Available at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/he

Comments on solid state hydrogen storage systems design for fuel cell vehicles

David Wenger[a,*], *Wolfgang Polifke*[c], *Eberhard Schmidt-Ihn*[a], *Tarek Abdel-Baset*[b], *Steffen Maus*[a]

[a]*Daimler AG, Kirchheim/Teck-Nabern, Germany*
[b]*Chrysler LLC, Auburn Hills, MI, USA*
[c]*TU München, Lehrstuhl für Thermodynamik, Garching, Germany*

ARTICLE INFO

Article history:
Received 15 January 2008
Received in revised form
24 February 2009
Accepted 19 May 2009
Available online 3 July 2009

Keywords:
Fuel cell vehicle
Hydrogen storage
Metal hydride
Requirements

ABSTRACT

In recent years, significant research and development efforts were spent on hydrogen storage technologies with the goal of realizing a breakthrough for fuel cell vehicle applications. This article scrutinizes design targets and material screening criteria for solid state hydrogen storage. Adopting an automotive engineering point of view, four important, but often neglected, issues are discussed: 1) volumetric storage capacity, 2) heat transfer for desorption, 3) recharging at low temperatures and 4) cold start of the vehicle. The article shall help to understand the requirements and support the research community when screening new materials.

1. Introduction

Hydrogen powered fuel cell vehicles represent one option to face the challenges of increasing individual mobility demands and decreasing oil reserves. While the protection of the environment and climate is the main reason for the development of this technology in Europe and Japan [1,2], the reduction of dependence on oil imports from politically unstable regions is the main goal in the US [3]. Furthermore, with such technologies, the car manufacturers also expected to develop competitive advantages by demonstrating sustainability, innovation and technology leadership. Significant progress has been achieved during the last 15 years. Nevertheless considerable challenges in terms of technology, infrastructure development and cost reduction have to be overcome before fuel cell vehicles will evolve from demonstration objects to a real business case.

Adopting a vehicle engineering point of view, the present paper discusses four important requirements on solid state hydrogen storage systems for fuel cell vehicle applications: volumetric vs. gravimetric storage capacity, refueling time at low temperatures, heat transfer for desorption and cold start capability. It will be seen that adopting an automotive engineering perspective leads to non-trivial, sometimes surprising conclusions regarding the formulation of design targets for solid state hydrogen storage system development.

* *Corresponding author at*: Present address: Wenger Engineering GmbH, Schillerstraße 18, D-89077 Ulm, Germany. Tel.: +49 163-8641621; fax: +49 731142354.
E-mail address: david.wenger@wenger-engineering.de (D. Wenger).
0360-3199/$ – see front matter
doi:10.1016/j.ijhydene.2009.05.072

Table 1 – Requirements of a fuel cell vehicle on hydrogen storage systems [13,14].

Range	600 km
Usable hydrogen mass	6–10 kg
Hydrogen delivery rate	0–2 g/s
Hydrogen delivery pressure	approx. 0.8 MPa
Operating temperature	−40 to 85 °C
Refueling time	≤3 min (98% capacity)
Cold start	Like diesel engine

2. Requirements

Table 1 lists some important requirements on hydrogen storage systems imposed by a typical 100 kW fuel cell vehicle. From a user's perspective, vehicle range is perhaps the most obvious design objective. The data in Fig. 1 indicate clearly that the range of current fuel cell vehicles is unsatisfactory, due to the difficulties of onboard hydrogen storage.

The mass of fuel required for a certain range can be derived directly from the specific energy consumption of the vehicle, see Fig. 2. Most fuel cell vehicles have a specific consumption in the order of 1–1.2 MJ/km, which corresponds to roughly 1 kg of hydrogen per 100 km.

The weight and volume of different vehicular hydrogen storage systems are shown in Fig. 3. Apparently, high pressure systems have by far the best gravimetric capacity, a factor of crucial importance in vehicle engineering. Hence high pressure storage was used in more than 90% of the fuel cell vehicles introduced in the last years [6]. Although 70 MPa high pressure storage can be regarded as the state-of-the-art in hydrogen storage, the volumetric capacity of this technology is still significantly below design targets stated, e.g. by DoE [11]. This shortcoming, combined with restrictions in tank design, is the main reason for the low range of current hydrogen-fueled vehicles.

Solid state hydrogen storage is a technology that has demonstrated significantly higher volumetric capacity, see again Fig. 3. The identification of storage materials with higher capacity is an active area of ongoing research. It is the objective of the present paper to identify proper design objectives, which should guide the further development of solid state hydrogen storage materials suitable for fuel cell vehicle applications.

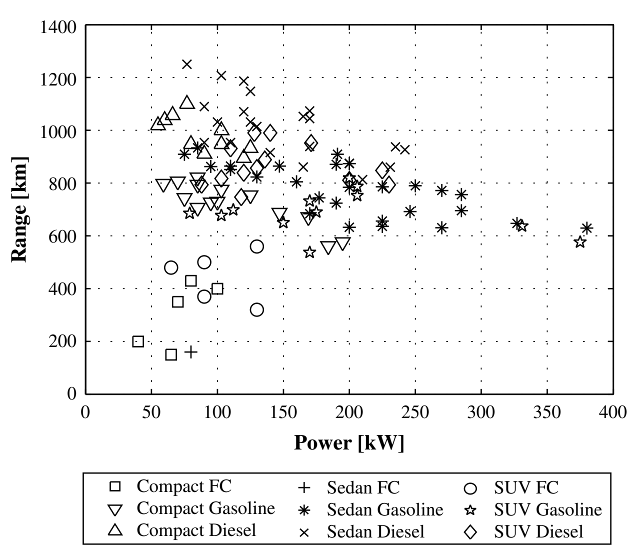

Fig. 1 – Range as a function of installed power in current fuel cell-, gasoline- and diesel-powered vehicles [4,5].

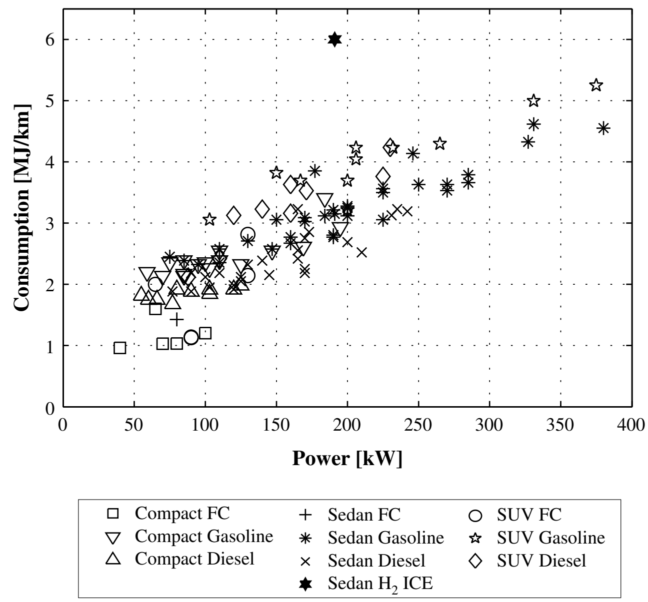

Fig. 2 – Specific energy consumption of different vehicles [4,5].

2.1. *Gravimetric vs. volumetric storage capacity*

A disadvantage of metal hydride storage systems is in general the high weight due to the low gravimetric storage capacity of thermodynamically suitable materials. Recently, many classes of materials were found to be technically reversible at moderate pressures, e.g. alanates [15], amide/hydride-systems [16] and borohydrides [17] (see Table 2). Also, kinetically stabilized materials that are supposed to be regenerated

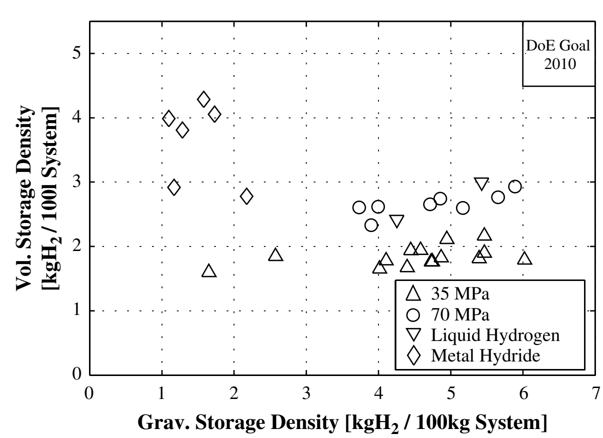

Fig. 3 – Volumetric and gravimetric storage density of different automotive hydrogen storage systems [7–9,10–12].