ANALYSIS OF A NON-RECYCLING HYDRIDE SYSTEM FOR POWERED WHEELCHAIRS

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Introduction

The power wheelchair market reported 93,467 power wheelchair users and 63,636 scooter users in 1996 (1), and the market continues to grow. The current source of power for these devices is wet or gel/sealed lead-acid batteries. These batteries have several disadvantages, creating an incentive for the investigation of a different type of power supply. The batteries are heavy, consume a significant volume in the wheelchair, and require recharging to replenish the power supply. Maintenance is also an issue, particularly with the wet lead-acid batteries.

A proton exchange membrane (PEM) fuel cell using hydrogen stored in sodium hydride was analyzed for its ability to be used as a power supply in wheelchairs. Sodium hydride releases the hydrogen upon reaction with water. Processes have been developed using metal hydrides that evolve hydrogen upon contact with water, but generally prove costly when one includes the cost of regenerating the hydride from the byproduct hydroxide. This analysis chooses a niche market- the power wheelchair market- where recycling would not be necessary. Because the hydride is not recycled, a major cost in the use of hydrides is avoided.

This analysis focuses solely on the power source of the wheelchair, ignoring all costs of the wheelchair itself. As the conventional power source, batteries were researched to determine the type, size, weight, and cost of typical wheelchair batteries. Information about PEM fuel cells and sodium hydride was also gathered to determine these parameters for a PEM fuel cell/sodium hydride power system. The two systems are compared on the basis of user convenience and yearly cost over a ten-year lifetime.

Current Wheelchair Power Systems

Battery Specifications. Wheelchairs are currently powered by wet (flooded) or gel/sealed lead-acid batteries. Gel/sealed lead-acid batteries are considered to be safer because the electrolyte will not spill and cause damage as can the electrolyte in wet lead-acid batteries. For this reason, only gel/sealed lead-acid batteries are approved for air travel (2). Gel/sealed batteries also require less maintenance; however, they are more expensive and provide less energy than a wet lead-acid battery of the same size. These specifications cause some people to purchase both types of batteries in order to have a set for travel and a set for every day use (3).

There are four standard groups of wheelchair batteries that are used for wheelchairs. According to MKBattery.com, they range from 23-63 lbs and 288-850 in^3. All the batteries are 12 volts. A powered wheelchair normally requires 24 volts, so two batteries are required and they are sold in sets of two. The cost ranges from around $150-$450 per set. The specifications provide battery capacities for a total discharge, but actually discharging a battery to this extent would damage it. MK Battery recommends using a 50% depth of discharge for best performance, so the actual amp hours that would be obtained from each battery is half of the listed value. Unless specified otherwise, a 50% depth of discharge (DOD) is assumed for all calculations in this analysis.

It was found that "manufacturers typically recommend gel-cell batteries over wet-cell batteries due to environmental and maintenance concerns with wet-cell batteries" (2), so the gel/sealed MK Batteries are the focus of this analysis. Within this type of lead-acid battery, the group 22NF and group 24 batteries were chosen for further analysis because they offer a middle range, applicable to most wheelchair users.

Total System. The capital cost is simply the cost of the battery charger. The batteries are expected to last one year on average (3, 4), so the costs of the batteries and recharging are added to create the yearly operating costs.

Hydride/Fuel Cell Wheelchair Power Systems

This alternative wheelchair power system involves the use of a PEM fuel cell for the power device and sodium hydride as the fuel source. Upon reaction with water, hydrogen is released, which would then be supplied to the fuel cell for conversion into power. Other than electricity, the fuel cell reaction products are sodium hydroxide and water. The sodium hydroxide could be collected and sold. The water could also be easily collected and disposed of or recycled. This system was chosen for consideration because of its smaller size and weight relative to batteries. Decreasing these parameters would create a higher energy storage capacity and decrease the burden of a heavy and obstructive load on the wheelchair.

Sodium Hydride. Sodium hydride would be used as the source of hydrogen for the fuel cell. Sodium hydride is currently a specialty chemical with a current price of $6.15/lb ($13.53/kg), according to Chemical Market Reporter. This creates a cost of $162/kg of hydrogen. If sodium hydride is used to fuel power wheelchairs, a larger market would be developed and that could bring down the cost. An estimation of the bare cost to produce sodium hydride can be used to estimate a larger production/lower cost case. The conventional process for sodium hydride manufacture involves electrolyzing sodium chloride and then sparging hydrogen gas through a bath of the molten sodium metal. The costs for this process create an estimated sodium hydride cost of $3.41/kg (5). This estimation provides a much lower cost for sodium hydride, making the cost of hydrogen $41/kg. The price does not account for packaging or sales profits, but provides a number for a general, lower cost scenario for sodium hydride.

In order to directly compare the sodium hydride to the battery, the amount of energy provided by each must be equal; therefore, the amount of sodium hydride necessary to provide the same amount of energy as a battery must be calculated. The amount of hydrogen can be estimated using its lower heating value and a fuel cell efficiency of 50%. The quantity of sodium hydride needed to provide this amount of hydrogen can then be calculated.

PEM Fuel Cell. The size of the PEM fuel cell can be estimated by first considering the amount of instantaneous power used by a wheelchair. This is estimated by calculating the kinetic energy needed to move a 170 lb person, 100 lb wheelchair, 2 lbs of sodium hydride, and a 4 lb fuel cell at a speed of 5 miles/hour (84 Wh). Considering the fact that this does not account for friction or uphill operation, and some people will weigh more and want to go faster (to go 7 miles/hour, 156 Wh would be needed), a 160 W PEM fuel cell was chosen for evaluation.

Sale of Sodium Hydride. The by-product of the reaction of sodium hydride with water is sodium hydroxide, which is a useful chemical and could be sold to recover some of the cost of the sodium hydride. Since we consider the wheelchair application to be a niche market, we do not feel that the amount of NaOH produced would be enough to affect the market price. The selling price of sodium hydroxide is estimated at $0.42/kg (6).

Total System. When the system is considered as a whole, it is apparent that the size and weight of the fuel cell, when compared to batteries, decrease the net cost of the fuel supply. The total weight of

the system (fuel cell plus hydride and water) is less than 3 kg, which is significantly lighter than the batteries (around 34 kg). The significant decrease in weight translates into less energy required to power the wheelchair. So the PEM fuel cell/hydride system would actually provide the user with a longer range than a battery system with the same energy. The amounts and costs of sodium hydride were calculated with consideration for the decreased system weight and the sale of sodium hydroxide

The economic feasibility of the system depends largely on the cost of the fuel cell, which for smaller fuel cells such as this could be estimated at $10/W (7). The system is not very realistic if the price of the PEM fuel cell stays at $16,000, but a mass production cost of $1600 would be reasonable considering the benefits that would be gained from a significantly smaller and lighter power system. The size and weight of the fuel cell/hydride system is less than a quarter of the battery system size and weight. The fuel cell/hydride system is also very flexible since the energy storage is a separate component and can be easily increased or decreased simply through the amount of hydride. A user could easily obtain much longer ranges that would be difficult to reach using lead-acid batteries.

Battery vs. Fuel Cell Power System

A comparison of the two wheelchair power supplies is performed by directly comparing the parameters of each system and evaluating the costs over a ten-year lifetime (Table 1). This allows the capital costs to be considered on a yearly basis. A ten-year lifetime is assumed for both the fuel cell and the battery charger, creating yearly costs of $160 and $25, respectively. Because the battery charger cost is not a significant amount and is not always an additional purchase, it is eliminated from these calculations.

Table 1. Power System Comparison over a Ten-Year Lifetime-Very Active User

Parameter	22NF or Equivalent Performance	
	Battery System	Fuel Cell System
Volume	954 in^3	129 in^3
Weight	34.1 kg	2.21 kg
Yearly Cost	$284.60	$1891 (current) $507 (future market)

Parameter	Group 24 or Equivalent Performance	
	Battery System	Fuel Cell System
Volume	1368 in^3	145 in^3
Weight	48.6 kg	2.53 kg
Yearly Cost	$358.62	$2777 (current) $682 (future market)

These calculations assume that the user consumes the maximum battery capacity (50% DOD) all 365 days a year. This is a profile for an extremely active user. Some very active users may require more than one set of batteries to fit their needs, doubling the yearly cost and making the fuel cell system a more competitive choice. Other users will require a less consistent and diminished amount of energy. Because the batteries would still deteriorate after one year even with less use (8), the battery costs remain the same for this type of user while the sodium hydride costs would greatly decrease (Table 2).

Although the fuel cell system costs are still higher than the battery costs, the decreased costs of the sodium hydride lessened the yearly costs of the fuel cell system by a considerable amount. The fuel cell system yearly cost is very dependent on the amount and cost of sodium hydride.

Table 2. Power System Comparison over a Ten-Year Lifetime-Less Active User

Parameter	22NF or Equivalent Performance	
	Battery System	Fuel Cell System
Volume	954 in^3	122 in^3
Weight	34.1 kg	2.04 kg
Yearly Cost	$284.60	$1025 (current) $334 (future market)

Parameter	Group 24 or Equivalent Performance	
	Battery System	Fuel Cell System
Volume	1368 in^3	135 in^3
Weight	48.6 kg	2.27 kg
Yearly Cost	$358.62	$1469 (current) $421 (future market)

Wheelchair users have a variety of lifestyles and it is clear that the benefits of a fuel cell system would weigh against the costs very differently for different users. For example, a user with an average daily energy consumption that was low but still needed a few days of long ranges would be a perfect customer of a fuel cell/hydride system. The flexibility of the system would allow the user to supply themselves with a large amount of energy on those long-range days while requiring small purchases of sodium hydride on a majority of the days. If forced to use batteries, this same user would need to purchase and carry the largest battery for just those few very active days. The users who would be inclined to stick with the conventional battery power supply would be those users that manage to get the most out of their battery. These users would have consistent daily energy needs that match the capacity of the battery sizes available. For some users, the battery sizes available are simply not large enough for all their needs. These users may wish to purchase a fuel cell/hydride system even at very high costs.

The fuel cell/sodium hydride system is capable of fulfilling the needs of users not satisfied with the conventional battery system and can compete with the battery system for certain types of power wheelchair users. If the price of sodium hydride should drop due to a larger market, the cost difference would become small and the advantages of this alternative system would make it very attractive to all wheelchair users.

References

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