 37% of females rated

hydrogen as a “good idea,”, whereas only 20% of males rated hydrogen at this level.

One of the questions that respondents answered was their thoughts on good points of hydrogen fuel. Responses included within the sample were “good for the environment,” “energy efficient,” “safer,” and “cost effective.” 48% of respondents indicated that hydrogen as a fuel was “good for the environment”. Only 5% of respondents indicated that it “saved fossil fuels”.

The survey also probed for negative comments, if any, related to hydrogen. Some of the responses given were, that “hydrogen is more expensive,” “safety issues (hydrogen explosions),” “cold weather operations,” “lack of availability,” and “fossil fuels are still used to produce.” Respondents were spread across categories with the majority, at 43%, stating “nothing” as a bad point to hydrogen. The cost of hydrogen was indicated by 8% of respondents. 3% of respondents indicated safety as a concern.

5. Conclusion

The HHICE Bus survey had respondents rate a variety of different bus attributes, as well as views on hydrogen as an alternative fuel in transit buses.

Overall, respondents viewed the bus and its attributes favourably. Respondents typically rated the attributes of the HHICE bus “much better” than that of regular transit. Overall, there is relatively little variation in these results by age strata or by gender.

As well, the response to hydrogen as a motive fuel was positive.

Reference

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[6] Hickson,A. , Sokol, C., 2005. Hydrogen Hybrid Internal combustion engine Bus Demonstration Canadian Transportation Research Forum, 662-672
[7] Demographic characteristics of the population of Winnipeg are based on Statistics Canada, Census of Canada data. The sample demographics are based on completed surveys.