Hydrogen Role on the Decarbonization Transition Route

Author: Elvirosa Brancaccio – Serintel Srl – Rome (Italy)

1. Introduction

Awareness of climate change impacts and the need for deep decarbonization has increased greatly in recent years. In 2018 the EU published its vision for the future of energy in Europe ‘A Clean Planet for All’ which aims at creating a “prosperous, modern, competitive and climate neutral economy by 2050.” A set of pathways has been developed and assessed that rely heavily on renewable energy and energy efficiency, with a role for natural gas and hydrogen.

The need to accelerate clean energy transitions is underscored by recent data: CO_2 emissions rose for a second year in a row in 2018 to reach a record high.

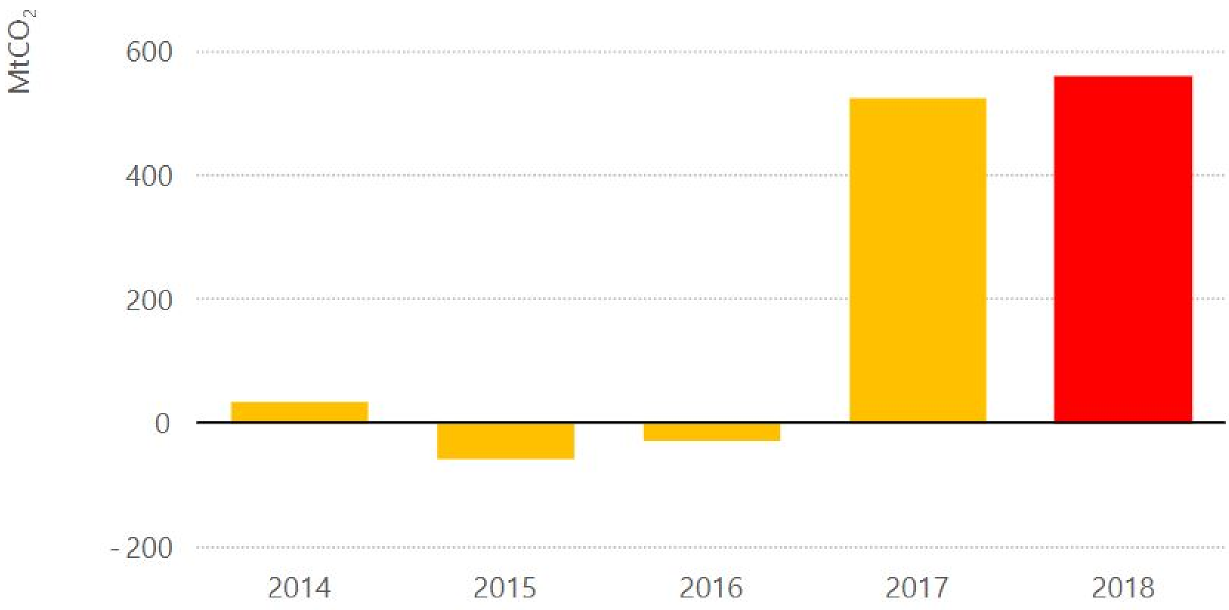

Figure 1 Annual change in global energy-related CO_2 emissions, 2014-2018[1]

In response to this growing awareness and the urgency of decarbonization, policy makers have taken action and in 2015 agreed to what is known as the Paris agreement. This has set the target to limit the expected global average temperature increase to significantly less than 2°C, with the ambition to keep to the limit to less than 1.5°C. In order to achieve such necessary and ambitious targets, the European economy, and in particular the energy sector, needs to significantly reduce CO_2 emissions to a fraction of current levels (e.g. -80%, -95%) with a growing consensus that net zero emissions will be required. Many changes will be required in how we work, travel, heat our homes and how we obtain the energy necessary to carry out all these activities, as shown in Figure 2.

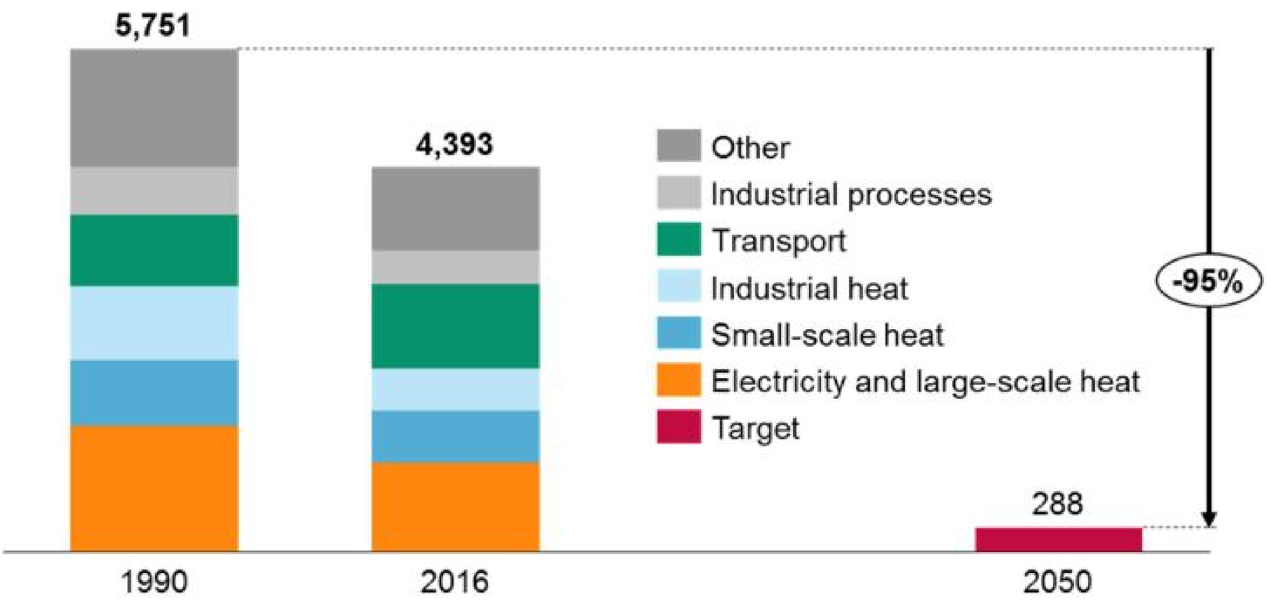

Figure 2 The scale of Europe's decarbonisation challenge – emissions by sector (MtCO2e)[2]

Hydrogen can help overcome many difficult energy challenges:

- Integrate more renewables, including by enhancing storage options & tapping their full potential
- Decarbonize hard-to-abate sectors – steel, chemicals, trucks, ships & planes
- Enhance energy security by diversifying the fuel mix & providing flexibility to balance grids

Either if there are challenges:

- costs need to fall;
- infrastructure needs to be developed;
- cleaner hydrogen is needed;
- regulatory barriers persist.[3]

A key feature of hydrogen is its ability to act as both a source of clean energy (for a variety of uses), and an energy carrier for storage. Hydrogen can be transported through existing pipelines, mixed with natural gas, and through dedicated pipelines in the future. It offers an energy storage solution that costs ten times less than batteries.

Hydrogen is already widely used for industrial purposes across the steel, petrochemical and food sectors, but it is now also being used in mobility. In the future, it could also replace natural gas to heat residential and commercial buildings. Hydrogen can also be transformed into clean electricity by injecting it into fuel cells.

The most interesting thing about hydrogen, is that it does not generate carbon dioxide emissions or other climate-changing gases, nor does it produce emissions that are harmful for humans and the environment. For this reason, it will play a key role in ensuring that European and global decarbonisation objectives are achieved by 2050.[4]

Low-carbon hydrogen from fossil fuels is produced at commercial scale today, with more plants planned. It is an opportunity to reduce emissions from refining and industry.

Figure 3 Hydrogen production with CO_2 capture is coming online[5].

[1] IEA 2019

[2] Source: 2016 National Inventory Submissions (Common Reporting Format) for EU, Norway and Switzerland Note: Transport here refers to ground-based transport. Aviation and waterborne transport are counted towards the 'Other' segment

[3] IEA, 2019

[4] https://www.snam.it/en/hydrogen_challenge/hydrogen_energy_transition/

[5] Keith Scott, Chapter 1: Introduction to Electrolysis, Electrolysers and Hydrogen Production, in Electrochemical Methods for Hydrogen Production, 2019, pp. 1-27 DOI: 10.1039/9781788016049-00001 eISBN: 978-1-78801-604-9

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The Green Chemistry

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1 Introduction and

Principles

An early conception of “green chemistry was developed in 1990 by P. Anastos and J. Warner[1] trough 12 principles ranging from prevention and atom economy to pollution prevention and an inherently safer chemistry. These principles, described below, offer a protocol to adhere in developing novel chemical processes.

1. ***Waste prevention:*** by prevent waste production, rather than clean up and treat wastes after having produced. Plan to minimize waste at every process’ stage.
2. ***Atom economy:*** reduce waste by recycling the number of atoms from all reagents that are incorporated into the final product. Use atom recycling concept in order to evaluate reaction efficiency.
3. ***Less hazardous chemical synthesis:*** design chemical reactions’ path in order to be as safe as possible. Consider the hazards of all substances handled during each single step of the reaction, including waste.
4. ***Designing safer chemicals:*** minimize toxicity directly by proper design. Predict and analyze factors such as physical properties, toxicity, and environmental impact of each designed process’ step.
5. ***Safer solvents & auxiliaries:*** look for the safest solvent available for any given step. Optimize the total amount of solvents and auxiliary substances used in order to minimize the waste produced.
6. ***Design for energy efficiency:*** find the least energy-intensive chemical route, thus reducing heating and cooling, as well as pressurized and vacuum conditions (i.e. try to stay as close as possible to ambient

temperature & pressure).

7. ***Use of renewable feedstocks:*** use feeds which are made from renewable (i.e. bio-based) sources, rather than other chemicals made from petrochemical products.

8. ***Reduce derivatives:*** minimize the use of temporary derivatives such as protecting groups in order to reduce the waste production.

9. ***Catalysis:*** Look for catalysts that help to increase selectivity, minimize waste, reduce reaction times and increase energy efficiency.

10. ***Design for degradation:*** design products that can degrade themselves easily into the environment. Ensure that both original and degraded products are not toxic, bio-accumulative, or environmentally persistent.

11. ***Real-time pollution prevention:*** real time control of chemical reactions to prevent the formation and the release of any potentially hazardous or polluting products into the environment.

12. ***Safer chemistry for accident prevention:*** developing chemical processes and procedures that are safer to inherently minimize the risk of accidents. Evaluate all the potential risks and assess them beforehand.

Today, more than 98% of all products and materials needed for modern economies is still derived from petroleum and/or natural gas, generating substantial quantities of wastes and emissions.

An exaggerated, but illustrative, view of **twentieth century** chemical manufacturing can be written as a recipe[2]:

- Start with a petroleum-based feedstock.
- Dissolve it in a solvent.
- Add a reagent.

- React to form an intermediate chemical.
- Repeat (2)–(4) several times until the final product is obtained; discard all waste and spent reagent; recycle solvent where economically viable.
- Transport the product worldwide, often for long term storage.
- Release the product into the ecosystem without proper evaluation of its long-term effects.

The recipe for the **twenty-first century** will be very different:

- Design the molecule to have minimal impact on the environment (short residence time, biodegradability).
- Manufacture from a renewable feedstock (e.g. carbohydrate).
- Use a long-life catalyst.
- Use no solvent or a totally recyclable solvent.
- Use the smallest possible number of steps in the synthesis.
- Manufacture the product as required and as close as possible to where it is required.

A typical example of the twentieth century chemical manufacturing production model is represented by plastic materials, which are also a typical example of linear economy: no-renewable resources, oil or ethane in this case, are used to produce plastic materials, which at the end of life become wastes and dispersed into environment. Today, some about 8 million of metric tons escapes into the world's oceans each year[3], most of it from countries in South East Asia, where plastics use has outplaced waste management infrastructure and the situation is approaching catastrophic proportions.

The green chemistry approach is the correct way to deal with the actual environmental situation, representing a promising strategy of future economic development also for industrialized countries.

Paul Anastas, then of EPA, and John C. Warner developed the Principles of Green Chemistry (Figure 1), which help explain what the definition means in practice. The principles cover such concepts as:

- Designing processes to maximize the amount of raw material that ends up in the product.
- Using safe, environmentally-benign substances, including solvents, whenever possible.
- Designing energy-efficient processes.
- Using the best form of waste disposal: not creating it in the first place.

Figure 1: Principles of Green Chemistry

[1] P. T. Anastas, J. C. Warner, The Twelve Principles of Green Chemistry, Oxford Univ. Press, Oxford – UK (1998).

[2] **Based on: Woodhouse, E. J. Social Reconstruction of a Technoscience? : The Greening of Chemistry.**

[3] **A.H. Tullo, Fighting ocean plastics at the source. Chem. & Eng. News, 96 (16) (2018) 29-34**

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Floating LNG (FLNG) Technical Challenges and Future Trends

Authors: Marco Cocchi – Researcher – Campus Bio-medico University of Rome

1 Introduction

Natural gas (NG) and liquefied NG (LNG), which is one trade type of NG, have attracted great attention because their use may alleviate rising concerns about environmental pollution produced by other fossil fuels as coal and oil.

In the figure below, the typical components of NG are reported giving also the idea of their relative amount:

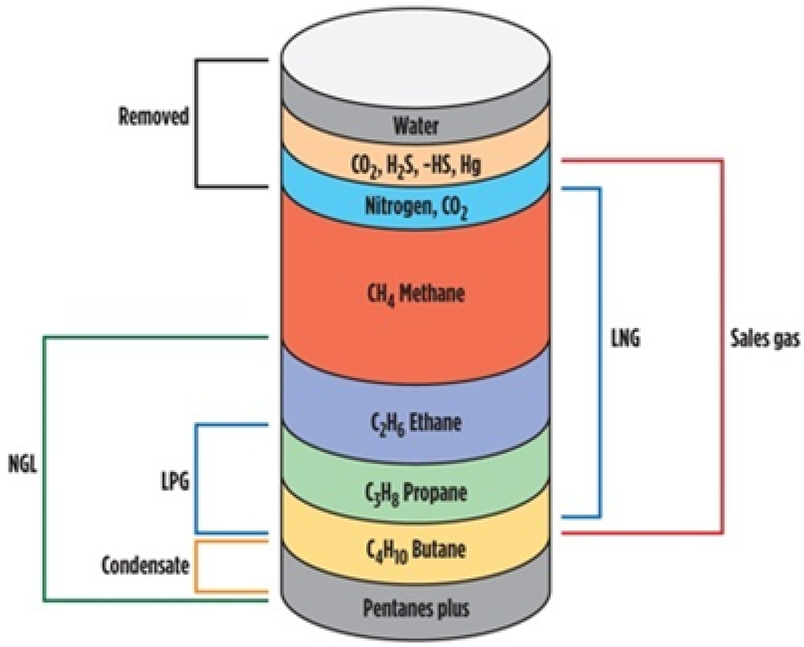

Figure 1: Natural gas composition[1]

There are two main distinctions in between the final products obtained from gas processing: *Pure natural gas liquids*, meaning that at least 90% of the liquid contains ONE type of primary molecule, as:

- Ethane
- Propane
- Normal Butane
- Isobutane

Mixed natural gas liquids, meaning that the liquid contains at least two different types of primary molecules, are:

- Ethane/Propane (EP) Mix
- Natural Gasoline

NG reserves may locate in embedded underground areas and a significant portion of the reserve is often located off-shore. The off-shore extraction of NG and its conversion in liquified NG has reached a turning point in terms of economic feasibility; in fact, just few years ago, that extraction type was thought to be:

- Environmentally unsafe, due to the lack in LNG off-shore previous practice
- Particularly expensive, due to the installation of long subsea NG pipelines

As a result, there are many efforts to excavate and monetize these stranded and offshore reserves with floating facilities where offshore liquefaction of NG is possible. Therefore, the development of floating LNG (FLNG) technology is becoming important.

Natural gas off-shore facilities as FLNG represent a very complex condensate of chemical plant technologies, designed to be installed in limited space conditions on dynamic moving vessels.

Space limitation of floating vessels is indeed a challengeable problem to overcome. Due to this reason, the amount of feed gas that can be reserved for floating liquefaction is restricted. Units for gas pretreatment operation are supposed to occupy about 50% of the available deck space of a floating production facility, although this relies on the impurity level in the feed gas stream. This indicates that FLNG is more suited to feed gas streams including low levels of inert gases and impurities. CO_2, hydrogen sulfide, nitrogen, mercury, and acid gases are the main impurities determining the amount of feed gas.

[1] ***https://www.saubhaya.com/chemical-makeup-of-natural-gas/***

Supercritical Geothermal Resources: Exploration and Development

Author: Elvirosa Brancaccio – Serintel Srl – Rome (Italy)

1. Introduction

The demand for clean, renewable energy is continuing to increase around the world. Much of that demand is being met with wind and solar power, but these resources are intermittent and therefore require balancing. Presently, developed geothermal resources are not adequate to provide the balancing that will be needed in the future thus attention is turning to supercritical geothermal resources.

Figure 1 Iceland Deep Drilling Project[1]

Utilizing supercritical fluids, geothermal could play an important role for carbon-zero energy future. These supercritical fluids provide much higher temperatures above 374 °C and pressure points above 22 MPa, providing much higher heat-content and lower density and so have the potential to generate around 10 times more energy than conventional geothermal for the same amount of extracted fluid [2].

Volcanic geothermal systems are associated with magmatic intrusions in the upper part of the Earth’s crust characterized by increased temperature, specific fluid enthalpy, and convection of groundwater. Conventional exploitation of geothermal fluids from such systems typically produces an average of about 3-5 MW electric power per well with a world total exploitation of geothermal energy in 2018 corresponding to about 14.4GW [3]. Conductive heat transfer from a magmatic intrusion to the surrounding groundwater occurs in the roots of the geothermal system below the depth of typical conventional geothermal wells. Recent modelling suggests that supercritical fluids with temperatures and enthalpies exceeding 400°C and 3000 kJ kg^{-1}, respectively, exist at the boundary between geothermal systems and the magmatic heat source, with such fluids possibly capable of generating up to 30-50 MW of electricity from a single well or ten times more than conventional geothermal wells.

[1] https://interestingengineering.com/iddp-drills-into-new-era-steam-energy-potential

[2]

http://www.thinkgeoenergy.com/utilising-supercritical-fluids-geothermal-could-play-a-crucial-role-for-nzs-carbon-zero-energy-future/

[3] A. Richter, *Global geothermal capacity reaches 14,369 MW – top 10 geothermal countries, Oct 2018*, Think GeoEnergy Geothermal Energy News, 2018.

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Energy Storage Using Thermal Processes and Nanotubes

Author: Marcello Pompa – Industrial Engineering – University "Campus Bio-Medico" of Rome

1. Theme description

Since 1970, the science had tried to find a solution at the energy crisis, developing new method to use and storage renewable energy[1].

The United States Department of Energy has expected that the world's energy consumption will be increased by 20% and that overuse fossil fuels will have a hard impact on climate[2].

The hardest current global challenge is to use the renewable energy rather than fossil fuels, improving the storage energy efficiency[3].

One of the most interesting technologies in the energy storage and conversion is the nanostructured materials for their mechanical and electrical properties[4].

Carbon nanotubes (CNTs) are a kind of nanostructured material with very good electrical and mechanical properties thanks to their dimension and surface properties. Carbon nanotubes were discovered in 1991 as a minor byproduct of fullerene synthesis[5]. The research into CNTs has increased, reducing significantly the cost of this technology and improving the processability and scalability[6]. Nanotubes discovered are of two types: single-wall and multiwall.

In the following, an overview the thermal processes to store energy, in particular the using of Carbon nanotubes in energy field (with a description of this technology and a presentation of the major results obtained by CNTs) are reported.

[1] https://www.history.com/topics/energy-crisis

[2] Shukla, A. K. S. S., &Vijayamohanan, K. (2000). Electrochemical supercapacitors: En- ergy storage beyond batteries. Current Science, 79.

[3] Arico, A. S., et al. (2005). Nanostructured materials for advanced energy conversion and storage devices. Nat Mater, 4(5), 366-377.

[4] Chung, J., et al. (2004). Toward Large-Scale Integration of Carbon Nanotubes. Lang- muir, 20(8), 3011-3017.

[5] Lijima, S. Nature 1991, 354, 56-57.

[6] Sherman, L. M. (2007). Carbon Nanotubes Lots of Potential–If the Price is Right. 01/05/12]; Available from:,

www.ptonline.com/articles/carbon-nanotubes-lots-of-potentialif-the-price-is-right.

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Intelligent Clothing to Improve Safety at Work and Support Production

Author: Marcello Pompa – Industrial Engineering – University "Campus Bio-Medico" of Rome

1. Theme description

In order to reduce costs, to improve worker productivity, some companies are driving the development of smart wearables and sensors in industrial environments[1].

Currently, the safety on work is guaranteed through PPE (personal protective equipment) like safety eyewear and other. The technology upgrades could make the standard do an even better[2].

Examples of possible Wearable technology that can greatly improve workplace safety are[3]:

- Smart bands and sensors embedded in clothing and gear that monitor workers' health and wellbeing by tracking factors such as heartrate, heat stress, respiration, fatigue and exposure. The data obtained could be sent to workers when critical levels are reached;
- In case of dangerous environments, machine and environmental sensors that provide contextual information to field workers to help them to know from what they are surrounded and wearable GPS tracking to help to know their spatial position;
- Smart glasses and other HUDs (Head-Up Display) that allow workers to access specific instructions and manuals in the field, in addition to allow remote guidance;
- In the insurance sector, clothing with camera-equipped could be used to document a job or incident for later review.

In the following, a review based on intelligent clothing, with future developments, are reported.

[1]**http://www.ehstoday.com/eye-face-head/ppe-and-internet-things**

[2]**https://blog.safetyglassesusa.com/technology-impacting-workplace-safety/**

[3]**https://brainxchange.io/3-great-use-cases-wearable-tech-ehs/**

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Smart Grids

Author: Marcello Pompa – Industrial Engineering – University "Campus Bio-Medico" of Rome

1. Theme description

Energy systems are changing fast. The methods to produce energy and the ways to transmit it are changing. The consumption of electrical energy is growing and its generation is becoming more decentralized, with grid management increasingly complex[1].

With the objective to overcome the weaknesses of conventional electrical grids, the Smart Grid was introduced. A Smart Grid is an electricity network based on two-way digital communication. This system allows for analysis, monitoring, communication and control with the aim to improve efficiency and reduce energy consumption and cost[2].

The Smart Grid has the opportunity to move the energy industry into a future more reliability, efficiency, and availability, allowing an improve of environmental health. During this period, it will be critical to carry out technology improvements, study, consumer education and standard regulations to ensure the benefits of the Smart Grid. The advantages of the Smart Grids are[3]:

- Slower time of restoration of electricity after power disturbances;
- Improve the transmission efficiency;
- Reduce costs;
- Increased integration of large-scale system based on renewable energy;
- Improved security
- useful to use the plug-in hybrid technology for electric vehicles[4].

In the following, a review based on smart grid, with example of installation and future development, are reported.

[1]https://www.siemens.com/global/en/home/products/energy.html

[2]https://www.techopedia.com/definition/692/smart-grid

[3]https://www.smartgrid.gov/the_smart_grid/smart_grid.html

[4]https://www.nema.org/Policy/Energy/Smartgrid/Pages/default.aspx

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Solar: paper like cells

Author: Marcello Pompa – Industrial Engineering – University “Campus Bio-Medico” of Rome

1. Theme description

There is a significant interest for the production of renewable energy. The researchers try every day to find or improve methods to produce green energy. One of the best renewable energy is the solar energy: available every day (though discontinuously)[1].

A new system to capture and use the solar energy is 3PV (printed paper photovoltaics)[2]. This technology uses an ink with electrical properties to print on a lot of materials (paper too) an advanced system of solar cell[3].

The 3PV is developed and study for the first time by the MIT researchers in 2011[4].

This new technology could be incorporated into clothing, accessories and etc. opening the ways to new method to use the solar energy[5]. The printed cells are flexible so it could be use in documents, windows, wall coverings, etc. adapting its form. Furthermore, this cheap technology could lead to produce new solar system in rural areas, needing reliable source of electricity.

The efficiency of the 3PV started in 2011 with 1%, reaching now about the 20%[6].

Additionally, the power-to-weight ratio of this technology is among the highest ever achieved: it is more efficient than common photovoltaic cells on glass substrates.

In the following, an overview of 3PV and the major results obtained by this technology until now are reported.

[1]**https://www.renewableenergyworld.com/index/tech.html**

[2]**http://blog.drupa.com/de/solar-cells-printed-paper/**

[3]**https://inhabitat.com/paper-thin-printed-solar-cells-could-provide-power-for-1-3-billion/**

[4]**http://energy.mit.edu/news/solar-cells-printed-on-paper/**

[5]**https://www.treehugger.com/clean-technology/solar-cells-can-now-be-printed-on-anything-even-paper-and-fabric.html**

[6]**http://blog.drupa.com/de/solar-cells-printed-paper/**

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Smart Fluid

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1. **Theme description**

A smart fluid, also called electro rheological fluid[1], is a liquid suspension of metals or zeolites which solidifies when electric current is applied to it, becoming fluid again when the current is removed.

Smart fluids can be divided in four main classes:

- electro-rheological (ER) fluids[2];
- magneto-rheological (MR) fluids[3];
- magneto rheological elastomer (MRE) fluids[4];
- electro-conjugate liquids[5].

Since 1960, the engineers tried to develop new devices based on ER smart fluids (vibration damper, flow control waves, etc.), without important results. The turning point was there in 1990, after the discovered of MR smart fluid: indeed, in 2002, suspension damping struts of the Cadillac Seville STS model automobile (based on smart fluids) was discovered[6].

The interest for this kind of technology is considerable and the perspective for a new device based on smart fluids is real.

In the following, a review on smart fluids, with future developments in the close future, is reported.

[1]
http://www.businessdictionary.com/definition/smart-fluid.html

[2]w. m. winslow: J. Appl. Phys., 1949, 20, 1137 – 1140

[3] j. rabinow: AIEE Trans., 1948, 67, 1308 – 1315

[4] B. X. Ju, M. Yu, J. Fu, Q. Yang, X. Q. Liu, and X. Zheng, "A novel porous magnetorheological elastomer: preparation andevaluation," Smart Materials and Structures, vol. 21, no. 3, Article ID 035001, 2012

[5] W.-S. Seo, K. Yoshida, S. Yokota, and K. Edamura, "A high performance planar pump using electro-conjugate fluid with improved electrode patterns," Sensors and Actuators A: Physical, vol. 134, no. 2, pp. 606–614, 2007

[6] r. stanway: Mater. World, February 2002, 10 – 12

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Desulfurization from Gas Oil: sulfur removal of gas oil to 10 ppm

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1. Introduction

The source of energy most used in the world is crude oil. Major portions of the crude oils are used as transportation fuels such as diesel, gasoline and jet fuel. However, the crude oil contains sulfur, typically in the form of organic sulfur compounds. The sulfur content and the API gravity are the properties that have more influence on the value of the crude oil. The sulfur content is expressed as a percentage of sulfur by weight and varies from less than 0.1% to greater than 5% depending on the type and source of crude oils[1].

The removal of organo-sulfur compounds (ORS) from diesel fuel is the key to reduce air pollution, reducing the emission of toxic gases (such as sulfur oxides) and other polluted materials. The adsorption desulfurization process is one of the easily and fast method to remove sulfur from diesel oils[2].

The adsorptive desulphurization of gasoline over nickel based adsorbent, provide high capacity and selectivity for the adsorptive desulfurization of gasoline. The adsorption involves C-S bond cleavage as evidenced, forming ethyl benzene from benzothiophene in the absence of hydrogen gas.

The hydrodesulfurized straight run gas oil having less than 50 ppm sulfur is treated with activated carbon fiber to attain the ultra-low sulfur gas oil having less than 10 ppm sulfur, for example.

The next paragraphs describe the desulphurization of gasoline with some of the used methods.

[1]Desulfurizati on of Gasoline and Diesel Fuels, Using Non-Hydrogen Consuming Techniques, Abdullah Al-Malki, King Fahad University of Petroleum and Minerals, October 2004

[2]Adsorption Process of Sulfur Removal from Diesel Using Sorbent Materials, Isam A. H. Al Zubaidy, Fatma Bin Tarsh, Noora Naif Darwish, Balsam Sweidan Sana Abdul Majeed, Aysha Al Sharafi, and Lamis Abu Chacra, Journal of Clean Energy Technologies, Vol1, No. 1, January 2013

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