2nd Decision Deck Workshop – Université Paris Dauphine – November 15-16, 2007

An MCDA approach for evaluating hydrogen storage systems for future vehicles

F. MONTIGNAC
Commissariat à l'Energie Atomique
Département des Technologies de l'Hydrogène
Laboratoire d'Essais et de Validation des composants Hydrogène et Pile à Combustible
17, rue des Martyrs - 38054 Grenoble – France
florent.montignac@cea.fr

Keywords:
Hydrogen technologies, hydrogen storage, evaluation, MACBETH

Abstract:
Research for new energy technologies is a major issue for the future. Hydrogen energy is often considered as one possible solution to overcome global warming and climate change phenomena. A wide variety of technologies is currently being investigated all over the world in the fields of hydrogen production (water electrolysis, natural gas reforming, thermochemical cycles, biomass gasification…), hydrogen storage (compressed gaseous hydrogen, liquid hydrogen, metal hydrides…), hydrogen distribution (gaseous hydrogen by pipelines or trucks, liquid hydrogen by trucks…) and final use (polymer electrolyte membrane fuel cells, solid oxide fuel cells, internal combustion engines…). The evaluation of the performances of these technologies is necessary for orientating Research and Development towards the most promising solutions. This study illustrates the implementation of an innovative MCDA approach for evaluating the performances of on-board hydrogen storage systems.

Compared to other fuels, hydrogen is characterized by a high gravimetric energy density (120.1 MJ/kg, versus 42.0 MJ/kg for oil) and, in standard conditions, by a very low volumetric energy density (0.011 GJ/m^3, versus 34.5 GJ/m^3 for oil, i.e. 3136 times lower than oil). In order to increase its volumetric energy density, hydrogen is stored in gaseous form (compressed gas), or as a liquid (20K) and also in solid media. Compressed and liquid storage technologies are rather established methods but still have some limitations concerning safety, hydrogen losses (boil-off phenomenon for liquid technology) and their energy intensive character (compression, liquefaction). Solid state storage appears as a possible attractive alternative due to its higher safety and volumetric energy density but improvements have to be made in order to increase gravimetric energy density, thermal management and up-scaling.

The aim of this study is to interact with car manufacturers in order to obtain a global positioning of the performances of the currently developed hydrogen storage technologies regarding final applications requirements. The approach is illustrated considering five technical evaluation criteria: system volume (l), system mass (kg), refuelling time (min), hydrogen loss rate (g/h/kg$_{H2}$) and conformability (adimensional). The MCDA method illustrated here is the MACBETH method (Measuring Attractiveness by a Categorical Based Evaluation TecHnique) which has been proposed by Carlos Bana e Costa, Jean-Marie De Corte and Jean-Claude Vansnick [1]. This method appears particularly adapted for the aggregation of evaluation criteria when both absolute and relative information are required (positioning the alternatives taking into account specific targets) and when various types of quantitative and qualitative data have to be processed (in our example, various units are used to measure the performances of the hydrogen storage systems and additionally "conformability" is measured qualitatively). Additionally the MACBETH method is associated to a user friendly decision support system (M-MACBETH) [2] which helps for the implementation of the whole multicriteria evaluation-aiding process. The method relies on a cardinal multicriteria aggregation procedure. At first its aim is to translate the performances $g_i(a)$ of the alternative a regarding each criterion g_i into a new performance $v_i(g_i(a))$ representing the attractiveness of the alternative a on a normalized scale. Secondly "scale constants" w_i are determined for each evaluation criterion in order to proceed to a weighted sum of the normalized scales. In other words, considering n evaluation criteria, the performance $v(a)$ of an alternative a can be modelled by the following formula:

$$v(a) = \sum_{i=1}^{n} w_i v_i (g_i (a)) \tag{1}$$

The implementation of MACBETH method is done interviewing a decision maker and determining with him/her scales of attractiveness v_i and scale constants w_i. In the example of the evaluation of hydrogen storage technologies for automotive applications, the interviewed decision maker is a car manufacturer.

One of the particularities of the MACBETH method is the introduction of two reference levels that have to be defined for each evaluation criterion. One level is called "acceptable" and the other level is called "satisfying". In the case of the evaluation of R&D, the following definitions have been chosen for these two levels:

- "acceptable level": level below which an important R&D effort will be required to allow the adoption of the technology.
- "satisfying level": level above which the criterion is a strong point of the technology and R&D for improving the performance regarding the studied criterion is not a priority.

At the end of this step, five new numerical scales of attractiveness are obtained (corresponding to the five technical evaluation criteria), each one being normalized with the acceptable reference level at 0 and the satisfying reference level at 100. Further, scale constants (weights) w_i are determined in order to proceed to the aggregation of these new normalized scales of attractiveness. In MACBETH method, these constants are determined through the definition of fictitious alternatives f_i. A fictitious alternative f_i is characterized by a satisfying performance for criterion g_i and acceptable performances for all other criteria.

To conclude, the evaluation of the performances of hydrogen technologies is necessary for orientating Research and Development efforts towards the most promising solutions. This study shows that the implementation of multicriteria evaluation-aiding methods such as MACBETH method can help decision makers of the hydrogen field in positioning the developed technologies with regard to specific final applications, by modelling their priorities between evaluation criteria as well as the eventual non linearity of their judgments on each evaluation criterion. Further, results obtained from the implementation of such a method can be used for the communication of detailed technical targets and R&D priorities towards technological partners. In this study the case of the hydrogen storage technologies is illustrated from a technical point of view. However, in the framework of a global evaluation and comparison of these technologies, other evaluation domains such as economics, environmental impacts, safety issues and social acceptance have to be taken into account.

References

[1] BANA e COSTA C., DE CORTE J.M., VANSNICK J.C., *MACBETH*, LSE OR Working Paper, London School of Economics, 2003

[2] M-MACBETH decision support system, available at http://www.m-macbeth.com