Technological challenges for alternative fuels technologies in the EU. A well-to-Tank assessment and scenarios until 2030 considering technology learning

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Abstract: The initial step of this analysis corresponds to the evaluation of the current state of the art (SoA) for various alternative fuels (AFs) and alternative sustainable automotive technologies (ASATs) across Europe, taking into account their detailed energetic, environmental and economic variables. The method to assess economic and environmental performance of AFs and ASATs corresponds to a well-to-tank (WTT) and tank-to-wheel (TTW) assessment complemented by scenarios until 2030, with projections of reference and high prices of major input variables of analysis. This analysis determines short and long term economic performance taking into account technology learning. 2nd generation biofuels offer potentials for meeting future fuel-energy demand, and are currently supported by main governments and programs. Initial results of this study also indicate that second generation biofuels offer promising solutions in terms of environmental performance but production costs, conversion efficiencies and by-products are major challenges that can influence the overall economic performance considerably. In addition, price volatilities for first generation biofuels feedstock play a major role on the competitiveness and economic performance of these fuels.

Keywords: *Sustainable transport, Low carbon fuels, Alternative fuels, Mobility technologies, Economic assessment*

1. Introduction

Biofuels and alternative fuels (AFs) have emerged strongly since last one decade as sustainable alternatives for the reduction of fossil fuel energy demand and emissions in the transport sector. Various AF production options include 1st generation biofuels (biodiesel and bioethanol) obtained from well established fermentation, oil extraction and trans-esterification processes, as well as emerging 2nd generation biofuels via BTL, gasification, CTL and other processes. Currently, several technological challenges and bottlenecks exist in different AF production options at different levels across the whole supply chain. Biomass supply constraints, inefficient and capital intensive production processes, fuel transportation and supply, onboard usage related problems and many others are such challenges that affect the success and proliferation of these AFs. The expected economic and environmental performance of these alternatives require not only a clear understanding of the current state of the art, but also a comparison between various alternatives along the complete supply chain as “well-to-tank” and “tank-to-wheel” analysis. Within this study, scenarios for the future development of the most important input variables in different AF production pathways have been defined with feedstock costs and production-scale effect variations that influence the overall economic performance.

2. Methods and modelling structure

The current state of the art and developments of AFs and ASATs have been studied by various authors in different projects and studies. In this study, the characterization of technologies along the whole technology cycle included an extensive literature review including research papers, studies, industrial information, etc. from 2003 until 2010, as well as expert’s interviews and assessments in order to screen the state of development of alternative fuel technologies along the technology cycle curve (S-Curve) [1,4]. State of the art updates and projections until 2030 were collected for 26 different AFs pathways through techno-economic databases including information on biomass feedstock requirements, production process input characterizations (inputs, quantities, efficiencies, costs, emissions) and other techno-economic and techno-environmental parameters. The main formulas and assessments used in this study include the annual cost of capital (ACC):

$$\mathbf{ACC} = \frac{IR}{1-\left(\frac{1}{(1+IR)^{Te}}\right)} * Ti * 1 - \left(\frac{1}{(1+IR)^{Te}}\right) * \left(\left(\frac{Tt-Te}{Tt}\right)\right)$$

Ti corresponds to total investments, *Te* to economic lifetime and *Tt* to technical lifetime while IR is the interest rate. For this particular research it was established as 8% for all AF technologies; however it could be higher for 2^{nd} generation and other unavailable technologies due to risks related. Total costs have been estimated as the sum of capital costs and O&M costs which were either found in existing examples or estimated based on the technical configuration of plants and assuming operating conditions (e.g. annual operation hours) by taking into account maintenance due to associated risks of new technologies [1,2,4].

2.1. Technology Learning

Technology learning is projected in the future development of specific investment costs based on the cumulative number of plants in relationship to an assumed progression ratio [4,5,6,7,8]. The currently existing plants especially for 2^{nd} generation AF technologies are either very new or with short commercial history thus making it difficult to have reliable data and technology experience. Therefore, this parameter has been built as an adjustable progress ratio (***Pr)*** as experienced in case of other industries like aviation, machinery, wind mills etc. and it reflects a maximum of 10 to 30% progress ratio differentiated in small and large scale plants. The following equation indicates the specific investment costs ***(SIC)*** taking into consideration total investments ***(Ti)*** and installed capacities ***(Ic).*** The indicator ***TPI*** corresponds to a technological progress indicator based on the assumed cumulative number of plants as function of time within 5 years periods.

$$\mathbf{SIC} = \frac{\mathbf{Ti}}{\mathbf{Ic}} * \mathbf{TPI} * \left(\frac{\mathbf{Log\ Pr}}{\mathbf{Log\ 2}}\right)$$

2.2. Well to Tank (WTT) and Tank to Wheel (TTW) assessment

The WTT assessment in this study relates to the amount of energy expended and the associated GHG emitted in various steps involved in production and delivery of the fuel. The economic assessment of the pathways considers the scale of production and revenue generated through by-products and other associated production costs. Depending on inputs, WTT economic performance [c€/kWh] and CO_2 emissions have been calculated with the steps involved in producing one kWh of alternative fuel and the corresponding inputs (like electricity, heat, fuel and biomass feedstock) as well as the corresponding emissions factors for each particular input variable. This detailed WTT analysis of the pathway(s) describes various processes involved in cultivation of the feedstock until the distribution of finished fuel at the filling station. The TTW assessment accounts for the energy expended and the associated GHG emitted by the fuel and vehicle technology combinations. In this assessment, the internal combustion engine vehicles were considered to propel with pure biofuel (such as ETBE, FT-diesel) or blended with conventional fossil fuel (E85, B5) [3,4,11]. Complete WTW CO2 emissions were assessed by combining the emission generated during the fuel production pathways WTT [gCO2eq/km] and TTW [gCO2eq/km] emissions generated by combustion of fuel at the level of vehicle. The data that WTW assessment includes are the WTT emitted GHG and expended energy (i.e. excluding the energy content of the fuel itself) per unit energy content of the fuel [MJf/100 km] and the TTW energy consumed by the vehicle per unit of distance covered.

3. Assumptions

3.1. WTT – Technology Pathways

Biofuel technology pathways were pre-selected by carrying out a pathway analysis based on the evaluation of costs and emissions performance at various stages of production until delivering biofuel at the filling stations. Year 2010 was selected for comparison between conventional and advanced biofuels, as AFs were to have a commercial start up onwards. In the respect of WTT assessment, 26 biofuel pathways were analyzed in this research and they are described in detail below.

Biodiesel pathways stated include rapeseed and sunflower grain cultivation and transportation to the extraction of oil in small scale (SS) or large scale (LS) extraction plants, production of biodiesel in small scale (SS) or large scale (LS) plants, distribution by trucks and storage at filling station (FS). The consideration of by-products for the assessment result in *8 pathways* for the case of biodiesel as indicated below.

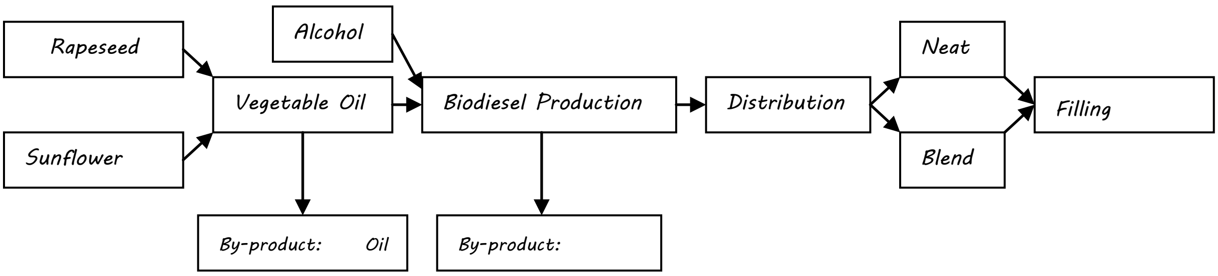

Figure 1: Biodiesel WTT pathways
Source: [1,2]

For bioethanol, *12 WTT pathways* were analysed for both conventional (1st generation) and advanced options (2nd generation) considering biomass production and transport, bioethanol production and distribution until the filling station (FS). Bioethanol production is modelled in small scale (SS) and large scale (LS) plants and the revenues generated from by-products were considered for the assessment (separate pathways for by-products revenues). For lignocellulosic ethanol, by-products have been considered along all the pathways but the differences lie among the feedstock used.

The six BTL Pathways (Figure 3*)* take into account the scale of production plants (small scale, medium scale and large scale) as well as the use of by-products (electricity, heat) however, the differences lie on the biomass pre-treatment techniques using either pyrolysis oil or woodchips pre-gasification in small, medium and large scale F-T Diesel production plants. Power generation data is currently based on demonstration or CHP standard configurations on efficiency and costs. The use of power generation by BTL has the highest contribution to reduce emissions and increase competitiveness.

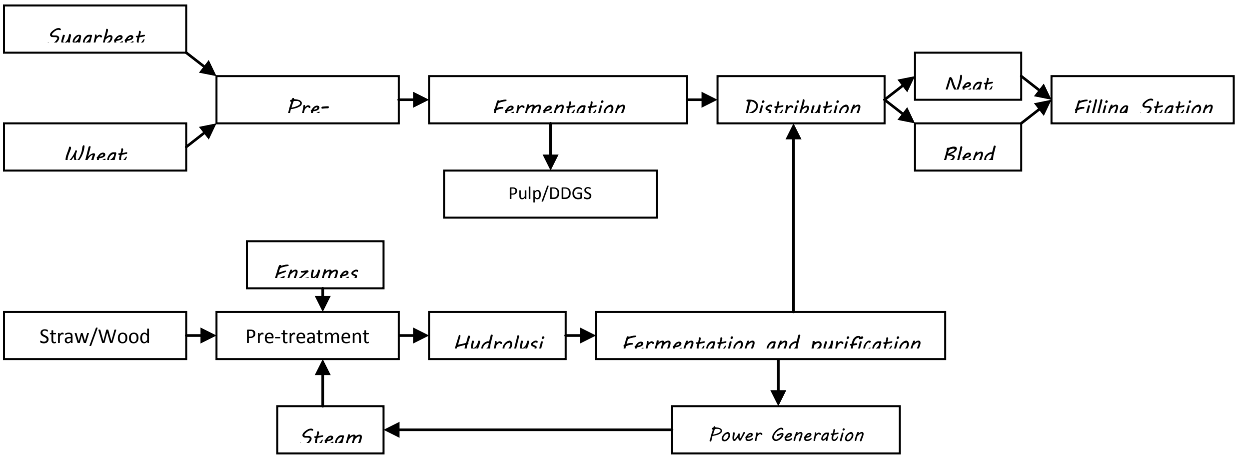

Figure 2: Bioethanol WTT pathways
Source: [1,2]

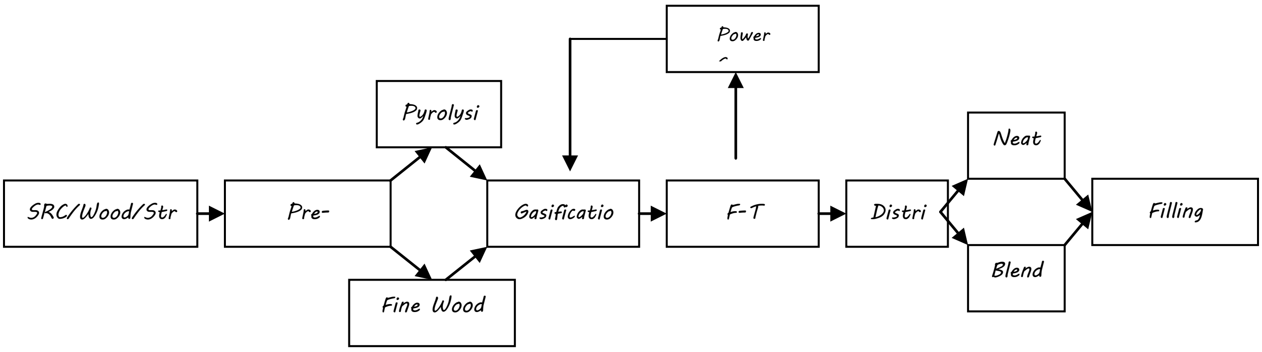

Figure 3: Biomass-to-Liquids Pathways
Source: [1,2]

3.2. Scenarios definition

One *reference and* one *high price* scenarios are defined in this research including the projection of the most important drivers for the production development of alternative fuels AF (e.g. feedstock prices, input prices, co-products). This is a new approach combining not only a mere techno-economic characterization of several technologies but simulating future economic performance under changing the most important parameters dynamically in 5 years steps until 2030. The scenario I (reference) projects until 2030 the most important input materials for alternative fuels production such as biomass feedstock prices, electricity, heat and fuels. The projection reflects conditions before the economic crisis for scenario I considered as a *reference* projection. Scenario II reflects a high prices environment for the same parameters.

With respect to the technology learning the progress ratio, shown as indexed changes in percentage below, reflects enhanced learning as cumulative capacities and production are achieved (scenario II). However, the technology learning projections partially simulate a normal and enhanced learning conditions for AF technologies not directly correlated with the price development of scenario I and II. The values for the major inputs projections for both scenarios and progress ratios are shown in Figure 4 in [c/kWh] and Figure 2 in [%].The projections have been cross checked with experts' assessments and the review of several studies on feedstock prices since 2004 until 2010 [1,2,4,9,10,11]; however, Figure 4 projections assumptions have been made based in correlation with the development of the projected diesel prices for both reference and high price environments. Two progress ratios changes for technology learning are assumed for modelling technology learning possibilities as shown in Figure 5.

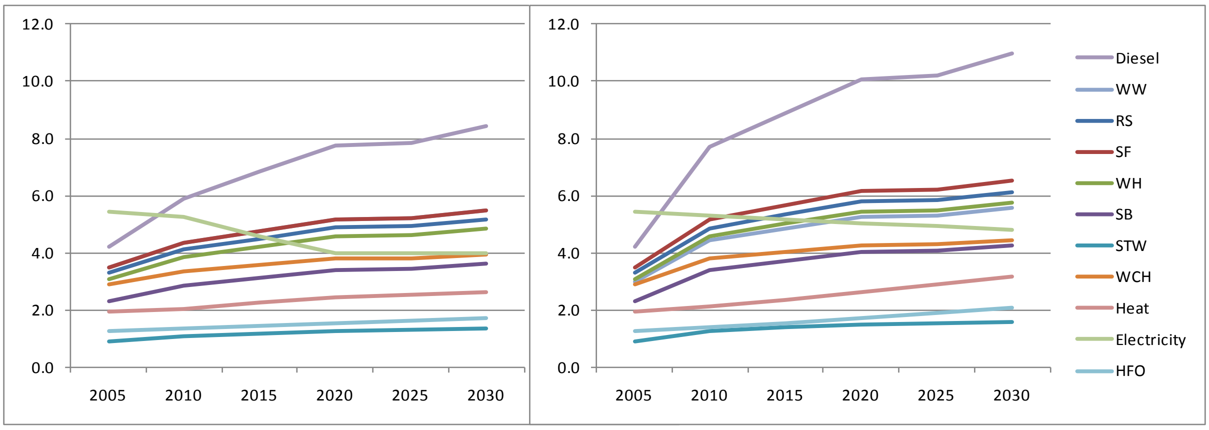

Figure 4: Assumed price changes for AF technologies inputs for scenario I (left) and II (right) until 2030 – [c/kWh]

Figure 5: Changes in progress ratios (PR) for AF technologies (large and small scales) for scenario I (left) and II (right) until 2030- [% - index year 2010]

The scenario assumptions should be carefully interpreted as they have strong interaction with other variables (e.g. yields, climate conditions, dietary changes, etc) not directly modelled in the present construct. These scenarios have been defined for all pre-selected pathways, in particular with their inputs such as feedstock for 1st and 2nd generation biofuels, heat, electricity or heavy fuel oil (HFO) among others. In addition, a further assumption is done for technology learning with lower or higher progress ratios in 5 years steps differentiated for small and large scale units.

4. Results and discussion

Results of WTT assessment are illustrated for biodiesel and bioethanol pathways in Figure 6 and Figure 7. BTL results are also available but omitted in graph form due to space limitation. Both figures illustrate the economic performance changes of AFs pathways for both the *reference and high price* scenarios as well as due to the considerations in enhanced technology learning progress ratios for the years 2010 until 2030 in 5 years steps. The number below the graphs corresponds to the number assigned to the pathway for each particular alternative fuel analysed. Pathway 1[1] (2010) and 27 (2030) for example are identical in configuration but 27 reflects 2030 results. Production economic performance increases 17% in scenario *reference* while almost 20% in scenario II compared to 2010 values. A 2.5% annual increase of rapeseed prices until 2030 (high prices) increases in 16% the costs for oil extraction and biodiesel production when compared to the *reference scenario*. The learning effects are observed in the right side graphs where pathway number 27 reduces its cost performance in further 2% by learning with high progress (experience) ratios of 75% for large scale plants and 80% for small scale plants.

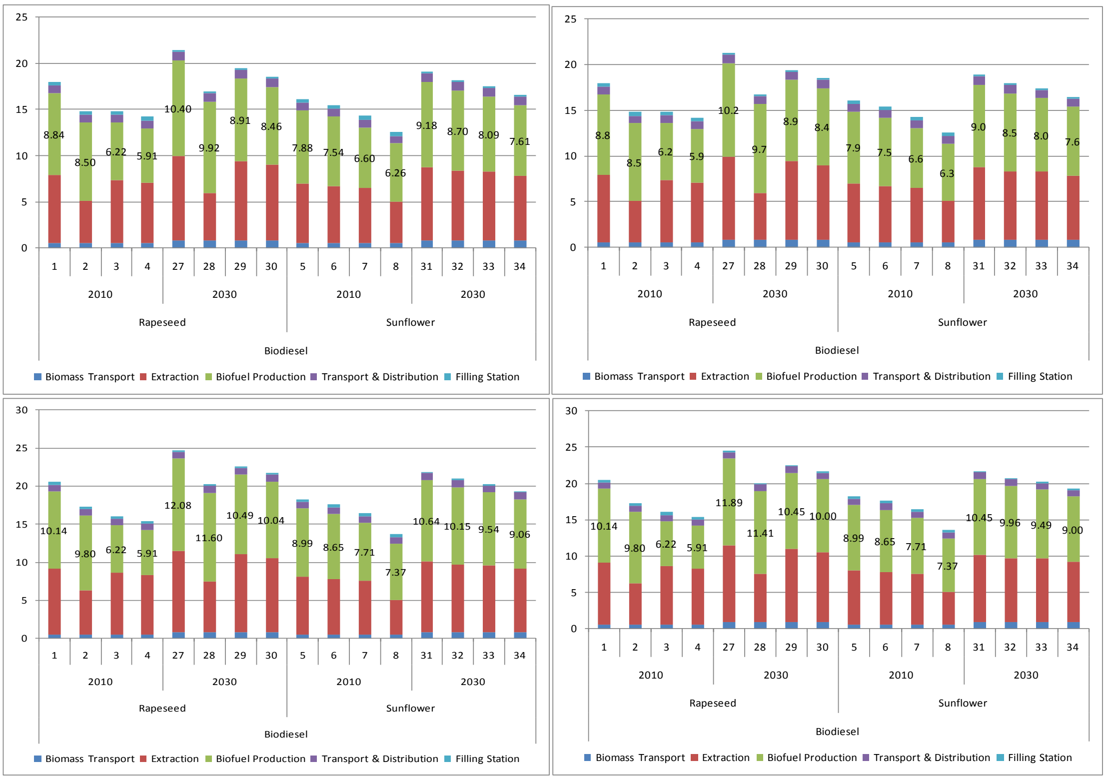

Figure 6: Results of the integrated WTT analysis (economic performance) for Biodiesel pathways for scenario I and II (up) and technology learning (right side graphs)- [c/kWh]

For biodiesel, as observed in the figures, pathways corresponding to large scale facility production, taking into account by-products credits, perform better with respect to economics (and emissions). The major part of the costs for all pathways corresponds to the extraction and production, especially the biomass feedstock prices varying from 50 to 85% of total producing costs. Oil extraction and subsequent biodiesel production are highly sensible to the variation on agricultural production costs.

Bioethanol pathways are grouped for starch (cereals) and sugar-beet crops and lignocellulosic biomass options (straw-2nd generation). The results indicate that the largest part of the costs for all options correspond to bioethanol production, of which the biggest share corresponds to the biomass costs and delivery at the bioethanol production facilities. Non-agricultural biomass feedstock (e.g. Straw) is less vulnerable to feedstock prices changes than the agricultural feedstock for 1st generation bioethanol, exhibiting higher vulnerability to volatile sugar and cereals markets. The benefits from increased learning rates remain marginal for

[1] Biodiesel from Rapeseed in *large scale* facility without by-products credits. Pathway 2 considers by-products also large scale. Pathway 3 and 4 are small scales with the same by-products considerations.

most of the producing options despite of a strong increase in experience (lower ratios) and therefore lower costs.

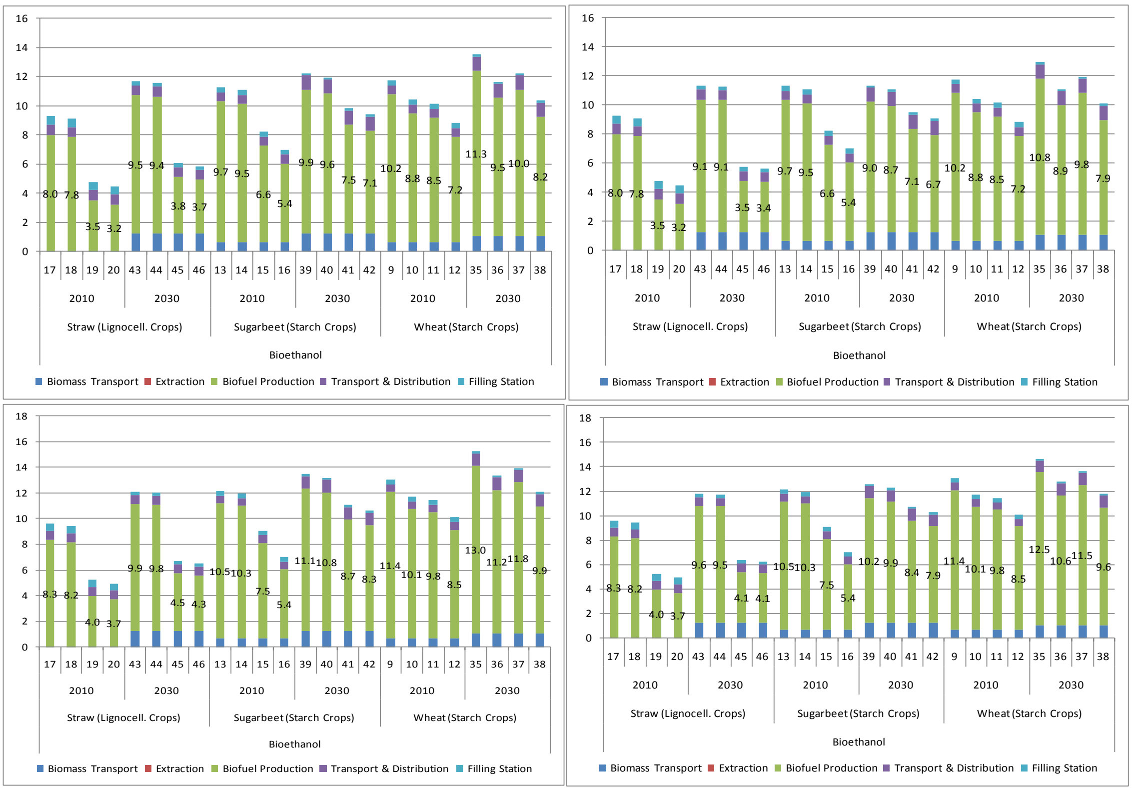

Figure 7: Results of the integrated WTT analysis (costs) for Bioethanol pathways for scenario I and II and technology learning (right side graphs)

The best cost performance corresponds to large scale plants considering by-products credits for animal feed substitution for both cereal and sugar crops. Large scale lignocellulosic bioethanol performs also better in 2010 while in 2030 it also demands logistically an organized supply of straw, however outperform compared to 1st generation options in *reference and high price* scenarios. However, such a facility does not exist currently in the market and this is just an indicative value of the cost ranges of these technologies. Furthermore, short rotation crops (wood) as feedstock for the production of bioethanol with similar plant characteristics have been used in the analysis. This technology is still in development phase and it could mean that higher capital expenditures, especially for large capacities are needed. This technology will enter the market only around 2010 and onwards, and efficiency improvements as well as capacity enlargements are expected to reduce costs in the future. Within the results, the highest emission reduction potentials are obtained for BTL facilities as the energy spent in the process is recovered using the co-generated gas to produce electricity and heat that can be reused internally in the process (self-sufficiency). Followed by the BTL facilities, the second highest reduction potentials are obtained from lignocellulosic ethanol. For biodiesel and bioethanol further emissions improvements are achieved when considering by-products credits as they substitute other materials.

5. Conclusions

The strong dependency of 1st generation alternative fuels on agricultural feedstock is observed in the results for their reference and high price scenarios developments. These technologies have still the potential to achieve costs reductions through learning, increase production, economies of scale; however, the results presented here only show a marginal benefit to increase economic performance. The high volatility of agricultural markets combined with strong climatic changes and increase in food demand poses higher pressures to producers to develop strategies that keep supply prices down. However, the results of this analysis indicate that large scales plants might have the possibility to perform better than smaller producers, partially also reflected on the possibility to have stocks (not modeled here), however, there are high direct increases in the economic performances of these options in these kind of fuels in high price scenarios prospects. Bioethanol pathways (2^{nd} generation (4-9.5 c/kWh) and starch/cereals 8-11 c/kWh) are close to get competitive with diesel projected prices in 2030 for both large and small scale configurations with by-products credits. Biodiesel inputs are strongly correlated with diesel prices increases and therefore results indicate that these pathways remain uncompetitive. BTL results for high price scenario considering stronger technology learning (ca. 7.8 - 12 c/kWh) are closer to be competitive to diesel projected prices in 2030 for large scale configurations with centralized biomass treatment concepts.

Furthermore, advanced AFs (2^{nd} generation biofuels) that are in R&D and Demonstration phase (non commercial technologies) pose higher risks for investors despite of the fact that they could have faster technology learning when entering the markets especially for certain portions of second generation routes such as lignocellulosic, BTL and Hydrogen. These options are high capital intensive with still unresolved technological challenges on biomass supply possibilities; meet end-use properties like energy content, chemical stability, refueling infrastructure, storage and ex-ante feedstock price projections. The better economic performance observed in these results are partially true in case lower biomass waste streams are used or high value by-products (co-generation) add to the income flows. However, these results should be considered cautiously as the input data for the simulation is based on data that is to be proved in real operating conditions that at the moment can only be obtained by demonstration or pilot projects. In emissions terms, pathways performing better relate to the ones where by-products credits are taken into account especially co-generation plants which definitely will reflect emissions reductions, requiring on the other hand more investments for additional facilities.

References

[1] Toro F, Hasenauer U, Wietschel M, Schade W (2008): Technology trajectories for transport and its energy supply.
[2] Toro, F. Techno-Economic Assessment of Biofuels in Europe, Working Paper Fraunhofer ISI, 2004, 2005.
[3] CONCAWE, EUCAR, JRC EU Commission, Well to Tank Reports, 2006, 2007, 2008.
[4] Toro, F. A., Reitze, F., Ajanovic, A., Hass, R., et al. (2010). State of the art for alternative fuels and alternative automotive technologies. Karlsruhe, Germany.
[5] Argote, Linda; Beckman, Sara L.; Epple, Dennis, 1990. 'The Persistence and Transfer of Learning in Industrial Settings'. Management Science 36(2): 140-154
[6] Dutton, John M.; Thomas, Annie, 1984. 'Treating Progress Functions as a Managerial Opportunity'. Academy of Management Review 9(2): 235-247
[7] Resch, G., Faber, T., Haas, R., and Huber, C. (2004): Experience Curves vs Dynamic Cost-Resource Curves. In: Energy & Environment, 15, pp. 309-321.
[8] Resch, G., Held, A., Toro, F., Haas, R., et. al., (2008): Potentials and prospects for renewable energies at global scale. In: Energy Policy, 36 (11), pp. 4048-4056.
[9] Toro, F.; Held, A., Ragwitz, M.; (2009): Assessment of the Potentials for Renewable Energy Sources. In: Ball, M.; Wietschel, M. (eds.): The Hydrogen Economy. Cambridge University Press, Cambridge, pp. 135-168.
[10] E4tech (2008): Biofuels Review: Greenhouse gas saving calculations; for the Renewable Fuels Agency, June 2008.
[11] OECD/FAO (2009). OECD-FAO Agricultural Outlook 2009-2018