Targets for On-Board Hydrogen Storage Systems: Current R&D Focus is on 2010 Targets

Table 1 DOE Technical Targets: On-Board Hydrogen Storage Systems				
Storage Parameter	**Units**	**2007**	**2010**	**2015**
System Gravimetric Capacity: Usable, specific-energy from H_2 (net useful energy/max system mass)[a]	kWh/kg (kg H_2/kg system)	1.5 (0.045)	2 (0.06)	3 (0.09)
System Volumetric Capacity: Usable energy density from H_2 (net useful energy/max system volume)	kWh/L (kg H_2/L system)	1.2 (0.036)	1.5 (0.045)	2.7 (0.081)
Storage system cost [b] (& fuel cost)[c]	\$/kWh net (\$/kg H_2) \$/gge at pump	6 (200) ---	4 (133) 2-3	2 (67) 2-3
Durability/Operability • Operating ambient temperature [d] • Min/max delivery temperature • Cycle life (1/4 tank to full) [e] • Cycle life variation [f] • Min delivery pressure from tank; FC= fuel cell, I=ICE • Max delivery pressure from tank[g]	ºC ºC Cycles % of mean (min) at % confidence Atm (abs) Atm (abs)	-20/50 (sun) -30/85 500 N/A 8FC / 10ICE 100	-30/50 (sun) -40/85 1000 90/90 4FC / 35ICE 100	-40/60 (sun) -40/85 1500 99/90 3FC / 35ICE 100
Charging/discharging Rates • System fill time (for 5 kg) • Minimum full flow rate • Start time to full flow (20 ºC) [h] • Start time to full flow (- 20 ºC) [h] • Transient response 10%-90% and 90% -0%[i]	min (g/s)/kW s s s	10 0.02 15 30 1.75	3 0.02 5 15 0.75	2.5 0.02 5 15 0.75
Fuel Purity (H_2 from storage)[j]	% H_2	99.99 (dry basis)		
Environmental Health & Safety • Permeation & leakage [k] • Toxicity • Safety	Scc/h - -	Meets or exceeds applicable standards		
• Loss of useable H_2 [l]	(g/h)/kg H_2 stored	**1**	**0.1**	**0.05**

Useful constants: 0.2778kWh/MJ, ~33.3kWh/gal gasoline equivalent.

Note: Above targets are based on the lower heating value of hydrogen and greater than 300-mile vehicle range; targets are for a complete system, including tank, material, valves, regulators, piping, mounting brackets, insulation, added cooling capacity, and/or other balance-of-plant components. Unless otherwise indicated, all targets are for both internal combustion engine and for fuel cell use, based on the low likelihood of power-plant specific fuel being commercially viable. Also note that while efficiency is not a specified target, systems must be energy efficient. For reversible systems, greater than 90% energy efficiency for the energy delivered to the power plant from the on-board storage system is required. For systems generated off-board, the energy content of the hydrogen delivered to the automotive power plant should be greater than 60% of the total energy input to the process, including the input energy of hydrogen and any other fuel streams for generating process heat and electrical energy.

Footnotes to Table 1

[a] Generally the 'full' mass (including hydrogen) is used, for systems that gain weight, the highest mass during discharge is used.

[b] 2003 US$; total cost includes any component replacement if needed over 15 years or 150,000 mile life.

[c] 2001 US$; includes off-board costs such as liquefaction, compression, regeneration, etc; 2015 target based on H_2 production cost of $2 to $3/gasoline gallon equivalent untaxed, independent of production pathway.

[d] Stated ambient temperature plus full solar load. No allowable performance degradation from –20C to 40C. Allowable degradation outside these limits is TBD.

[e] Equivalent to 100,000; 200,000; and 300,000 miles respectively (current gasoline tank spec).

[f] All targets must be achieved at end of life.

[g] In the near term, the forecourt should be capable of delivering 10,000 psi compressed hydrogen, liquid hydrogen, or chilled hydrogen (77 K) at 5,000 psi. In the long term, it is anticipated that delivery pressures will be reduced to between 50 and 150 atm for solid state storage systems, based on today's knowledge of sodium alanates.

[h] Flow must initiate within 25% of target time.

[i] At operating temperature.

[j] The storage system will not provide any purification, but will receive incoming hydrogen at the purity levels required for the fuel cell. For fuel cell systems, purity meets SAE J2719, Information Report on the Development of a Hydrogen Quality Guideline in Fuel Cell Vehicles. Examples include: total non-particulates, 100 ppm; H_2O, 5 ppm; total hydrocarbons (C_1 basis), 2 ppm; O_2, 5 ppm; He, N_2, Ar combined, 100 ppm; CO_2, 1 ppm; CO, 0.2 ppm; total S, 0.004 ppm; formaldehyde (HCHO), 0.01 ppm; formic acid (HCOOH), 0.2 ppm; NH_3, 0.1 ppm; total halogenates, 0.05 ppm; maximum particle size, <10 µm, particulate concentration, <1µg/L H_2. These are subject to change. See Appendix F of DOE Multiyear Research, Development and Demonstration Plan (www.eere.energy.gov/hydrogenandfuelcells/mypp/) to be updated as fuel purity analyses progress. Note that some storage technologies may produce contaminants for which effects are unknown; these will be addressed as more information becomes available.

[k] Total hydrogen lost into the environment as H_2; relates to hydrogen accumulation in enclosed spaces. Storage system must comply with CSA/NGV2 standards for vehicular tanks. This includes any coating or enclosure that incorporates the envelope of the storage system.

[l] Total hydrogen lost from the storage system, including leaked or vented hydrogen; relates to loss of range.

Basis for Targets

Background

Early materials-based targets for onboard hydrogen storage systems were well designed to promote scientific research in the critical area of hydrogen storage. Promising new technologies were nurtured under these targets, and meaningful improvements in existing technologies were achieved. The focus now swings from demonstrating possibilities to making commercially viable components and products. Logically there is a concomitant change from discovery-oriented targets to engineering-oriented targets, and target levels are increasingly driven by system needs and customer expectations. In addition, the storage system must strive to serve both ICE and fuel cell vehicles. These system targets are aggressive (e.g. 9 wt%). They are not meant to extend what is known by another incremental step, rather they are a challenge to the industrial and scientific communities to reach in terms of innovative, even radical, new ways to achieve what the consumer expects: a hydrogen vehicle that does everything current vehicles do, at a similar cost, but with the societal advantages of hydrogen. The targets are based on the U.S. weighted average corporate vehicle (WACV) that includes minivans, light trucks, economy cars, and SUV/crossover vehicles in proportion to their sales. Depending on progress in other areas related to hydrogen vehicle development, these targets may have to be altered and will be periodically revisited.

System Gravimetric Capacity: Usable specific energy from hydrogen, net

This is a measure of the specific energy from the standpoint of the total onboard storage system, not just the storage medium. The term specific energy is used interchangeably with the term gravimetric capacity. The storage system includes interfaces with the refueling infrastructure, safety features, the storage vessel itself, all storage medium, any required insulation or shielding, all necessary temperature/humidity management equipment, any regulators, electronic controllers, and sensors, all on-board conditioning equipment necessary to store the hydrogen (compressors, pumps, filters, etc.), as well as mounting hardware and delivery piping. Obviously, it cannot be so heavy as to preclude use on a vehicle. Further, the fuel efficiency of any vehicle is inversely related to the vehicle's mass. If the intent is to create an efficient, and thus lightweight vehicle, and to have it meet all customer expectations in terms of performance, convenience, safety, and comfort, then the total percentage of the vehicle weight devoted to the hydrogen storage system must be limited. These targets lead to the ultimate goal of greater than 300 mile range in such a vehicle by the year 2015, and are suitably discounted in earlier years based on the assumptions of the expected vehicle usage and customers for those initial vehicles.

The targets are based on customer expectations, rather than on the capabilities of the current candidates for hydrogen storage. For reference, the total fuel system in the WACV with a weight of about 1740 kg with a fuel capacity of 19.8 gallons and a resultant range (@ 18.7 mpg) of 370 miles, has a mass of about 74 kg (including 55.4 kg of fuel). (The above fuel economy includes the EPA adjustment factor.) The energy in that fuel totals (33.3 kW-h/gal x 19.8 gallons =) 659 kWh, and the resultant specific energy is (659/74) = 8.9 kWh/kg. For fuel economy gains of 2.5 and 3.0X, the corresponding specific energy for the WACV are approximately 3.5 and 3 kWh/kg, respectively. Obviously, these targets include an expectation that vehicle and powertrain efficiency improvements will be forthcoming. The target is in units of net useful energy in kWh per maximum system mass in kg. "Net useful energy" is used to account both for unusable energy (i.e. hydrogen left in a tank below minimum powertrain system pressure requirement) and for hydrogen-derived energy used to extract the hydrogen from the storage medium (e.g. fuel used to heat a hydride to initiate or sustain hydrogen release). "Maximum system mass" implies that all of the equipment enumerated above plus the maximum charge of hydrogen are included in the calculation. Reactive systems increase in mass as they discharge; in such systems the discharged mass is used. Light duty vehicles with current fuel cell efficiencies of ~50% were used to estimate the targets below.

Usable, specific-energy from H_2 (H_2 mass/max system mass)	kWh/kg net	1.5	2	3

System Volumetric Capacity: Usable volumetric energy density from hydrogen, net

This is also a measure of energy density from a system standpoint, rather than from a storage medium standpoint. The term energy density is used interchangeably with the term volumetric capacity. As above, the on-board hydrogen storage system includes every component required to safely accept hydrogen from the delivery infrastructure, store it on board, and release conditioned hydrogen to the powerplant. Again, given vehicle constraints and customer requirements (i.e. aerodynamics for fuel economy, luggage capacity for people), the system cannot take up too much volume, and the "shape factor" that the volume occupies becomes important. Also, as before, any unusable fuel must be taken into account. The targets assume both increased vehicle efficiency and the ability to store hydrogen in volumes that are currently dedicated to systems that may not be required in a hydrogen-fueled vehicle (i.e. a catalytic converter or muffler). For reference, the WACV described above (with a roughly 20-gallon tank) has a total fuel system volume of about 107 liters (including tank with vapor space, filler tube, pump, filter, fuel lines, vapor canister, valves, and mounting straps), stored energy of about 659 kWh, and a resultant usable energy density of about (659/107 =) 6.15 kWh/L net. For fuel economy gains of 2.5 and 3.0X, the energy density is approximately 2.5 kWh/L and 2 kWh/L, respectively. Today's gasoline tanks are considered conformable. Conformability requires a tank to take irregular shapes, and to "hug" the space available in the vehicle, but right angle bends and inch wide protuberances are not required. For conformable fuel tanks the required volumetric energy density may be reduced up to 20% because space not allocated for fuel storage may be used without a penalty. Because early hydrogen storage systems may not be completely conformable, an additional 20% is added to these targets to give approximately 3 kWh/L and 2.5 kWh/L for fuel economy gains of 2.5 and 3.0X respectively. The target is set at 2.7 kWh/L. By contrast liquid hydrogen by itself has a density of 2.35 kWh/L. The targets are in units of net usable energy in kWh per system volume in liters. Light duty vehicles with current fuel cell efficiencies of ~50% and non-conformable fuel tanks (e.g., spherical or cylindrical storage tanks) were used to estimate the targets below.

Usable energy density from H_2	kWh/L net	1.2	1.5	2.7

Specific storage system cost:

This target refers to the total projected cost of the entire on-board hydrogen storage system, including all hardware and storage media, plus an amortized estimate for any components or media that would have to be replaced for the system to demonstrate a useful life of 150,000 miles in a vehicle. It is understood that the onboard fuel storage system for a hydrogen fueled vehicle may never reach the low cost of a fuel system in a current production vehicle, but it is expected that the societal benefits of hydrogen vehicles, combined with potential cost offsets and improved vehicle and powertrain efficiencies, will justify these targets. The target is in units of (2003 US) dollars per kW-h of usable energy capacity ("usable energy" has been previously defined). The use of constant dollars is to facilitate direct comparisons. For reference, the example WACV would have a system cost of about $269 and a usable capacity of 659 kWh, for a resultant specific storage system cost of $0.41/kWh. Accounting for 2.5 and 3.0X fuel economy gains, the cost becomes $1.03-$1.23/kWh. Note that the cost of the *first* charge (and any additional costs associated with the first charge such as preconditioning cost), is included in the specific storage system cost, regardless of storage method (e.g. high pressure tanks, chemical storage, metal hydrides, etc.). For example, if the first charge is 8 kg of hydrogen at a cost of $2.50/kg (within the cost target of $2 to $3 per kg hydrogen) the specific storage system cost is approximately $1.30/kWh, assuming a 3.0X fuel economy gain. Targeting for cost competitiveness in 2015, the cost target has been set at $2/kWh.

Specific storage system cost	$/kW·h net (2003 US$)	6	4	2

Fuel cost:

This target is meant to provide guidance for chemical storage systems that are regenerated off-board. It also includes costs for compression, liquefaction, delivery, chemical recovery, etc. as required. The cost of regenerating by-products must be considered in terms of the fuel cost targets. This target reflects hydrogen cost independent of production pathway. Although fuel cost targets prior to 2015 are not pathway independent and thus not specified for all potential pathways (e.g., natural gas reforming, biomass, electrolysis, photobiological, etc.), an approximate hydrogen cost of $4 to $5/kg can be used for estimating storage system cost in the near term. The unit of $/gallon gasoline equivalent (gge) is equivalent to $/kg of hydrogen.

Fuel cost	2001 US$/ gallon gasoline equivalent (pump price)	- ----	2 to 3	2 to 3

Durability/Operability:

Operating temperature (/solar load): The storage system must dependably store and deliver hydrogen at all expected ambient conditions. The operation range expands with time. This reflects the expectation that the limited demo fleets will experience a less severe subset of ambient conditions. As commercial sales begin the vehicles can be expected to experience the full range of conditions, and eventually will be expected by consumers to operate perfectly in any weather encountered. The units are degrees C. The notation (sun) indicates that the upper temperature is a hot soak condition in full direct sun, including radiant heat from the pavement.

Operating ambient temperature	°C	-20/50 (sun)	-30/50 (sun)	-40/60 (sun)

Minimum/maximum delivery temperature of H_2 from tank: Fuel cells currently operate at approximately 80 C. If the temperature exceeds 100°C operation is unacceptable. In addition, if hydrogen enters above the cell temperature, this adds to the already significant water management and heat rejection problem. Thus, an upper limit on temperature is desirable. The value of 85 C is selected based on today's PEMFC technology. Over time, a higher value such as 100 C may be substituted because fuel cells are likely to operate at increasingly higher temperatures, and as the fleet size is increased, it will also become increasingly important that the storage system comply more closely with the fuel cell preferred operating range. The lower limits reflect both wider acceptance of fuel cells in varying climates and fuel cell improvements for lower temperature operation. The units are degrees C.

Delivery temperature of H_2 from tank	°C	-30/85	-40/85	-40/85

Cycle life: Customers expect the fuel system to last the life of the vehicle, typically 150,000 miles. Assuming a 300mile range, that amounts to 500 full fill cycles. Many customers fill at partial capacity rather than at empty, requiring more fill cycles which implies more exposure to refill conditions and more time at the maximum fill level. Demo fleets may not require the customer expected durability, so 500 cycles is acceptable. Once wider sales start, 150000-mile life will be expected so an engineering factor is applied to ensure product reliability. At full fleet capability the risk increases and the engineering factor is raised to near that expected of gasoline. The units here are simply the number of cycles that must be demonstrated as a mean value. The cycle is defined as going from quarter full to full.

Cycle life (1/4 tank to full)[i]	Cycles	500	1000	1500

Cycle life variation: Manufactured items have item-to-item variation. The variation as it affects the customer is covered by the cycle life target; the variation as it affects testing is covered in this target. It is expected that only one or two systems will be fabricated to test life of early concepts. The data generated has great uncertainty associated with it due to the low number of samples. Thus a factor is required to account for this uncertainty. The effect is to increase the required cycle life based on normal statistics using the number of samples tested. The value is given in the form XX/YY where XX is the acceptable percentage of the target life (90 means 90%), and YY is the percent confidence that the true mean will be inside the xx% of the target life (95 indicates 95% confidence or an alpha value of 0.05). For demonstration fleets this is less critical and no target is specified to functionally enable single specimen testing. Variation testing needs to be included for general sales. By the time full fleet production is reached, testing levels will also need to tighten, but availability of multiple samples will no longer be a problem. This entire sequence is standard practice in the mass production of automobiles and their components. Units are in minimum percent of the mean and a percentage confidence level.

Cycle life variation	% of mean (min) @ % confidence	N/A	90/90	99/90

Delivery Pressure from hydrogen storage system (minimum acceptable): This target acknowledges that the onboard hydrogen storage system is responsible for delivering hydrogen in a condition that the powerplant can use. Since there can be no flow without a pressure differential, a minimum supply pressure is required just to move the hydrogen from the bulk storage to the powerplant. If the hydrogen were merely available at the entrance to a fuel cell, for instance, any pumps necessary to push or draw that fuel through the stack would be considered part of the fuel storage system. This is the only target that is different for fuel cells and for internal combustion engines. This is because the IC technology relies on pressurized fuel injection, and is envisioned to advance from low-pressure central or port injection to high-pressure in-cylinder direct injection by 2010. The units are in kilopascals and bar (roughly, standard atmospheres) absolute pressure.

Delivery pressure (minimum acceptable at full flow) FC=fuel cell, ICE = internal combustion engine	Atm (abs)	FC: 8 ICE: 10	FC: 4 ICE: 35	FC: 3 ICE: 35

Delivery Pressure from hydrogen storage system (maximum acceptable): This target is for the pressure delivered from the on-board hydrogen storage system to the automotive power plant. This target ensures that the on-board hydrogen storage system should not be designed such that extraordinary measures for pressure regulation are required before fuel is supplied to the fuel cell system.

Delivery pressure (maximum)	Atm (abs)	100	100	100

Charging/Discharging Rates:

System fill time (5-kg H_2 system): Consumers expect to refuel a vehicle quickly and conveniently, especially on extended trips. The filling target is designed to parallel current customer experience.

Currently, gasoline vehicles are filled in about 2-5 minutes, with small vehicles taking less time and large ones more time. Based on the expected efficiency of fuel cell vehicles, 5 to 13 kg of hydrogen will be needed for light duty vehicles. The target applies to systems with 5 kg H_2 *or less*, with larger systems requiring proportionally more fill time. The long-term goal is to achieve near parity with current gasoline filling times. Demo fleets could operate with longer fill times. The units are minutes.
Important note for scale models with less than 5kg of hydrogen: For scale models of solid-phase storage systems, one should keep the fill <u>time</u> constant - realizing that fill time involves not only delivery of the hydrogen, but also heat transfer and kinetic factors (in solid phase storage options) - and instead scale the mass flow rate to the scale model's size. For example, a laboratory scale system with 200 mg of metal hydride should achieve complete adsorption during recharging within 3 minutes to be consistent with 2010 targets.

System fill time (5 kg)	min	10	3	2.5

Minimum full-flow rate: This target is a measure of the maximum flow rate of hydrogen required by the powertrain to achieve the desired vehicle performance. It is based on an average 3000 lb. current production vehicle, which typically has a powerplant of about 150kW, but modified to account for a FreedomCAR goal of 45% efficiency for a hydrogen-powered internal combustion engine. It is based on actual measured maximum gasoline fuel flow. This should not be considered only a transient phenomenon (though a vehicle would not accelerate through an entire tank of fuel, it might be called upon to tow a large, heavy trailer up an 18-mile grade, such as is found on Interstate 5 near Baker California). However, because fuel cell efficiency is poorest at full load, while ICEs are at or near their highest efficiency at full load, fuel cell vehicles will require the 2005 target level. Fuel cells are not likely to require the increase in this requirement with time. Several comments are in order here. These targets will ensure that, whatever the motive technology, the storage systems will be capable of meeting its requirements. Further, it protects for the possibility that IC engines powered by hydrogen may actually precede FC vehicles to market (and thus help to create a need for a hydrogen infrastructure). Second, this target is still quite limited, as it neglects the requirements of the ICE powered SUV/minivan/light truck segment, which currently makes up 50% of the market. Finally, this target is intended to indicate the potential for scalability for the hydrogen storage technology. This target is in units of mass/time normalized to powerplant size.

Minimum full flow	(g/sec)/kW	.02	.02	.02

Start time to full-flow at 20°C:
The vehicle may be able to start based on hydrogen in the lines, but to maintain adequate function without the need for a second energy storage medium (batteries), full flow must be available almost instantly. Customers are currently accustomed to sub second start times. And full power available on demand any time after the key is released. The units for this target are seconds after start. Early demo fleets may not require starting times that rival current ICE technology, so a longer time is allowed. However, once large-scale production is started a value near that of an ICE is given. This need not mean the entire storage system must start in 5 seconds- only that it is capable of delivering fuel at maximum flow if requested. A small, moderate pressure buffer could serve to lengthen the true start up time. The mass and volume of the buffer would be charged against the system mass and volume. The target start time to achieve 50% rated power for the complete fuel cell system is 30 seconds (for 2005) and 5 seconds (for 2010 and 2015). The storage system targets for start time to full-flow are set to meet the overall powerplant needs. In addition, the storage system must provide some flow to the powerplant within 25% of the time target for full-flow.

Start time to full flow at 20°C	Sec	15	5	5

Start time to full-flow at minimum ambient (-20 C):
See Start time at 20°C. The longer times reflect current customer expectation that in cold weather starting is more difficult. It is important to note that batteries are at their worst power capabilities at very low temperature. If a battery assist were contemplated, the battery system would likely have to be sized based on this starting condition, and thus would be rather large. This is why it is desirable to avoid batteries if possible. The target start time to achieve 50% rated power for the complete fuel cell system at –20 C is 60 seconds (for 2005) and 30 seconds (for 2010 and 2015). Consistent with the above target, some flow will be required to the powerplant within 25% of the full-flow target time. Given the possibility that some hydrogen may be used to assist with cold start of the powerplant, the storage system is set to achieve full-flow within 50% of the start time for the powerplant. Units are in seconds.

Start time to full flow at min ambient	Sec	30	15	15

Transient response 10% to 90% and 90% to 0%: Transient response is one of the greatest challenges a vehicle powertrain faces. The storage system must track the needs of the fuel cell closely to provide adequate power and a suitable driving experience and must meet the fuel cell system requirement of 2 seconds (2005 target) and 1 second (2010 and 2015 targets). The transient response is not symmetric. The 10 to 90% transient target is to meet the demand of the fuel cell or ICE during acceleration. The 90 to 0% transient reflects the fact the fuel cell can stop using hydrogen almost instantly and the fuel supply must stop quickly enough to avoid over-pressuring any part of the system. This parameter impacts performance, fuel cell durability, and vehicle control. The units are seconds to change between 10% flow and 90% flow, or 90% flow and no flow.

Transient response 10% to 90% and 90% to 0%	Sec	1.75	0.75	0.75

Purity:

Hydrogen must be relatively pure going to the fuel cell or system efficiency will be degraded; ICEs are much more forgiving, though an exhaust after-treatment system may not be. Units are in volume % on a dry basis. Even inert impurities can degrade performance by progressively diluting the hydrogen at the anode, and necessitating venting of the anode, including some of the stored hydrogen. See target table footnote for specific impurity levels. It is also assumed that impurities from the hydrogen source do not degrade storage system performance. In other words, the hydrogen output from the storage system should be able to meet fuel cell purity targets without contaminating the 99.99% hydrogen input to the storage system. The fuel purity requirements are set to meet ISO specification ISO/PDTS 14687-2. The specification is an interim document and, as additional operational experience is gained with the existing fleet of fuel cell vehicles, it will likely be modified. See Appendix F of DOE Multiyear Research, Development and Demonstration Plan (www.eere.energy.gov/hydrogenandfuelcells/mypp/), to be updated as fuel purity analyses progress.

Purity of H_2 from tank	% (dry)	99.99	99.99	99.99

Environmental, Health & Safety:

Permeation/leakage, toxicity and safety: These targets are of great importance because they deal with protecting the health and well being of the owner. These types of concerns are generally regulated by the government. Only the permeation and leakage target has a clear set of units, standard cc of hydrogen per hour. Permeation and leakage is differentiated from hydrogen loss in that hydrogen that leaves the storage system but is first transformed into another species (e.g. water, via catalytic oxidation in a vent line) is not included in permeation and leakage but would be included in hydrogen loss. Permeation and leakage thus pertains to the possibility of generating a combustible hydrogen-air mixture outside the storage tank. Toxicity covers the possibility of consumer exposure to the storage material in normal, or abnormal conditions, plus worker exposure during manufacture and assembly. Safety covers all the typical safety statutes including certification and operation of vehicles, manufacture, transport, dispensing of fuel, and end of life issues. In each of these categories, compliance with federal standards, and potentially state and local standards will be required.

Permeation and leakage	Scc/h	Meets or exceeds applicable standards
Toxicity		Meets or exceeds applicable standards
Safety		Meets or exceeds applicable standards

Hydrogen loss: This target protects against loss of range after extended periods of rest, for example parking during a vacation. Demonstration fleets are not expected to operate extensively in the normal consumer cycle, and the owners are better prepared to deal with low fuel situations, thus a lower standard is required. Vehicles purchased by consumers will be expected to have minimal perceptible loss of range after a week or two of parking, similar to gasoline vehicles today. Because the targets are normalized to mass of hydrogen stored, this target protects all tank sizes equally. At a value of 0.1, a full tank will require more than a year to empty. The units are g/h of hydrogen lost via all routes, per kg of hydrogen stored.

Loss of useable hydrogen	(g/h)/kg H_2 stored	1	0.1	0.05