A Road Map for Second-Generation Fuels for Internal Combustion Engines

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Abstract— The depletion of natural resources, fast growing vehicle density and increased pollutant emission in the environment have alarmed a great. Rapid exploitation of the natural resources led to the high price rise of the petroleum fuels. These fuels also add major environmental pollutant CO2, which is a greenhouse gases also. The stringent rules and environmental regulation led the researchers to think about alternative resources of the transportation and industrial fuels. Looking at huge demand of diesel fuel for transportation sector, captive power generation and agricultural sector, the second-generation fuels are being viewed a substitute of diesel fuel. The present review paper focuses on the available resources of alternative fuels, their production, social and environmental impacts, research gap.

Key words: Second-generation fuels, Biodiesel, F-T fuels

I. INTRODUCTION

The availability and environmental impact of energy resources will play a critical role in the progress of the world's societies and the physical future of our planet. The majority of human energy needs are currently met using petrochemical sources, coal, oil or animal fat. The second-generation fuels are the suitable alternative for the internal combustion engine fuels. These fuels are secondary fuels produced from the different sources.

Biomass is the oldest source of energy and currently accounts for roughly 10% of total primary energy consumption. While traditional biomass in form of fuel wood still is the main source of bioenergy, liquid biofuel production has shown rapid growth during the last decade [1].

During recent years, the production of many first-generation biofuels has faced heavy criticism regarding its sustainability. On the one hand, rises in agricultural commodity prices have spurred discussions as to which extent first-generation biofuels can be produced without endangering food production. On the other hand, the release of GHG associated with land use changes led to controversial discussions on the effectiveness of first-generation biofuels to reduce global carbon emissions. Despite the fact that some of the currently produced biofuels are performing well in terms of economic and environmental sustainability, now the ongoing debates shifted focus onto second-generation biofuels, which are based on non-edible biomass and promise to avoid the sustainability concerns related to current biofuel production [2, 3].

Keeping in view the energy demand in future and depletion of conventional resources of fuels, an effort have been made to collect the information about alternative fuels, resources, production and their potential role in the future energy supply and environmental impact.

II. SECOND-GENERATION BIOFUELS

First generation biofuels are biofuels, which are on the market in considerable amounts today. Typical 1st-generation biofuels are sugarcane ethanol, starch-based or 'corn' ethanol, biodiesel and Pure Plant Oil (PPO). The feedstock for producing 1st-generation biofuels either consists of sugar, starch and oil bearing crops or animal fats that in most cases can also be used as food and feed or consists of food residues. Second-generation biofuels are those biofuels produced from cellulose, hemi-cellulose or lignin.

The second-generation biofuel can either be blended with petroleum-based fuels combusted in existing internal combustion engines, and distributed through existing infrastructure or is dedicated for the use in slightly adapted vehicles with internal combustion engines (e.g. vehicles for DME).

The second-generation biofuel includes- cellulosic ethanol, BTL-diesel, bio-SNG and Fischer-Tropsch fuels [4]. Fig. 1 shows the share of biomass mass in total primary energy. India is having good potential of biomass nearly 30%. The second-generation biofuels are not yet produced commercially, but R&D efforts have been undertaken for different conversion routes, as shown in Table 1, and so far there is no clear trend showing which technology will be the most promising future option. The two main conversion routes are:

1) Bio-chemical route: This process is based on enzymatic-hydrolysis of the lingo-cellulosic material through a variety of enzymes that break the cellulosic material into sugars. In the second step of the process, these sugars are fermented into alcohol which is then distilled into ethanol.
2) Thermo-chemical route: The first step in the process is the gasification of the feedstock under high temperature into a synthesis gas. This gas can then be transformed into different types of liquid or gaseous fuel, so-called "synthetic fuels" (e.g. BTL-diesel, bio-SNG).

Biofuel group	Specific biofuel	Production process
Bioethanol	Cellulosic ethanol	Advanced enzymatic hydrolysis and fermentation
Synthetic biofuels	Biomass-to-liquid (BTL), F-T diesel, Biomethanol, Dimethyl ether (DME)	Gasification and synthesis
Methane	Bio-synthetic natural gas (SNG)	Gasification and synthesis
Bio-hydrogen	Hydrogen	Gasification and synthesis

Table 1: Different conversion routes and the producible second-generation biofuels [5]

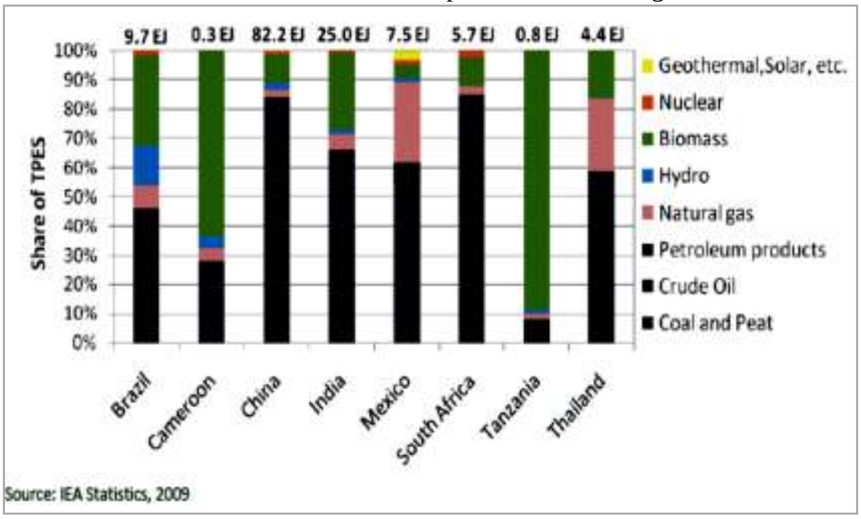

Fig. 1: Biomass in total primary energy supply-2007 in selected countries [6]

A. Feedstock Characteristics

Second-generation biofuels are based on lignocellulosic material, i.e. biomass, which is abundant virtually everywhere around the globe. Biomass can be derived from natural ecosystems (like forests, grassland or aquatic ecosystems), or can also be produced by cultivating bioenergy crops like perennial grasses or wood species. Furthermore, any kind of lignocellulosic waste like straw or sawdust can be used. Table 2 shows the potential lignocellulosic feedstock for second-generation biofuels.

Resources	Second-Generation Biofuel Feedstock	Technical requirements For harvesting/ collection	Potential advantages	Availability
Agriculture	Straw, stover	Existing pasture machinery (e.g. baler)	No competition with food; no additional land required; collection can prevent pests	During crop harvesting season
Forestry & logging	Treetops, branches, stumps	Specialist machines to collect residues efficiently	Relatively cheap; no additional land required; removal can help to prevent forest-fires	Year-round (if residue mat is not needed to protect soils during rainy season)
Crop processing	Coffee, rice, corn, cacao (shells, husks, cob)	No additional technical equipment; no additional infrastructure	By-product - no food competition; no additional land required; concentrated at processing site; avoids disposal costs	Year-round
Sugar and firstgeneration bioethanol Production	Sugar cane, sweet sorghum, sugar beet (bagasse, pulp)	No additional technical equipment; no additional infrastructure	No food competition; concentrated at ethanol plant; no additional land required; avoids disposal costs	During feedstock harvesting season
Vegetable oil production	Canola, oil palm, jatropha (presscake, shells, fruit bunch)	No additional technical equipment; no additional infrastructure	Concentrated at oil mills; currently very cheap; no additional land required; avoids disposal costs	During crop harvesting season
Forestry processing	Sawdust, bark	No additional technical requirements	Concentrated at saw and paper mills; no additional land required; avoids disposal costs	Year-round
Municipal solid waste	Palettes, furniture, demolition timber	Separation from other waste might be	Concentrated at landfill site; no additional land required;	Year-round

Resources	Second-Generation Biofuel Feedstock	Technical requirements For harvesting/ collection	Potential advantages	Availability
		required	avoids disposal costs	

Table 2: Overview on potential lignocellulosic feedstocks for second-generation biofuels [6]

III. PRODUCTION TECHNOLOGY

A. Methanol:

Methanol is mainly produced from syngas, which can be produced from Fossil Fuels – NG, Crude oil, Coal; Renewable resources – Wood and municipal solid wastes [7]. It involves two technologies- steam reforming reaction and water-gas shift reaction. Steam reforming reaction $CH_4 + H_2O \xleftrightarrow[800-1000^\circ C,\, 20-30\, atm]{Nickel\ based\ Catalyst} CO + 3H_2$ and water-gas shift reaction $CO + H_2O \longleftrightarrow CO_2 + H_2$ and methanol synthesis reaction-

$$2H_2 + CO \xleftrightarrow[800-1000^\circ C,\, 20-30\, atm]{Nickel\ based\ Catalyst} CH_3OH$$

B. F-T Fuels:

The Fischer-Tropsch fuels, is a second-generation fuel patented by Franz Fischer and Hans Tropsch, from synthesis of petroleum at normal pressure using metal catalysts in 1926. F-T fuels are the synthetic fuels, generally known as gas-to-liquid fuels [7], [8]. The resources for F-T fuels are Coal, Biomass and agro-wastes and F-T fuels can be produced as shown in Fig 2. The general chemical reaction is given as-

$$nCO + (2n+1)H_2 \rightarrow C_nH_{2n+2} + nH_2O \quad (Exothermic)$$

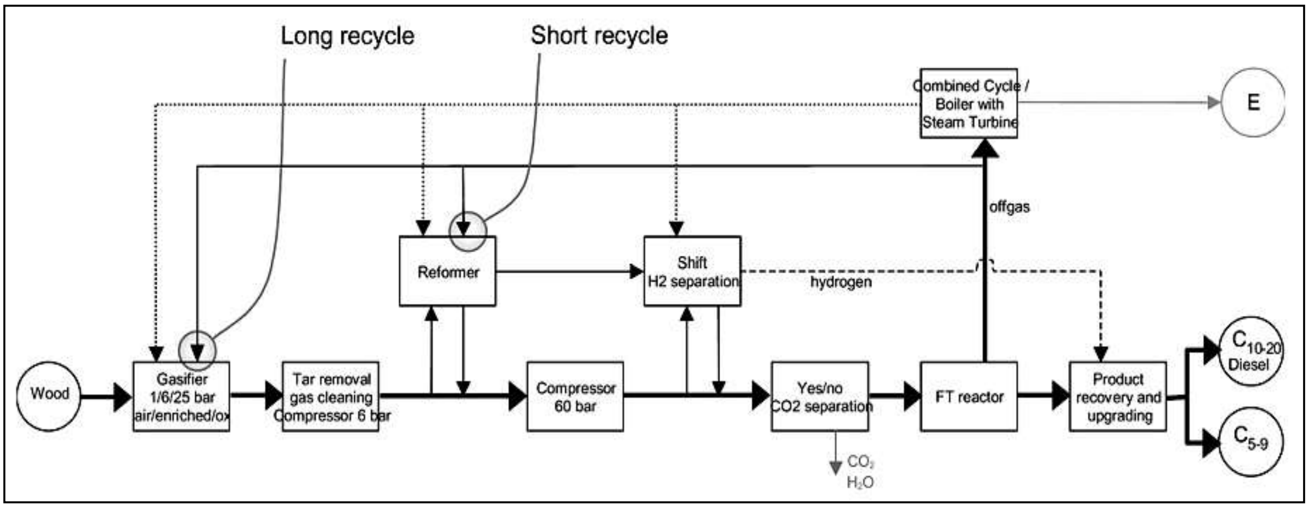

Fig. 2: Overview of FT liquids producing plant [9]

IV. IMPACTS OF SECOND-GENERATION FUELS

A. Potential social impact

Employment and regional growth will probably be the most important drivers for the implementation of second-generation biofuel projects in major economies and developing countries. The potential for creation of jobs along the value-chain varies depending on the feedstock choices. Use of dedicated energy crops will create jobs in the cultivation of the feedstock, whereas the use of residues will have limited potential to create jobs since existing farm labour could be used. The following conclusions regarding labour were found for the countries included in this study:

1) Sufficient labour for feedstock cultivation and transport could be provided in all of the studied countries.
2) Requirement of highly skilled engineers for the biofuel conversion will generate employment opportunities in the large emerging countries with experience in other energy industries or first-generation biofuel production (i.e. Brazil, China, India, South Africa).
3) Significant capacity building would be required in Cameroon, Tanzania, and to a certain extent in Thailand, to successfully adopt second-generation biofuel technologies [6].

B. Potential environmental impacts and GHG balances

The environmental impact of second-generation biofuel production varies considerably depending on the conversion route as well as the feedstock and site-specific conditions (climate, soil type, crop management, etc.). An important driver for biofuel promotion is the potential to reduce lifecycle CO_2 emissions by replacing fossil fuels. As shown in Fig 3, lignocelluloses are more environmental friendly. Currently available values indicate a high GHG mitigation potential of 60-120%, similar to the

70-110% mitigation level of sugarcane ethanol (IEA, 2008c) and better than most current biofuels. However, these values do not include the impact of land use change (LUC) that can have considerable negative impact on the lifecycle emissions of second-generation biofuels and also negatively impact biodiversity [11].

To ensure sustainable production of second-generation biofuels, it is therefore important to assess and minimise potential LUC caused by the cultivation of dedicated energy crops. This deserves a careful mapping and planning of land use, in order to identify which areas (if any) can be potentially used for bioenergy crops.

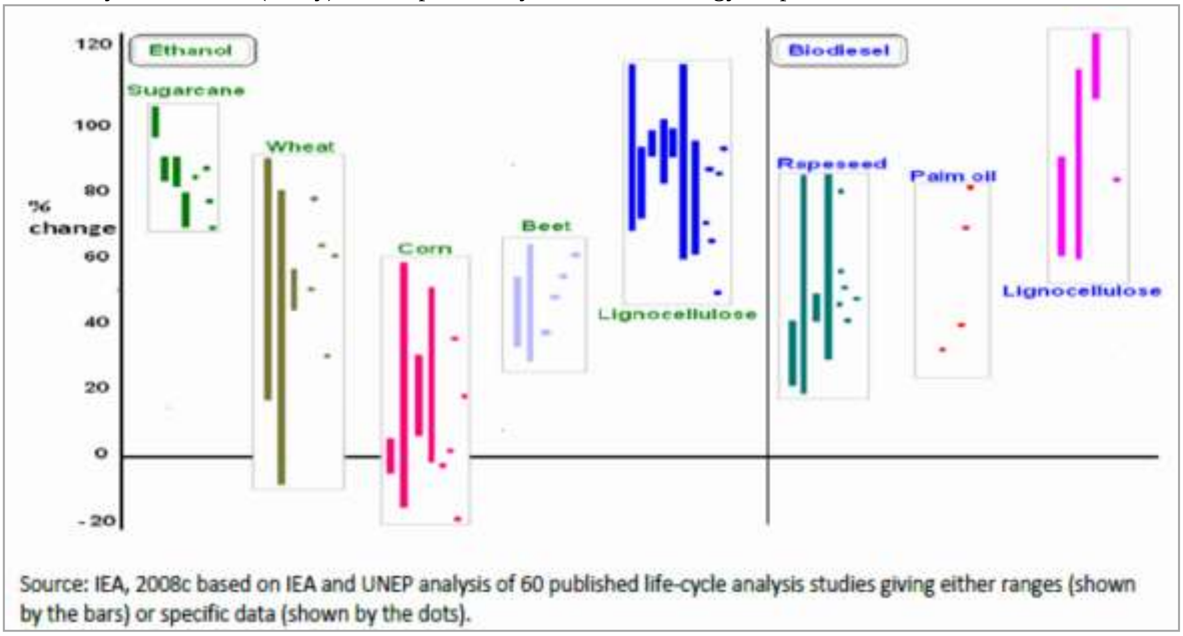

Fig. 3: Comparison of well-to-wheel emission changes of different biofuels compared to fossil fuel

V. RESEARCH GAPS AND NEXT STEPS

It is still too early to fully assess the potential social, economic and environmental impacts of large scale second-generation biofuel production in practice. The following research steps are suggested to understand better the potential and impact of second-generation biofuels in developing countries and emerging economies:

- Creation of a global road map for second-generation biofuels, to enable governments and industry to identify steps needed and to implement measures to accelerate the required technology development and uptake.
- Set-up of pilot and demonstration plants outside the OECD in order to develop supply chain concepts, assesses feedstock characteristics, and analyse production costs in different parts of the world.
- Collection of field data from commercial second-generation biofuel production from residues to better understand impacts on agricultural markets and the overall economic situation in developing countries.
- Improved data accuracy on sustainably available land in developing countries to determine the potential for dedicated energy crops [10].

VI. CONCLUSIONS

The second-generation fuels technologies are mainly in a pilot or demonstration stage and are not yet operating commercially. The main obstacle for second-generation biofuels is high initial investment costs as well as higher costs for the end-product compared to fossil fuels or many first-generation biofuels.

- There is a considerable potential for the production of second-generation biofuels.
- Demand for second-generation biofuels is growing, driven by ambitious biofuel mandates in particular in OECD countries, and a growing desire by scientists and policy makers to ensure the sustainability of biofuel production.
- Investments in agricultural production and infrastructure improvements would promote rural development and can significantly improve the framework for a second-generation biofuel industry. This will allow developing countries to enter second-generation biofuel production once technical and costs barriers have been reduced or eliminated.
- Agricultural and forestry residues should be the feedstock of choice in the initial stage of the production, since they are readily available and do not require additional land cultivation.
- To ensure a successful deployment of second-generation biofuels, technologies requires intensive RD&D efforts over the next 10-15 years.

REFERENCES

[1] Davis, Stacy C. and Susan W. Diegel. 2006. Transportation Energy Data Book: Edition 25, Oakridge, TN: Center for Transportation Analysis, Oak Ridge National Laboratory, Report ORNL-6974. Retrieved http://cta.ornl.gov/data/download25.shtml (access date: 8/6/06)
[2] Kopyscinski, J., Schildhauer, T.J., Biollaz, S.M.A., Production of synthetic natural gas (SNG) from coal and dry biomass – A technology review from 1950 to 2009, Fuel, Volume 89, Issue 8, August 2010, Pages 1763-1783, DOI:10.1016/J.FUEL.2010.01.027
[3] Wang, J., Jiang, M., Yao, Y., Zhang, Y. and Cao, J., Steam gasification of coal char catalyzed by K2CO3 for enhanced production of hydrogen without formation of methane, Fuel, Volume 88, Issue 9, September 2009, Pages 1572-1579, DOI:10.1016/J.FUEL.2008.12.017
[4] IEA Bioenergy Task 39, 2009.
[5] First- to-second Generation Biofuels Technologies, IEA, 2008a.
[6] Sustainable production of second generation biofuels, IEA Repot -2010.
[7] Ramdhas, A.S., Alternative Fuels for Transportation, CRC Press, Taylor & Francis Group, 2011.
[8] S.S. Gill, S.S., Tsolakis, A., Dearn, K.D. and Fernandez, J.R., Combustion characteristics and emissions of FischereTropsch diesel fuels in IC engines, Progress in Energy and Combustion Science xxx (2010), pp 1-21, DOI:10.1016/j.pecs.2010.09.001
[9] Hamelinck, C.N., Faaij, A.P.C., Uil, H.D. and Boerrigter, H., Production of FT transportation fuels from biomass; technical options, process analysis and optimization, and development potential, Energy, Vol 29, 2004, pp 1743–1771
[10] IEA, 2008a; http://www.iea.org/textbase/papers/2008/second_Biofuel_Gen.pdf)
[11] Review and analysis of the reduction potential and costs of technological and other measures to reduce CO_2-emissions from passenger cars, Final report, TNO Science and Industry (Assignor European Union, October 31, 2006).
[12] Tijmensen, M.J.A., Faaij, A.P.C., Hamelinck, C.N. and Hardeveld, M.R.M., Exploration of the possibilities for production of fischer tropsch liduids and power via biomass gasification, Biomass and Bioenergy, Vol 23, 2002, pp 129 – 152.