Biomass - an environmental friendly production source for hydrogen

Mihai Anghel, Violeta-Carolina Niculescu, Ioan Stefanescu, and Radu Tamaian

Abstract**—** The aim of our study is to assess the economic feasibility of producing hydrogen from biomass. There are three options for producing hydrogen from biomass. Our efforts must be focused on maximizing the reforming and shift conversions along with maximum economical recovery of hydrogen from the PSA. This study demonstrates that hydrogen can be produced economically from biomass. The pyrolysis-based technology, in particular, because its coproduct opportunities, has the most favorable economics.

Keywords**—**biomass, environment impact, emissions, hydrogen, renewable.

I. INTRODUCTION

Hydrogen is forecast to become a major source of energy in the future, thus offering a potentially non-polluting, inexhaustible, efficient, and cost-attractive energy carrier. In the last 10 years, the defining issues with respect to H_2 economics have changed dramatically. However, refineries now have become net consumers of H_2 in an effort to reduce pollution and meet environmental regulations.

Reducing the demand on fossil resources remains a significant concern for many nations.

Renewable-based processes like solar or wind-driven electrolysis and photobiological water splitting hold great promise for clean hydrogen production; however, advances must still be made before these technologies can be economically competitive.

For the near- and mid-term, generating hydrogen from biomass may be the more practical and viable, renewable and potentially carbon-neutral (or even carbon-negative in conjunction with sequestration) option [1].

In 2004, the International Energy Agency`s (IEA) Program on the Production and Utilization of Hydrogen launched its new Task 16, *Hydrogen from Carbon-Containing Materials*, to bring together international experts to investigate some of these near- and mid-term options for producing hydrogen with reduced environmental impacts.

Today’s energy and transport system, which is based mainly on fossil energy carriers, can in no way be evaluated as sustainable. Concerns over energy supply security, climate change, local air pollution, and payable energy services are having a growing impact on policy making throughout the world. Increasingly, hydrogen is seen as offering a range of benefits not generally available from fossil fuel combustion which is receiving ever greater attention as policy priorities change (see among others. Creating a large market for hydrogen as an energy vector offers effective solutions to both the aspects of emission control and the security of energy supply: hydrogen is nearly emission-free at the point of final use, it is a secondary energy carrier that can be obtained from any primary energy source and it can be utilized in different applications (mobile, stationary, and portable).

Hydrogen as a secondary energy carrier is only a transmitter, like electricity, used to bring energy to the market and therefore the question to be answered first concerns the EU’s future energy feedstock mix. Domestic energy resources are limited within the EU and therefore one open research question is whether it is a sustainable option to produce hydrogen outside the EU and import it?

This study aims to identify economically optimal and viable hydrogen corridors between the EU and neighbouring countries and the feasibility and necessity of such corridors. The analysis is based on consistent hydrogen scenarios and looks at the barriers to and the benefits from establishing a pan-European ‘energy network’ for hydrogen. Collecting RTD state of the art insights and involving stakeholders for consensus building are additional goals of the study.

In addition to large-scale fossil-based production with carbon sequestration and production from biomass, small-scale reforming for distributed generation is included in the activity [2]. The wide range of options for sources, converters and applications shown in Fig. 1, though not exhaustive, illustrates the flexibility of hydrogen and fuel cell energy systems.

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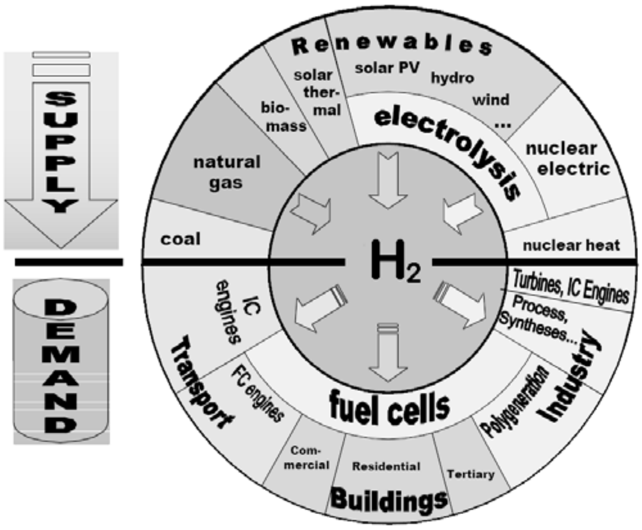


Fig. 1 Hydrogen: primary energy sources, energy converters and applications [2]

Public acceptance of hydrogen as an energy carrier for transportation and power generation technologies depends on the public`s confidence in the safety of the vehicles and power systems, as well as the raw and delivery and storage infrastructure [3].

To enable successful introduction of hydrogen and fuel cells into the market, the development of appropriate technical codes and regulations providing high levels of safety and environmental protection should be considered. The lack of appropriate safety requirements could delay technology implementation, could lower technology adoption rates, or could raise the costs [4].

The purpose of our study is to demonstrate that hydrogen can be economically produce from biomass and without environmental harmless effects.

II. BIOMASS - SOLUTION FOR FUTURE HYDROGEN-BASED FUEL

In the last years the biomass has attracted considerable attention as a renewable energy source because it is the only renewable source of fixed carbon. Biomass has been recognized as a major world renewable energy source to supplement declining fossil fuel resources. Biomass appears to be an attractive feedstock for three main reasons. First, it is a renewable resource that could be sustainable developed in the future. Second, it appears to have formidably positive environmental properties resulting in no net releases of carbon dioxide and very low sulphur content [5].

Third, it appears to have significant economic potential provided that fossil fuel prices increase in the future. The biomass energy potential can be recovered either by direct use in combustion systems or by upgrading into a more valuable and usable fuel or gas or higher-value products for the different industries. Investigations have shown that the combustion of biomass is not such economical [6], [7].

So the upgrading by pyrolysis, liquefaction, or gasification becomes more attractive. Biomass pyrolysis has been practiced for centuries in the manufacture of charcoal, but only in the last time the physical and chemical processes during pyrolysis were investigated [8].

The conversion of biomass into fuels that can be readily assimilated into the existing fuel infrastructure is a significant challenge. There are two basic approaches to conversion of biomass—thermochemical and biochemical. Biochemical routes are extremely selective to the desired product—e.g., ethanol, but are relatively slow, and produce a dilute aqueous solution that must be further processed to produce the final product.

The rates of thermochemical reactions are much faster, but tend to be less selective—producing a range of products that must also be further purified. Among the alternatives for thermochemical processes, gasification has the advantage of breaking down the structure of biomass of widely differing composition into a synthesis gas that is relatively uniform in the concentrations of the main components: CO_2, CO, H_2O, and H_2. This syngas can, in principle, be converted into a number of end products such as Fischer-Tropsch liquids (primarily linear hydrocarbons) or oxygenates. Each end product has certain advantages, and one positive aspect of thermochemical processing of biomass via syngas is that the target products can often be changed by simply changing the catalyst used in the final step of the process. Among are candidate end products, C_2^+ oxygenates such as ethanol are attractive because they can be easily reformed at the point of use to produce a hydrogen-rich gas for fuel cells [6].

Our paper describes the relevant technologies that convert biomass to hydrogen. In evaluating the viability of the conversion routes, each must be put in the context of the availability of appropriate feedstock and deployment scenarios that match hydrogen to the local markets.

Co-production opportunities are of particular interest for near-term deployment since multiple products improve the economics; however, we didn`t analyse co-product development.

First of all, in hydrogen production from biomass, we must identify the optimum match of feedstock, production technology, and end-use options. Comparison of technical and economical aspects is the only way to make rational selection of appropriate research and development paths in this complex and rich technical area. Regional perspectives will vary greatly and, hence, opportunities will be different for Europe, North America, Asia, and the developing regions of the world [1].

The gasifier systems incorporate biomass drying and steam production with the process heat available.

In biomass conversion processes, a hydrogen containing gas is normally produced similar to the gasification of coal. Currently, the pathways followed are steam gasification (direct or indirect), entrained flow gasification, and more advanced concepts such as gasification in supercritical water, application of thermo-chemical cycles, or the conversion of intermediates (e.g. ethanol, bio-oil or torrified wood). None of the concepts have reached a demonstration phase for hydrogen production [9].

Biomass gasification is a research and development area shared between H_2 production and biofuels production. Gasification (and pyrolysis) is considered the most promising medium term technology for commercialization of H_2-production from biomass.

Biomass gasification is one of the promising technologies that could be strategic in enabling biomass to meet future energy needs in an efficient manner. Specifically, the gasification technology allows production or co-production of hydrogen, electricity and clean liquid fuels. Thus, it could provide a much needed product flexibility and would offer a route for an integrated bioenergy concept. In addition, gasification could enable convenient ways for capturing carbon dioxide from biomass-based energy systems. Moreover, biomass can be cogasified with coal and the combined system could offer operative and environmental advantages for both feedstocks. Co-production, or poly-generation, systems could be an attractive alternative for the production of electricity and fuels. These systems could improve the economics of fuels production and exploit synergies between the constituent processes. Moreover, in multiplying the market segments that can be supplied and, thus, the potential sources of profit, they could increase the adaptability and robustness of energy-services companies in the marketplace. Among other biofuels, biomass-derived Fischer-Tropsch (F-T) liquids are seen as an attractive medium-term option. F-T liquids are premium products, with no sulfur or nitrogen and very low contents of aromatics, having attractive applications. Initially, they could be used as blending stock for petroleum-derived gasoline and diesel in order to comply with more stringent environmental regulations being enforced today or in preparation. Specifically, they could be used to assist refiners in meeting ultra-low-sulfur diesel specifications. Later on, they can be introduced more broadly as high-quality fuels that, while compatible with the available fuel-delivery infrastructure, could enable the introduction of advanced internal combustion engines and/or be used in hybrid-electric cars or in fuel cell vehicles (using on-board reforming). Some automobile manufacturers are pursuing activities to support the introduction of F-T liquids. Although short-term efforts appear to be concentrated on F-T liquids from natural gas (using the so-called gas-to-liquids or GTL technologies), subsequent steps in their strategy head towards biomass-based fuels. On the other hand, biomass-based electricity generation constitutes an attractive option for the introduction of renewable energy resources. It is already used in several countries, although mainly in co-generation schemes where low-cost surplus biomass is available, such as pulp and paper industrial facilities. The gasification technology could offer an advanced and more convenient option for electricity production from biomass, as compared to conventional combustion-based plants. Higher conversion efficiencies can be achieved, in particular in small-size facilities, a wide range of feedstock qualities could be used and pollutant control can be facilitated [7].

A typical flow sheet for production of hydrogen from biomass is presented in Fig. 2. Energetically drying of biomass might not be justifiable; therefore other pathways based on wet biomass are sought as well. Biomass feedstocks are unrefined products with inconsistent quality and poor quality control.

The production methods vary according to crop type, location and climatic variations. Erratic fuels have contributed to the difficulties in technological innovation: less homogenous and low quality fuels need more sophisticated conversion systems.

There is a need to rationalize the production and preparation of fuel to produce more consistent, higher quality fuels (described by standards). Larger scale systems tend to be suitable for lower quality cheaper fuels and smaller plants tend to require higher fuel quality and better fuel homogeneity.

A better understanding of this relationship and the specific tolerances that each technology can accommodate are needed.

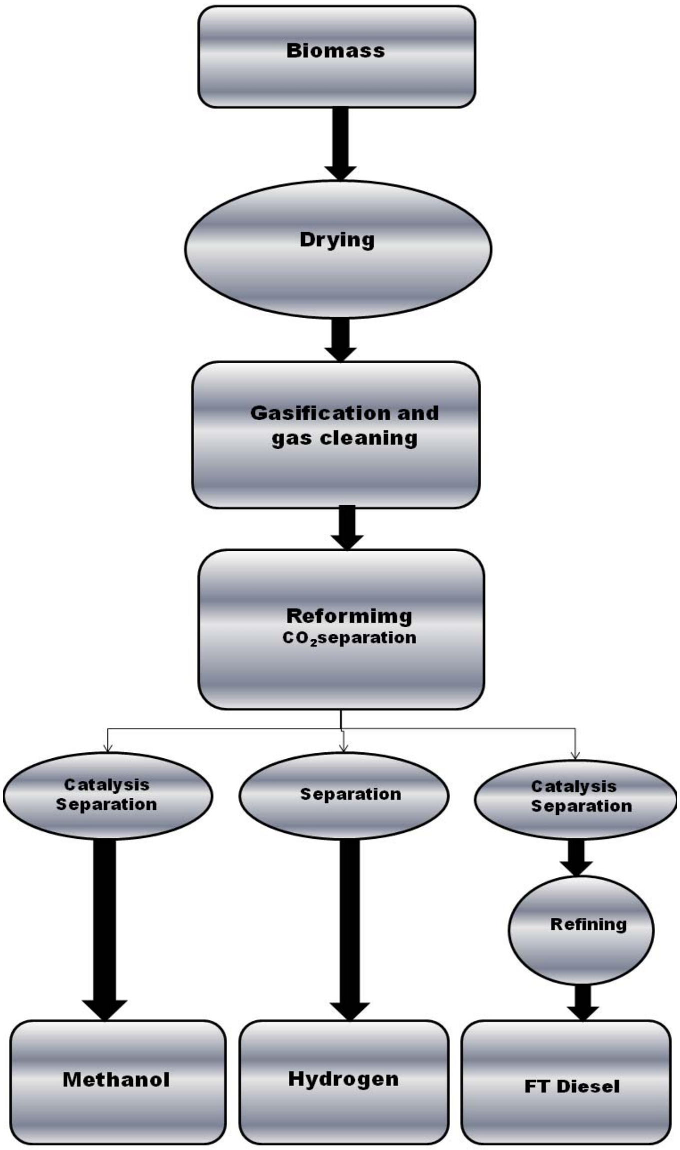


Fig. 2 Generic flow sheet for methanol, hydrogen or FT diesel production via biomass gasification

The first gasification technology (Fig. 3, left) is based on a low pressure, indirectly-heated gasifier, like that developed at Battelle Columbus Laboratories (BCL) specifically for biomass gasification. Future Energy Resources Corporation (FERCO) now owns the rights to this technology and is demonstrating it at the existing McNeil power plant in Burlington, Vermont [10]. This system is called indirectly-heated because the heat necessary for the endothermic gasification reactions is supplied by hot sand circulating between the char combustor and the gasification vessel. After clean-up, the syngas is cooled so that it can be compressed to the pressure required for the pressure swing adsorption (PSA) unit plus the expected pressure losses in the reactors. Following compression, the gasifier product gas is steam reformed and passed through two water-gas shift reactors to produce a gas concentrated in H_2 and CO_2. Finally, the hydrogen is purified in the PSA prior to storage and distribution.

The second gasification system (Fig. 3, middle) uses the IGT gasifier [11], which is a direct-fired high pressure gasifier, the process having similar steps to the Battelle/FERCO system. The major system components for the IGT hydrogen production process include biomass handling and drying, followed by gasification for which an air separation unit is required, hot gas clean-up, reforming, shift conversion, and hydrogen purification.

The third process (Fig. 3, right) is fast pyrolysis of biomass [12], followed by coproduct separation and steam reforming to produce hydrogen. Biomass is dried and then converted to oil by very quick exposure to heated particles in a fluidized bed. The char and gases produced are combusted to supply heat to the reactor, while the product oils are cooled and condensed. For this analysis, it was assumed that the bio-oil would be produced at several smaller plants which are closer to the sources of biomass, such that lower cost feedstocks can be obtained. The bio-oil is then shipped by truck from these locations to the hydrogen production facility. It is more economical to produce bio-oil at remote locations and then ship the oil, since the energy density of bio-oil is higher than biomass. Once the bio-oil arrives, a water extraction process separates the lignin-derived coproduct from the carbohydrate fraction of the oil. Hydrogen results from the carbohydrate fraction by steam reforming and shift conversion, followed by PSA for purification [13].

TABLE 1
TOTAL FIXED CAPITAL INVESTMENT

H_2 production rate (kg/day)	Batelle/ FERCO	IGT	Pyrolisis
22.73	53.80	72.00	18.80
75.79	128.80	169.40	59.40
113.68	172.30	227.20	N/A

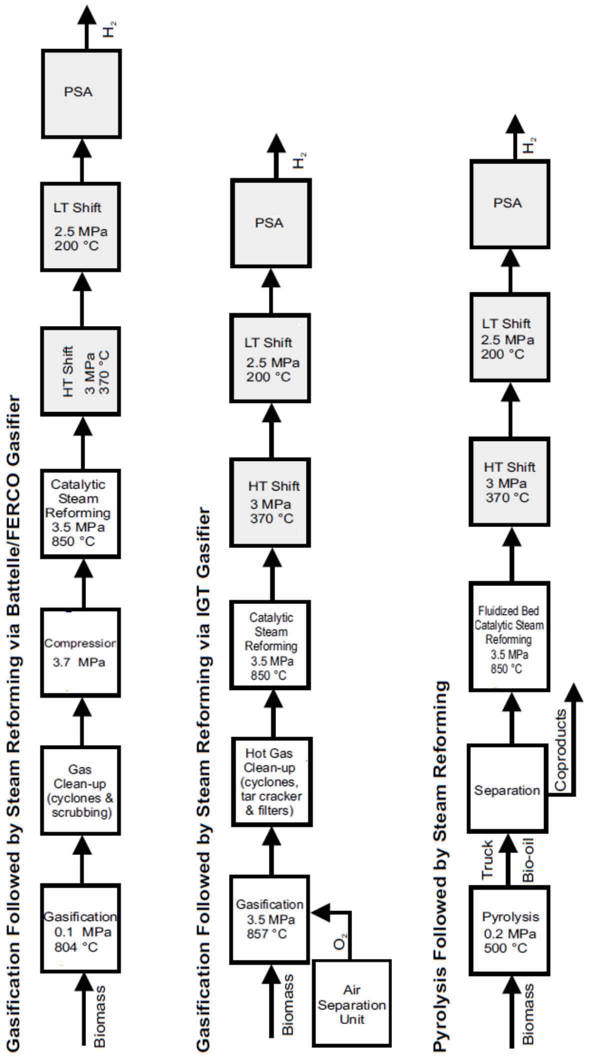


Fig. 3 Three pathways for conversion of biomass to hydrogen

The resulting capital costs for each system are shown in Table 1. The IGT technology has the highest capital investment followed by Battelle/FERCO and then pyrolysis, although it is important to remember that the cost of pyrolyzing the biomass is rolled into the price of the bio-oil feedstock. For the IGT system, the oxygen plant and gasifier each account for about 25% of the total capital investment. The highest capital cost items for the Battelle/FERCO system are the compressors. In total, the compressors make up 32% of the total installed capital, with the compressor used to boost the pressure of the gasifier product gas accounting for 22% of the total equipment cost. In the pyrolysis case, the reformer and PSA account for the majority of the capital costs, at 31% and 51%, respectively [8].

Since the plant gate hydrogen selling price is one of the desired results from the analysis, the cell containing its calculated value was set up as a forecast cell. This means that statistical values such as the mean, median, mode, and standard deviation were determined.

Crystal Ball®, a software package offered by Decisioneering, aids in risk assessment decisions by giving results and probabilities for those results and has the ability to vary several parameters at once, thus identifying the combined uncertainty of the results. Additionally, Crystal Ball® predicts which variables have the most influence on the study outcome. When the user defines each variable, they also specify the type of distribution, the range for that variable in the analysis, and the most likely value so that Crystal Ball® has a starting point. The software operates within Microsoft Excel®.

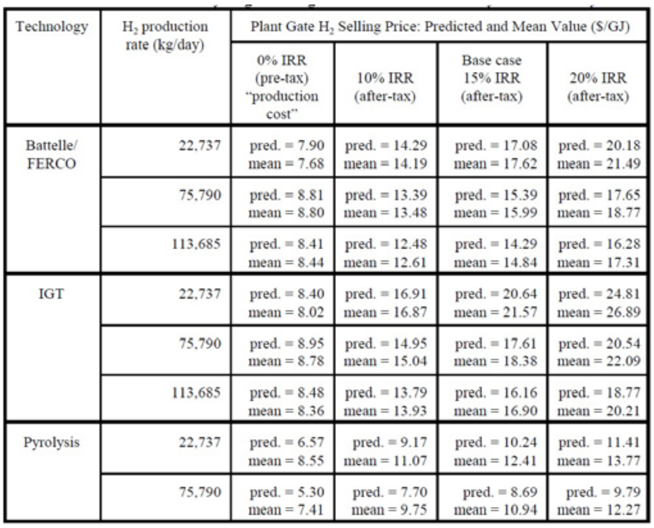
Fig. 4 lists two values for each case, the predicted hydrogen selling price from the Excel® cash flow spreadsheet, labelled as “pred.”, and the mean hydrogen selling price as determined by Crystal Ball®. The mean hydrogen selling price takes all of our assumptions and uncertainties into account. Depending on the technology and plant size, the predicted plant gate hydrogen selling price ranges from \$8.7 to \$20.6/GJ for an IRR of 15% [1].

The pyrolysis case produces the cheapest hydrogen, followed by the Battelle/FERCO gasifier, and then the IGT system. The hydrogen selling price increases with an increasing IRR, and decreases as the plant size increases due to economy of scale. In most instances, the predicted hydrogen selling price is less than the sensitivity analysis mean.

This is expected because Crystal Ball®’s sensitivity analysis incorporates the variance of the assumptions into the hydrogen selling price. For the gasifier systems, the predicted hydrogen selling price is fairly close to the mean (within \$1/GJ) except for the higher 20% IRR cases.

The pyrolysis cases had a predicted hydrogen selling price that was usually about \$2/GJ lower than the sensitivity results. The difference between the predicted and mean hydrogen selling price is twice the difference of the gasifier cases, demonstrating that there is a greater variability built into the pyrolysis assumptions. It is easier to reform the gasifier product gas than it is to reform the carbohydrate fraction of the bio-oil. Additionally, there is significant uncertainty regarding the selling price of the adhesives coproduct.

The char yields reflected by the Fig. 5 were produced by pyrolyzing cherry sawdust at temperatures equal to 450ºC. At this temperature the samples were kept for different residence time: between 5 minutes and 30 minutes. As it can be seen the char yields decreases as the residence time increases. We have obtained the biggest value of char yields in case of the shorter residence time – 30.48% and the smaller value of char for the longer time (30 minute), equal with 28.71% [1].



Technology	H_2 production rate (kg/day)	Plant Gate H_2 Selling Price: Predicted and Mean Value (\$/GJ)			
		0% IRR (pre-tax) “production cost”	10% IRR (after-tax)	Base case 15% IRR (after-tax)	20% IRR (after-tax)
Battelle/ FERCO	22,737	pred. = 7.90 mean = 7.68	pred. = 14.29 mean = 14.19	pred. = 17.08 mean = 17.62	pred. = 20.18 mean = 21.49
	75,790	pred. = 8.81 mean = 8.80	pred. = 13.39 mean = 13.48	pred. = 15.39 mean = 15.99	pred. = 17.65 mean = 18.77
	113,685	pred. = 8.41 mean = 8.44	pred. = 12.48 mean = 12.61	pred. = 14.29 mean = 14.84	pred. = 16.28 mean = 17.31
IGT	22,737	pred. = 8.40 mean = 8.02	pred. = 16.91 mean = 16.87	pred. = 20.64 mean = 21.57	pred. = 24.81 mean = 26.89
	75,790	pred. = 8.95 mean = 8.78	pred. = 14.95 mean = 15.04	pred. = 17.61 mean = 18.38	pred. = 20.54 mean = 22.09
	113,685	pred. = 8.48 mean = 8.36	pred. = 13.79 mean = 13.93	pred. = 16.16 mean = 16.90	pred. = 18.77 mean = 20.21
Pyrolysis	22,737	pred. = 6.57 mean = 8.55	pred. = 9.17 mean = 11.07	pred. = 10.24 mean = 12.41	pred. = 11.41 mean = 13.77
	75,790	pred. = 5.30 mean = 7.41	pred. = 7.70 mean = 9.75	pred. = 8.69 mean = 10.94	pred. = 9.79 mean = 12.27

Fig. 4 Predicted Plant Gate Hydrogen Selling Price and Mean Sensitivity Price from Crystal Ball®

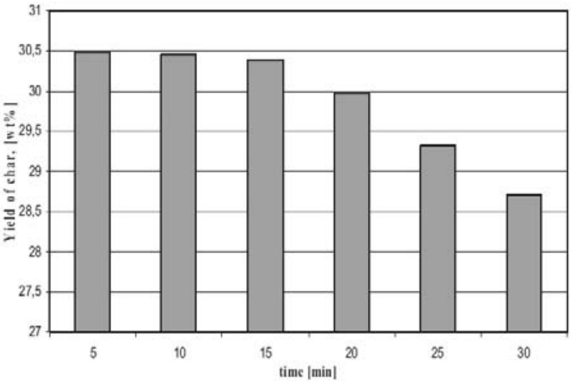


Fig. 5 The pyrolysis char yields versus residence time

The heating rate has a big influence on product distribution. A rapid heating rate increases volatile yields and decreases char yield. A rapid heating leads to a fast depolymerization of the solid material to primary volatiles while at a lower heating rate dehydration to more stable anhydrocellulose is limited and very slow. The result is that very small amounts of char are produced in the primary reactions at rapid heating. Our experiments have demonstrated this theory. The char yields for a heating rate of 10 ºC/min were lower than yields achieved at the lower heating rate of 5 ºC/min. The char yield decreased from 39.98 % to 29.98 % as the heating rate was raised from 5 ºC/min to 10 ºC/min.

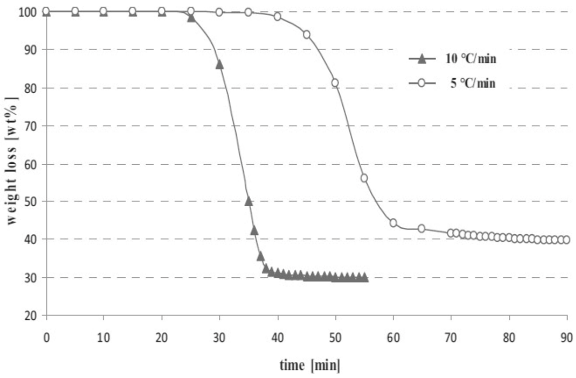


Fig. 6 Heating rate influence on char yields

III. HYDROGEN PURIFICATION BY PRESSURE SWING ADSORPTION (PSA) METHOD

The PSA process for hydrogen separation is based on the capacity of adsorbents to adsorb more impurities at high gas-phase partial pressure than at low partial pressure. The principle is illustrated in Fig. 5. Impurities are adsorbed in an adsorber at higher partial pressure and then desorbed at lower partial pressure [14], [15]. The impurity partial pressure is lowered by “swinging” the adsorber pressure from the feed pressure to the tail gas pressure, and by using a high-purity hydrogen purge. Hydrogen is adsorbed in only small amounts.

The process operates on a cyclic basis. In order to provide constant feed, product and tail gas flows, multiple adsorbers are used. Each adsorber undergoes the same process steps in the same sequence, but the steps are staggered with respect to time. A simple cycle sequence chart is shown in Fig. 7 for a system with four adsorbers.

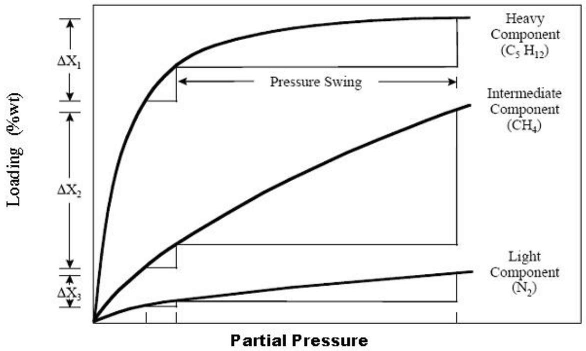
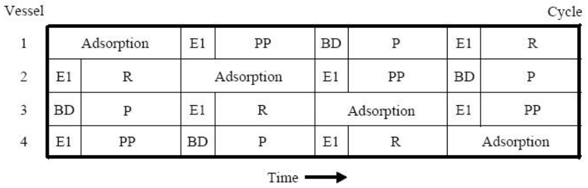


Fig. 5 Adsorption Isotherms



Vessel							Cycle
1	Adsorption	E1	PP	BD	P	E1	R
2	E1	R	Adsorption	E1	PP	BD	P
3	BD	P	E1	R	Adsorption	E1	PP
4	E1	PP	BD	P	E1	R	Adsorption

E = Equalization (CO/Current Depressurization)
PP = Provide Purge (CO/Current Depressurization)
P = Purge
BD = Blowdown (Counter/Current Depressurization)
R = Final Repressurization

Fig. 7 PSA Cycle Sequence

The driving force for the separation is the impurity partial pressure difference between the feed and the tail gas. A minimum pressure ratio of approximately 4:1 between the feed and tail gas pressure is usually required for hydrogen separation [13]. The optimum feed pressure range for PSA units in refinery applications is 200-400 psig. The optimum tail gas pressure is as low as possible.

Fig. 8 shows the influence of a system pressure levels on hydrogen recovery for a fixed feedstock and process configuration.

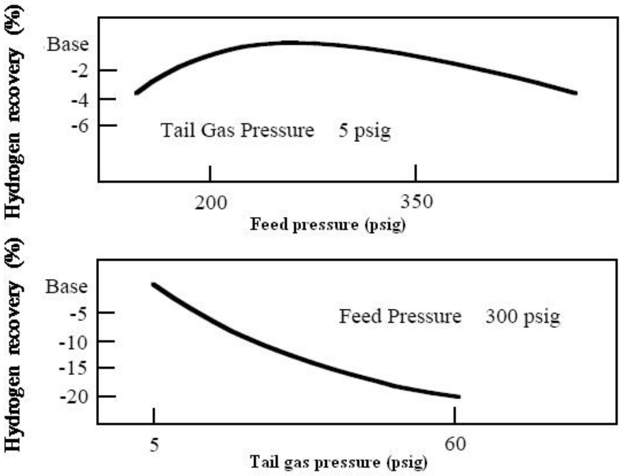


Fig. 8 Effect of pressure levels on PSA systems [8]

The PSA separation is chromatographic in nature, meaning that the lightest impurities will appear first in the product, followed by the more strongly adsorbed impurities. Relative adsorptivity of typical feed impurities is given in table 2.

TABLE 2
RELATIVE STRENGTH OF ADSORPTION FOR TYPICAL IMPURITIES

Non-adsorbed	Light	Intermediate	Heavy
H_2	O_2	CO	C_3H_6
He	N_2	CH_4	C_4H_{10}
	Ar	C_2H_6	C_5+
		CO_2	H_2S
		C_3H_8	NH_3
		C_2H_4	BTX
			H_2O

The advantages of the PSA process are its ability to remove impurities to any level (e.g. ppm levels if desired), and to produce a very high purity hydrogen product. Typical PSA hydrogen product purities range from 99 to 99.999 %vol. High hydrogen purity is often of benefit to downstream processes, and because of this, most units are designed to produce the high purities mentioned above [15] - [17].

The hydrogen recovery achievable by PSA units is moderate, typically 80-92% at optimum conditions, and 60-80% when the tail gas is delivered at higher (40-80 psig) pressure. The system configuration is varied to optimize the recovery for specific pressure levels, flow rates and stream compositions [18].

Pretreatment considerations are important to the selection of a hydrogen separation process. The extent to which feed pretreatment is required affects cost, operating flexibility and ease of operation. A knowledge of which contaminants and their maximum concentration in the feed is important to the design of a PSA unit, since strongly adsorbed components can permanently deactivate some adsorbents intended for removal of light components.

Feed composition has a large impact on the selection of a hydrogen separation process. Streams with 75-90 %vol hydrogen are most economically upgraded by PSA or membrane processes with the selection being based on flow, pressure, and pretreatment requirements [17]. Hydrogen product purity is critical to process selection. Feed pressure and product flow rates must be considered together when selecting the hydrogen purification process. PSA systems have moderate capital costs in the small flow range, and have good economies of scale.

The capital and operating cost associated with feed, product, and/or tail gas compression, is almost always a significant portion of the total separation system costs. Compressor requirements often determine which process is most economical [19]. Small systems with low feed pressure favour PSA (compression requirements usually dictating selection).

IV. APPLICATIONS AND COSTS OF HYDROGEN FROM BIOMASS

Hydrogen from any source, including biomass, can be used as a conventional fuel: burned using air in engines, boilers or turbines in order to obtain energy.

Also, hydrogen can be used to obtain electricity directly, without the thermodynamic limitations of a thermal process, in nearly all types of fuel cells [20].

But, if hydrogen is used as a combustion fuel with air, small amounts of pollutants will result, such as NO_x, due to the high temperatures reactions with nitrogen in air. Anyway, these pollutants are in smaller levels then the ones resulting from the combustion of common hydrocarbon fuels. In the case of fuel cell, the only emission is water vapour.

Hydrogen from biomass could be added to the gas transmission or gas distribution grid, and the resultant blending gas used in the same way as gas is today. “Town gas” manufactured from coal contains about 50% hydrogen by volume. A potential benefit of hydrogen from biomass is the lower emission of CO_2. The drop of emissions is proportionally with the degree of addition of such “green hydrogen” [21].

There are considerably variations in the gas composition and properties, both within and among countries. The gas properties are regulated but allow substantial variation.

IEA organization achieved a study [20] on three gas markets (Netherlands, UK, France) from Europe, with different technical and operational constrains. Hydrogen blending was study in three steps: introduction, to 3% by volume; intermediate step, to 12%; maximum blending to 25%. Fig. 9 shows some results, in terms of costs, benefits and specific CO_2 reduction costs. We can observe that the advantages are significant but costs are relatively high, also compared with the costs of CO_2 capture and storage. This analysis appears to be thorough, accounting for a large number of factors and critical elements.

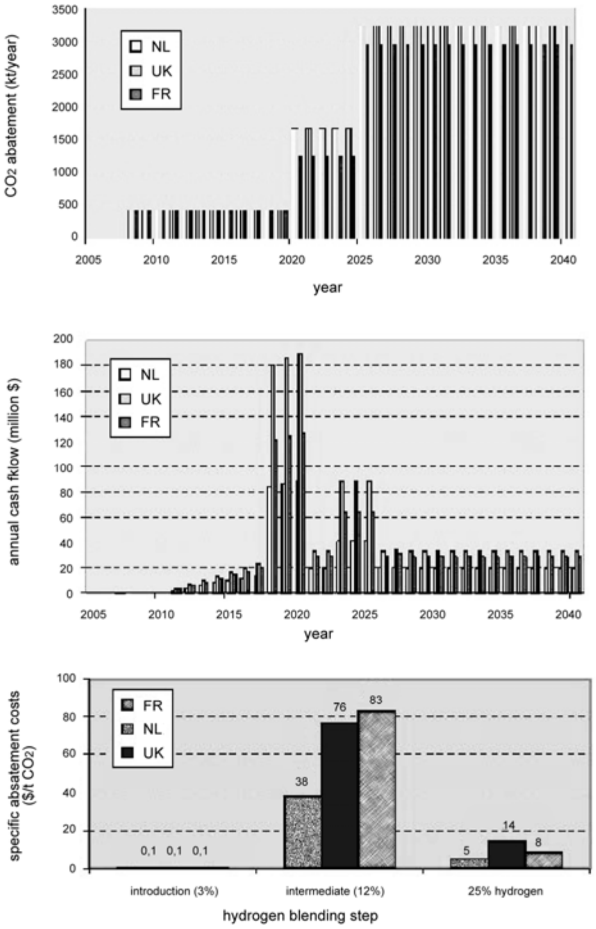


Fig. 8 Estimated CO_2 abatement benefits (top), costs (middle), specific costs (bottom) [14]

Regarding our country, Romania, some estimations show that the costs for production of hydrogen from biomass are similar with the costs for Bulgaria and Turkey (table 3) [22]. In the column feedstock/electricity there are two values. The value from brackets refers to the feedstock or electricity costs in c/kWh (0.1$/kWh), while the first value represents the specific feedstock/electricity costs per kWh hydrogen produced and includes the efficiency of the process.

TABLE 3
COMPARATIVE STUDY OF HYDROGEN PRODUCTION COSTS

Country	**Hydrogen production**	**Feedstock / electricity costs c/kWh H_2 (c/kWh)**	**Plant related costs (c/kWh H_2)**	**Total production costs (c/kWh H_2)**
Romania	**Biomass staging reforming**	**3.4 (1.59)**	**2.5**	**5.9**
Bulgaria	**Biomass staging reforming**	**3.6 (1.65)**	**2.5**	**6.1**
Turkey	**Biomass staging reforming**	**3.6 (1.65)**	**2.5**	**6.1**

V. CONCLUSIONS

Bio-fuels can be used as an alternative fuel for transport, as can other alternatives such as liquid natural gas, compressed natural gas, liquefied petroleum gas and hydrogen. Recently, there has been growing interest in bio-fuels due to the rising energy costs and environmental problems. Hydrogen is considered in many countries as an important alternative energy indicator and a bridge to a sustainable energy future.

The promise of hydrogen as an energy carrier that can provide pollution-free, carbon-free power and fuels for buildings, industry, and transport makes it a potentially critical player in our energy future [23].

The aim of this paper was to establish the efficiency of hydrogen production from biomass in order to use the H_2 as an energy carrier or fuel offering significant reduction in the emissions of NO_x, hydrocarbons, CO, and CO_2.

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