Current Status and Future Perspectives of Clean Energy Technologies in UFSCar

Walter Libardi
Federal University of São Carlos(UFSCar), Brazil

1. Introduction

Despite the fact that the Brazilian energy matrix is considered one of the most renewable in the world, the country still presents a high consumption of fossil energy. Taking into account oil for motor vehicles, natural gas and coal for thermoelectric and plants, Brazil´s dependence is considerably high. Hydroelectric energy is the main source of energy to produce electricity in the country, although with only 25% of hydrological potential being used. Another issue concerns the high costs and time involved in dam construction, impracticable for generating energy. Consequently, there has been a decrease in the construction of hydroelectric plants mainly due to limited access to the hydrological potential, delays related to the environmental legislation and permission processes for dams and reservoirs as well.

In 2002 the Brazilian government created the PROINFA program with the following objectives: increasing the participation of alternative renewable sources such as wind and biomass and reducing the greenhouse effect. In Brazil, biomass has been used in the domestic energy supply from materials like sugarcane, eucalyptus and residues.

Brazil has an enormous potential to generate energy from sunlight, but this production is yet to be consistent, given the high installation costs. In recent years, due to government subsidies, residential and industrial consumers have been producing their own energy.

2. R&D activities related to clean energy technology

In recent years there have been frequent changes - from managers, priorities and policies - from major Brazilian science and technology institutions. Brazil has had the Science, Technology and Innovation Program for the Hydrogen Economy in the last decade, but it is now stalled. The previous government launched the Science, Technology and Innovation Plan for Renewable and Biofuel Energies (2018-2022), which points to the need for hydrogen production and storage technologies. However, there are no specific funding programs for clean energy or hydrogen. Without long-term guidelines and specific grants, clean energy and hydrogen projects will hardly achieve continuity and integration with industry. The 2050 National Energy Plan in preparation redefines Brazil's energy, clean energy and hydrogen R&D priorities.

From publications found in Web of Science (WoS) database, it is possible to overview Brazil's and UFSCar's contribution to the research on hydrogen production, storage and the use. Brazil has its largest global contribution on hydrogen production (2.1%). UFSCar stands out in the research on hydrogen production (11.3% of brazilian publications) and storage (23.4%).

On hydrogen production, UFSCar focuses on the development of (1) new functional materials for water splitting, (2) heterogeneous catalysts for methane and ethanol performing reactions and (3) catalysts for the removal of CO from hydrogen streams. On hydrogen storage, a prospective study conducted by UFSCar identified exponential growth in WoS publications between 2000 and 2009, followed by stabilization until 2015. The publication number remains stable since then. Thirteen researched materials classes for hydrogen storage were identified. The most researched are Metal-Organic-Frameworks (MOFs), Simple Hydrides and Carbon-based materials. UFSCar is carrying out research on (1) High Entropy Alloys (HEA), (2) Mg and Ti alloys and (3) advanced processes such as severe plastic deformation and high-energy ball milling applied for Mg- and Ti-based alloys. Future challenges in clean energy technologies, expected international collaborative framework in your institute.

3. Specific Research activities in hydrogen, CCUS, and related technologies

One of the most important technological issues for enabling H_2 energy is the development of ways to store it safely, efficiently and economically. Solid state hydrogen storage using metal or complex hydrides is an interesting alternative when compared to the more conventional gaseous (under high pressures, e. g. 700 bar) or liquid (under very low temperatures, e. g. 21 K), especially due to the high gravimetric and volumetric capacities that can be attained. Metal or complex hydrides can present also other interesting functional applications, as heterogeneous catalysis, refrigeration, thermal energy storage and electrochemical energy storage, among others.

In our Laboratory of Hydrogen in Metals (LH2M) at the Materials Engineering Department (DEMa), we work since 2001 on the development of materials and technologies related to solid state hydrogen storage, producing more than 70 papers in peer-reviewed journals. So far, we have concentrated our efforts on Mg- and Ti-based systems. On the context of solid hydrogen storage, magnesium-based materials are sometimes called 'high-temperature hydrides', with high gravimetric capacity, while titanium-based materials are called 'low-temperature hydrides', presenting also low gravimetric capacities. In the case of Mg, we have developed studies for the synthesis or processing of MgH_2, Mg_2FeH_6, Mg_2CoH_5 containing different additives or second phases. Commercial Mg alloys as AZ31, AZ91, ZK60 were also investigated as low cost hydrogen storage materials. In the case of Ti, we studied the TiFe intermetallic and also body-centered cubic Ti-Cr-V (or related compositions) processed by different mechanical routes.

We have shown in a series of scientific papers[1] that processing routes involving severe plastic deformation (SPD) – e. g. extensive cold rolling or cold forging, equal channel angular pressing deformation, etc. – can be used to produce nanostructured Mg- or Ti-based materials for hydrogen storage. Compared to the more conventional high-energy ball miling (HEBM), the SPD techniques are faster and more straightforward and therefore are possibly less costly. The processing conditions can be adjusted to allow full H-absorption/desorption to occur in a few minutes. The materials processed by SPD have a much lower surface area than the ball-milled powders and therefore are much less susceptible for contamination by the impurities present in air, as oxygen and moisture. The development of the SPD processing routes for Mg- or Ti-based materials aiming hydrogen storage is a recent achievement that counted with intense contribution of researchers from UFSCar.

Related programs/projects conducted by the institute (further information on programs/projects are found in the template)

- Processing and Characterization of Amorphous, Metastable and Nanostructured Alloys/Development of nanostructured Mg-based nanocomposites with enhanced H-absorption/desorption properties for hydrogen storage (2014 – 2019)

- Mg- and Ti-based Alloys with Controlled Microstructure, Texture and Surface Area for Hydrogen Storage / Comparative evaluation of the effects of different processing routes on structural characteristics and hydrogen storage properties of selected Mg- and Ti-based alloys (2017/2020)

4. International collaboration

[1] The main results of our contributions in this topic are summarized in the review entitled 'Hydrogen Storage in Mg and Mg-Based Alloys and Composites Processed by Severe Plastic Deformation' by D.R. Leiva, A.M. Jorge, Jr., T.T. Ishikawa and W.J. Botta (Materials Transactions, v. 60, p. 1561 – 1570, 2019).

4-1 International alliance/networking development

UFSCar has a strong participation in international cooperation agreements in research. It has partnerships with 55 research international institutions distributed in 23 countries, and in technology there are 48 institutions in 20 countries. These international cooperation include joint projects, exchange of researchers, workshops and specific sessions on the subject in large congresses organized by Brazilian entities. Of these 20 countries, Spain, France, Germany and Canada highlight for an academic relationship for the training of graduate students. All these activities have contributed to the scientific and technological strengthening of our researchers, our institution and also to the formation of our students.

4-2 International joint R&D activities

UFSCar through its research agency has encouraged its various groups to develop renewable energy technologies such as biomass, photovoltaics and hydrogen generation with international participation. For hydrogen storage, UFSCar has partnerships with 38 research institutions distributed in 17 countries. For biomass, UFSCar has partnerships with 320 research institutions distributed in 28 countries. All of these research groups have received financial support from various government agencies such as FAPESP, CNPq and CAPES and some with support from the private sector.

Related programs conducted in the institute (further information on programs/projects are found in the template)

- Investigation of water electrolysis and photo-electrolysis. Development of new functional materials for water splitting. Study of the functional aspects of water splitting reaction using finite elements methods.
- Hydrogen and Synthesis gas production by reforming reactions.
- High Entropy Alloys for Energy Storage Based on Hydrogen/Applied and basic research on the electrochemistry and H-sorption properties of multicomponent alloys aiming hydrogen storage applications.
- Mg- and Ti-based Alloys with Controlled Microstructure, Texture and Surface Area for Hydrogen Storage / Comparative evaluation of the effects of different processing routes on structural characteristics and hydrogen storage properties of selected Mg- and Ti-based alloys.

5. Future perspectives

Researchers from the Hydrogen Storage Group at UFSCar are constantly working with national and international collaborators to advance the development of materials with enhanced hydrogen storage properties that could be produced with low cost. Many details remain unexplained regarding the correlations between structure and properties of SPD Mg- or Ti-based based materials for H_2 storage. Several challenges are still faced to improve the attractiveness of these alloys or composites for hydrogen applications. New and interesting results are continously being obtained by the use of unconventional processing routes, as for example friction stir processing (FSP); by the adaptation of more conventional processes as cold forging or filling; or by the variation of significant processing conditions, e.g. performing cold rolling under protective atmosphere. The elaboration of Mg or MgH_2-based composites with relevant amounts of low temperature hydride formers as TiFe or $LaNi_5$, should bring consistent advances in the level of the hydrogen storage properties. The new concepts of alloy design related to ‘high entropy alloys’ are currently under investigation at UFSCar, as well as the production of metal-polymer nanocomposites for hydrogen storage, with better air-resistance.

Dr. Walter Libardi

2016 Vice-President, Federal University of São Carlos(current).
2014 Head of the Materials Engineering Department.
2011Coordinator of the CAPES/BRAFITEC Program
2007 Coordinator of the Materials Engineering Course.
2004 Coordinator of the Materials Engineering Course.
1993 Visiting Scholar, Northwestern University-USA
1991 Vice-Coordinator of the Materials Engineering Course.
1981-Coordinator for Mechanical Teacher Training
1980 Vice-Coordinator of the Materials Engineering Course.

Research Biography
2010 – Concrete Creep
2000 - Mechanics of Refractory Concrete Fracture
1993 – Concrete Fracture Mechanics
1980- Mechanical Vibration of Thin Bars
1976 – Mechanical Vibration

Academic Background
1990 Ph.D. in Engineering, University of São Paulo
1979 Master of Engineering, University of São Paulo
1975 Bachelor of Engineering, University of São paulo