International Energy Agency

IEA

Advanced Fuel Cells

Annex XIX

Stationary Fuel Cells

Subtask 3

Fuel for Fuel Cells

Summary Report

Subtask 3: Fuel for Fuel Cells

Contents

1. Introduction

This paper represents a short description of the comprehensive study carried out under the IEA Implementing Agreement, Annex XIX, subtask 3, Fuels for Fuel Cells. The full text of the study is available at Annex XIX.

Purpose of the Study

The development of the different kinds of fuel cells and fuel cell systems has been enforced within the last decade and the range of applications is presently expanding very fast. Fuel cells for stationary combined power and heat production, fuel cells for decentralized power production and emergency power, fuel cells for energy supply of hand-held electronic equipment and fun articles are only some of these different applications of this new technology. Small and low temperature fuel cells need hydrogen as feedstock for operation, whereas high temperature fuel cells can be operated with different hydrocarbons due to their ability of internal reforming. Where does the hydrogen for low temperature fuel cells come from? It can be produced from hydrocarbons by steam reforming, via electrolysis of water with electricity coming from different sources, and a lot of other methods. The purpose of the study is to give an overview over the different kinds of fuel cells and their possible feedstock, the availability of this feedstock in the countries of the member states of this Implementing Agreement of IEA, where Annex XIX is part of. The purpose of the study is also to allow estimation about the future ability of penetrating the market by the new fuel cell technologies and to estimate their potentials for energy supply in the different kinds.

2 Fuel Cell Types

General Decription

The various fuel cell technologies cover a wide scope of applications ranging from battery applications through electrical propulsion up to power stations due to their inherent modularity, high efficiency, and cleanliness. Highly reliable energy supply of small units like laptops, consumer electronics, units in spacecrafts and aircrafts, applications for supply of automotive electrical propulsion systems and auxiliary power units (APU) and as modular basic building blocks for stationary power production systems as well as combined heat and power units (CHP) or tri-generation units (combined heat, power, cooling energy) can be realized with fuel cells. The fuel cell technologies in principle differ in the utilized electrolyte giving them their names and in operating temperatures, which basically determines the ranges of possible applications and the utilization of different fuels.

The list of possible usable fuels is long and comprises

- pure hydrogen,
- gaseous or gasified hydrocarbons (natural gas, biogas, sewage gas, coal mine gas, methane containing gas mixtures, etc.),
- synthesis gases (mixtures of hydrogen and carbon monoxide)

As oxidant both pure oxygen and air are used.

Fuel cells are operating inherently clean, produce hardly emissions and offer maximum electrical efficiency.

The basic functional mechanisms of the different fuel cell types already are addressed in literature, so we have only to discuss the differences of the two temperature classes of fuel cells:

- low temperature fuel cells,
    - Alkaline fuel cell (AFC),
    - Phosphoric acid fuel cell (PAFC),
    - Proton exchange membrane fuel cell (PEM or PEMFC)
- high temperature fuel cells
    - Carbonate fuel cell, often called Molten Carbonate Fuel Cell (CFC or MCFC)
    - Solid oxide fuel cell, ceramic fuel cell (SOFC)

The principle function of the mentioned fuels cells are described within the comprehensive report and hints are given, which fuels are applicable for the fuel cell types respectively. Also specific types of applications are indicated as consequence to their different operating principles, their operating temperatures and their typical behaviour.

3. Fuels for Fuel Cells

General Classification

Fig. 3.1 shows a possible general classification of the most important fuels for fuel cells along their source, whether they are based on fossil, renewable or secondary sources.

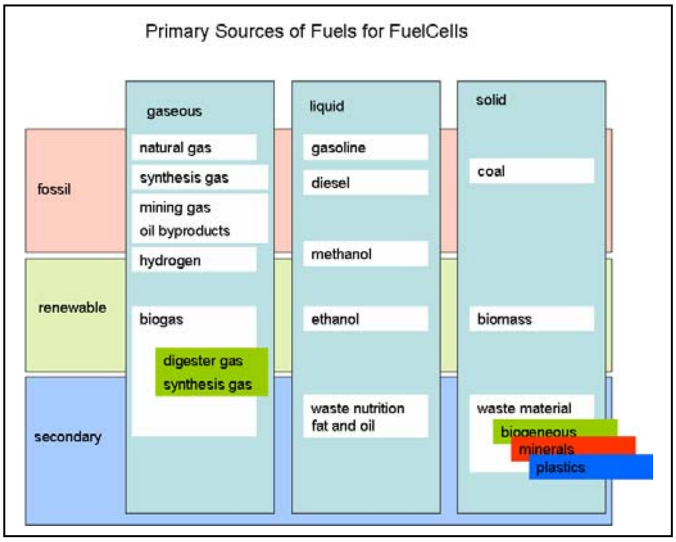


Fig. 3.1: Sources of Fuels for Fuel Cells

The difference between renewable and secondary shall be explained more exactly on the example of biogas: biogas can be produced by fermentation from virgin biomass, e. g. corn. Such biogas is called "renewable". Big areas of corn plantations are built up worldwide for that purpose. Biogas also can be produced from biological waste material: harvest residuals, manure, used nutrition fats and oil, green and residual material from maintaining landscape, slaughter house residuals, residuals from food industry, etc.. Such biogas is also a renewable one, but based on "secondary" sources, meaning "sources already used".

Gasification of biomass and organic waste material

In principle there exist four methods of gasification of biomass and organic waste material (see fig. 3.2):

- Burning: produces heat and not combustible exhaust gas containing mostly small amounts of CO and pollutant components as NOx, higher hydrocarbons, tar, soot, etc.
- Anaerobic digestion or fermentation: produces biogas (digester gas) from a lot of materials which are biodegradable. Not possible for ligno-celluloses containing materials like wood and wood-products.
- Gasification: produces synthesis gas (syngas) from all hydrocarboneous material in adapted gasification processes. Two principal methods of gasification exist:

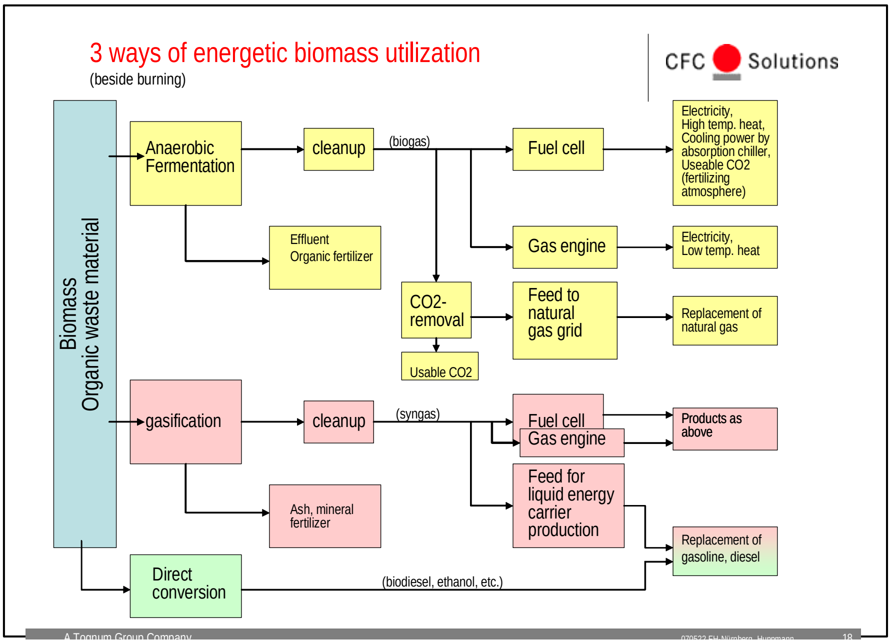


Fig. 3.2: Utilization of biomass (beside burning)

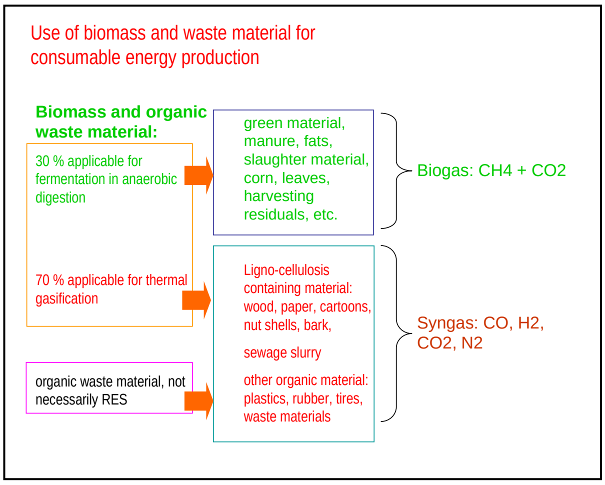
- o Autothermal gasification: This process uses the heat of a partial combustion of the material to be gasified for feeding the gasification process. In an autothermal gasification process the material to be gasified will be burnt together with an understoiciometric amount of air and the resulting endothermal pyrolysis transfers the material into the gas phase by cracking the big hydrocarboneous molecules. Since the pyrolysis is made together with air, the resulting gas contains the nitrogen from the air as an inert component. As the combustible components of the resulting gas are mainly CO and H2 (both with an approximately LHV of 3 kWh/m3) the gas has a much lower LHV due to the high amount of N2 and CO2. Typical LHV of such gases are 1,2 to 1,5 kWh/m3. The gas quality can be increased by using oxygen or oxygen-enriched air for gasification; adding steam increases the LHV of the product gas also.

- o Allothermal gasification: In this process the gasification agent is steam. In most of these gasifiers the material to be gasified is blown into a fluidized bed zone, which is fluidized by steam only. Since the gasification reaction is endothermal, additional heat is introduced into the gasification fluidized bed by different means (heated sand, steel balls, heat pipes, etc.). Most biomasses need a gasification temperature of approximately 900 to 950 °C for gasification with steam. Due to the fact that no air contributes to the gasification process no nitrogen is contained in the product gas. Including some percent of methane coming from the light fraction of the biomass (mostly up to 10 %) the resulting gas has a LHV of higher than 3.5 kWh/m3. Additional, the amount of produced gas has a higher LHV compared with the amount of used biomass, because of the hydrogen of the water-steam used and the input of thermal energy.

- Direct conversion: The direct conversion is possible for some kinds of virgin biomass:
  - o Sugar containing biomass, e. g. sugar cane, sugar beets , potatoes and others can be used for production of ethanol, which represents a replacement of liquid fossil fuels
  - o Rape and palm oil can be used for direct conversion to methyl ester (biodiesel)
  - o Synthesis gas form gasification of biomass can be directly converted to liquid fuels replacing fossil fuels by Fischer-Tropsch synthesis.

Typical for most methods of direct conversion is a very small basis for usable materials. Most of them are competing the production of nutrients directly.

The following figures 3.3 to 3.4 give an overview over the mentioned methods and list the usable materials for each method.



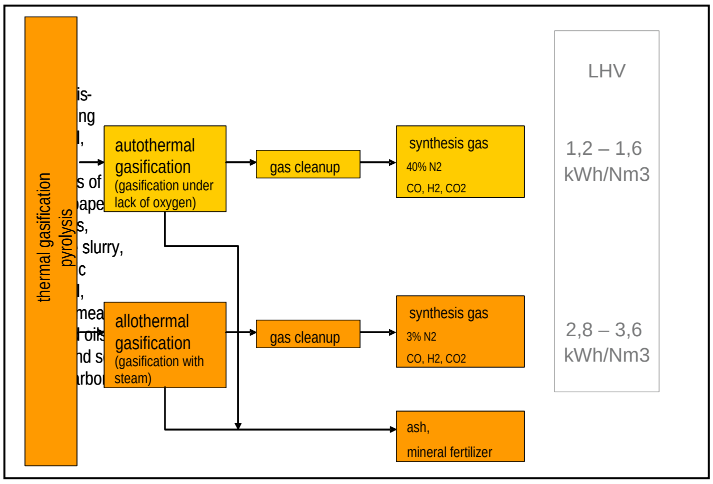


Fig. 3.3: Biomass utilization for consumable energy production by gasification - biogas - synthesis gas
Fig. 3.4: Autothermal and allothermal gasification

Syngas Utilization:

The development of gasification systems for wood, cartoon, paper, wooden harvest residues (e. g. nut shells and other residual material) and other waste material has not yet reached industrial standard. Many systems are under development, but no one is really ready and available for application. The MCFC has been tested in many lab scale projects with success for its operability with syngas, but till now no full size MCFC system is tested in an operation with syngas. Here should be mentioned an EU-project, where the adaptation of the MCFC system of MTU Onsite Energy, the HotModule®, to different wood and waste gasification systems is under investigation (EU-Project *BigPower*, Project leader VTT, Finland).

Other Fuels - Methanol

A HotModule® combined heat and power production plant is under operation since September 2004 in Berlin, Germany at BEWAG facilities, which is a local utility company in Berlin (Fig. 3.5). This modified HotModule is designed for operation with methanol and all possible methanol-natural gas mixtures. As the plant has been started with natural gas for practical reasons the operation with methanol started in January 2005. Its operability with pure methanol and continuously changed mixtures of methanol and natural gas is proven meanwhile. For methanol operation the electrical efficiency reached up to 47%.

Fig. 3.5: The Methanol HotModule at BEWAG, Berlin, Germany

4. Conclusions

Running fuel cells on biofuels could bring environmental benefits by combining the high efficiency of fuel cells with renewable energy sources. Demonstration projects have been running around the world, combining fuel cells with biofuels from gasification, landfill and anaerobic digestion plant. High temperature fuel cells (MCFCs and SOFCs) have been identified as better suited for integration with biofuels due to their higher tolerance to contaminants and their ability to internally reform biofuel gases, leading to lower operational costs. However, some contaminants present in the biofuel can be poisonous to the fuel cell and therefore need to be removed downdraft to the fuel cell. The development of new fuel cell materials, better able to withstand biofuel contaminants, may help in promoting biofuel fed fuel cells, by removing the need for an additional gas-clean up process.

Decentralized systems could use biogas and gasification gas as fuel. Biogas production is commercial technology. Gasification is under demonstration. The economic competitivity of biogas systems depends how much benefit is gained of using waste, which otherwise would have negative price as disposal. Hence the comparison to fuels obtained from biomass is often irrelevant.
Liquid biofuels, like methanol, ethanol, and DME and gaseous SNG may be produced in large centralized facilities. Because natural gas and biogas are the best current fuels for high temperature fuel cells, the feeding of SNG produced from biomass to existing pipeline network would be technically relevant. This could be done by integrating oxygen gasification or steam based gasification with gas-cleaning to methanation process.

In relatively small-scale (90 ktoe/a) methanol and DME have lowest production costs. In Central Europe, considerably larger (5- to 10-fold) biofuel production concepts have been proposed and assessed. If raw materials would be available for those capacities, the production costs could be reduced further. Ethanol production from sugar and starch containing raw materials is commercial technology. Bioethanol exported from Brazil is the lowest cost alternative. However, presently these amounts are relatively small, but they are expected to grow.

Biodiesel production via esterification route is commercial technology. However, higher hydrocarbons, like biodiesel, are more prone to coke formation and hence more research on reforming of these bio-fuels is needed before proceeding to demonstration scale.

In the case of liquid biofuels competition with transportation sector would be significant.

The results on biofuel costs from different sources are only comparable to a limited extent because the cost estimates are highly variable. Production costs depend on several factors such as time of estimate, scale of production, location, process concept assessed, financial parameters applied, and even source of the estimate. In addition, feedstock cost has a major effect of product cost. If agricultural by-products are used as feedstock, potential subsidies have to be taken into account. Note also that most of the concepts assessed are still on development stage, and it is difficult to compare them to already industrial alternatives. Hence, case specific cost assessment is necessary.