REFUEL: POTENTIAL AND REALIZABLE COST REDUCTION OF 2ND GENERATION BIOFUELS

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ABSTRACT: The REFUEL assesses steering possibilities for and impacts of a greater market penetration of biofuels. Several benefits are attributed to second generation biofuels, fuels made from lignocellulosic feedstock, such as higher productivity, less impacts on land use and food markets and improved greenhouse gas emission reductions. The chances of second generation biofuels entering the market autonomously are assessed and several policy measures enhancing those changes are evaluated. It shows that most second generation biofuels might become competitive in the biofuel market, if the production of biodiesel from oil crops becomes limited by land availability. Setting high biofuel targets, setting greenhouse gas emissions caps on biofuel and setting subtargets for second generation biofuels, all have a similar impact of stimulating second generation's entrance into the biofuel market. Contrary, low biofuel targets and high imports can have a discouraging impact on second generation biofuel development, and thereby on overall greenhouse gas performance. Since this paper shows preliminary results from the REFUEL study, one is advised to contact the authors before quantitatively referring to this paper.

Keywords: liquid biofuels, costs, learning curves

1 INTRODUCTION

Biofuel production in Europe is encouraged with policy instruments such as the Biofuel Directive, and production is rising. Currently, biofuels are mainly produced from oil crops (PVO and biodiesel from rapeseed or sunflower), and sugar and starch crops (bioethanol, bio-ETBE). Furthermore, one can observe the expectation of second generation biofuel production emerging in the market in the coming years.

Second generation biofuels, generally diesel or gasoline replacing fuels made from lignocellulosic feedstock, have several comparative advantages over first generation biofuels. These advantages presumably include lower greenhouse gas emissions, higher productivity, more feedstock potential and/or less biodiversity loss.

2 RESEARCH QUESTION

The costs of second generation biofuels are expected to decline as production experience is accumulated. This paper uses an assessment of this expected future cost decline to indicate whether the entrance of second generation biofuels into the biofuel market might happen autonomously, or additional incentives are needed to force - if desired - the entrance of second generation biofuels.

Within the REFUEL project, the chances are assessed for second generation biofuels to take over the market, and policy options to facilitate this taking over are evaluated. For this research aim, the REFUEL project incorporates endogenous learning within the cost-based biofuel model BioTrans. This paper shows initial results of the upgraded BioTrans model. The quantitative outcomes shown in this paper are still subject to change and should therefore not be interpreted at face value.

3 METHODOLOGY

3.1 BioTrans: cost-based modelling

The costs of biofuels are evaluated with the cost-based model BioTrans, given a certain biofuel target. The assumption of the biofuel target being fulfilled at the least cost leads to a, geographically diversified, mix of biofuels produced and consumed. The full chain costs of biofuels are considered, from feedstock cultivation to vehicle modification.

The cost categories are:

- Feedstock costs (crop, waste & residuals) (Fig. 1,2); The feedstock is characterized as cost-supply curves, which change in time. As for energy crops, the costs are generally declining in time, while the potential is increasing. Land claims for food production and for the preservation of nature are taken into account.

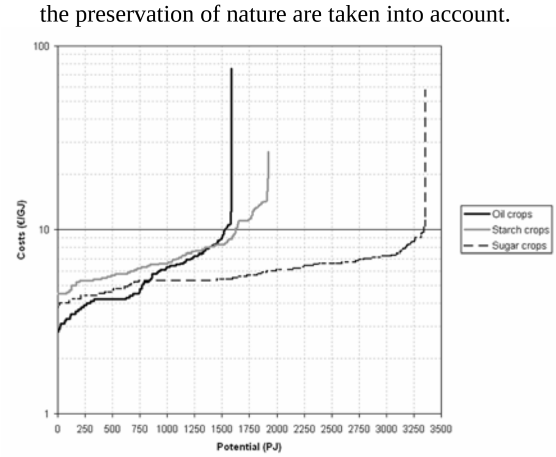

Figure 1: Cost-supply curves for first generation feedstock in 2010.

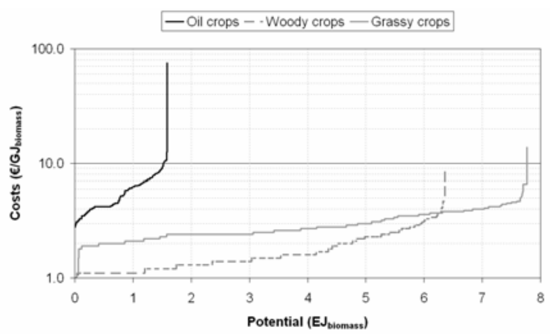

Figure 2: Cost-supply curve of oil crops compared to 2nd generation crops' cost-supply curves, in 2010.

- Conversion costs;
  The conversion costs include the costs of imports (if any), and the costs of auxiliary products and benefits of by-products. Section 3.2 elaborates on the cost reduction of the conversion processes;
- Transport costs;
  The transport costs cover both the international transports and the domestic transport. Distribution, that is the delivery of fuels to filling stations, is a separate cost category.
- Distribution costs;
- Additional end use costs;
  The end use costs are the costs of changes to vehicles technology compared to the costs of technology needed for fossil fuels. The end use costs might therefore be negative.

3.2 Endogenous learning

Feedstock costs decline in time at fixed rates, but it is assumed that conversion costs decline as function of cumulative production volume. The rate of decline is typically characterized by the progress ratio (PR): the relative costs after a doubling of cumulative volume produced. Thus, a PR of 0.90 tells that the costs decline to 90% of the costs after the cumulative volume has doubled - thus a cost reduction of 10%. However, emerging technologies do not have a 'track record' on which to fit the learning curve. One way to deal with the data insufficiency is to extrapolate learning curves from supposedly similar technological developments. REFUEL has chosen to introduce a scale dependent component in the learning curves of second generation biofuel technologies, as economies of scale often play a dominant role in initial cost reduction of emerging technologies.

Scale factor R is derived from empirical data based on the following relation:

$$\left(\frac{scale(t)}{scale(t_0)}\right)^R = \frac{cost(t)}{cost(t_0)}$$

Based on empirical data and literature references, the scale factor for bioethanol has been estimated at

$$R = \begin{cases} 0{,}70 & \text{if } 0\,\text{MW} \le scale < 1000\,\text{MW} \\ 0{,}85 & \text{if } scale \ge 1000\,\text{MW} \end{cases}$$, see also Fig.3.

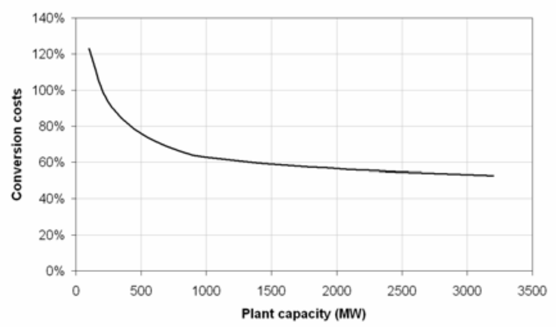

Figure 3: Cost reduction as function of plant size.

Limitations on the development of scale, or typical plant size, are:

- maximum plant size is 3 to 5 GW_{input};
- doubling time of typical plant size is 3 to 5 years;
- a single plant can serve up to 5 to 10% of the market;
- not all sub-processes necessary profit from economy of scale (e.g. certain pre-treatments of biomass do not).

On top of this scale dependent cost reduction, a scale independent learning curve is placed.

To obtain a scale independent learning curve for lignocellulosic to ethanol technology, we estimated several other variables. The cost decreasing potential was estimated based on the capital cost on component level from [3] providing the initial investment cost. From [4] we obtained a learning potential on component level, however not coupled to time or a required installed capacity of the specific technology. First the initial investment costs were calculated for the base year 2005. Then we applied the learning potentials from [4] on component level and calculated the overall learning potential, which amounted to 8.1%. Then we postulated that this 8.1% will be reached over the period from 2005 to 2030 and assume a volume of ethanol production.

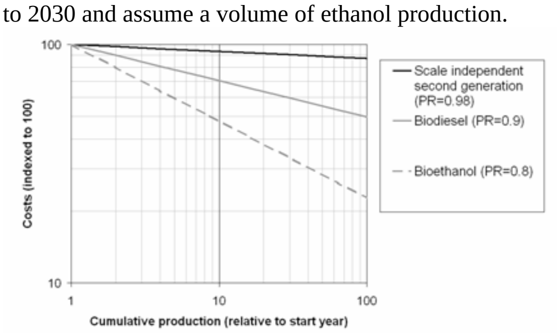

Figure 4: Relation between cumulative production and cost reduction.

First generation is assumed to have progress ratios of 80-90%. Second generation has cost reduction mainly due to economies of scale, as mentioned. Scale independent cost reductions follow learning curves with progress ratios of 98-99%, see Fig.4.

4 RESULTS

4.1 Base case

The cost reductions of biofuels are estimated given a certain biofuel target development path. Two base cases are defined on which certain policy measures can be implemented. Table I shows the biofuel shares in respective cases, as fraction of fuel demand in the PRIMES transport scenarios. The policy measures shown in this paper will be variants that are based on the High case.

Table I: Biofuel target in base cases

	Low case	High case
Biofuel share in 2005	2 %	2 %
Biofuel share in 2010	5 %	5.75 %
Biofuel target in 2020	10 %	14 %
Biofuel target in 2030	15 %	25 %

4.2 Potential cost reductions

The cost reductions in the biofuels production depend on the past production. Therefore, the maximum cost reduction occurs when the entire biofuel target is met with a single, specific biofuel. It ensures the highest production volume and thus the largest cost reduction for that specific biofuel (see Fig.5). Note that oil crop potential is fully used from 2014 onwards, and that the maximum plant size for second generation biofuels is reached in these computations just after 2020.

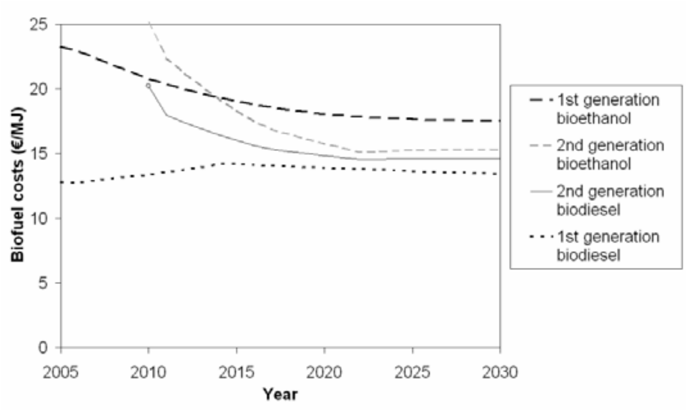

Figure 5: Full chain cost development of biofuels, given realization of potential cost reductions. Second generation biodiesel in the current example is bio-Fischer-Tropsch diesel.

4.3 Biodiesel production in low and high cases

Biodiesel can be produced at comparatively low costs. BioTrans therefore estimates that low biofuel demands will be met by first generation biodiesel production (see Fig.6).

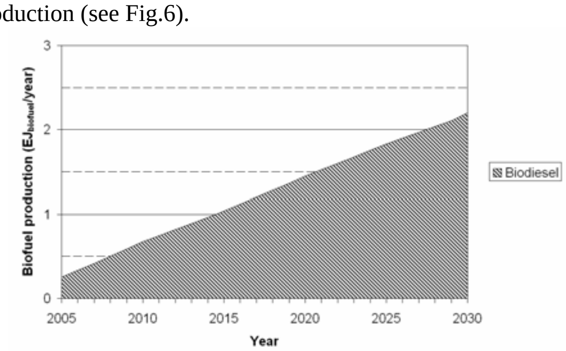

Figure 6: Biofuel production in the Low case.

However, oil crops potential is insufficient to meet a high demand in later years. The missing potential is filled by second generation biodiesel (e.g. in Fig. 7 by bio-Fischer-Tropsch diesel).

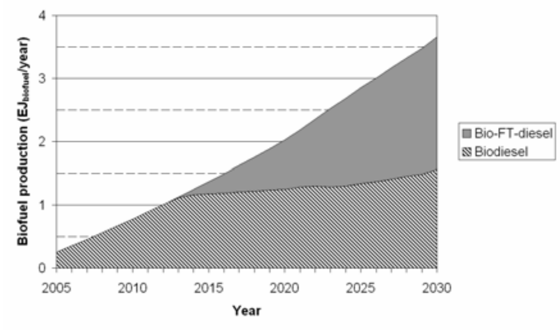

Figure 7: Biofuel production in the High case.

Second generation biodiesel creates volume, and achieves cost reduction through learning, although it will hardly compete with first generation biodiesel on costs. Still, a sufficiently high biofuel target creates better opportunities for second generation biodiesel to partially compete with first generation biodiesel.

4.4 Ethanol production in high variant

The competition between first and second generation bioethanol is of a different nature. Second generation ethanol starts at higher costs than first generation, but might become cost competitive once it has broken through. For this, an incentive market needs to be created for second generation bioethanol. Assume, for example, a specific 2nd generation bioethanol target of 2.5% of the generic biofuel target in 2010, rising to 25% in 2020. The initial support for 2nd generation ethanol leads to a complete, 100% market take over of second generation ethanol, see Fig.8.

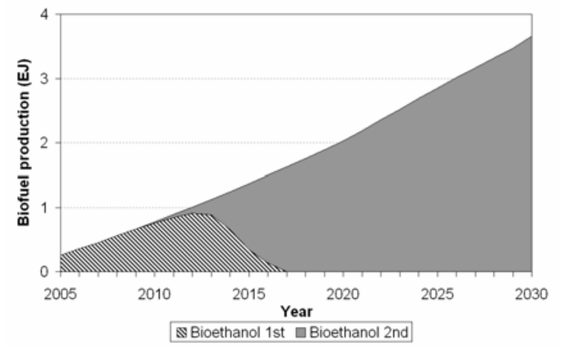

Figure 8: Possible effects of second generation sub-target: removal of cost-based lock-in.

Fig. 9 shows how 2nd generation bioethanol becomes less costly than 1st generation bioethanol. Consider that as first generation shares become smaller, on average cheaper feedstock might be used. Consequently, the average full-chain bioethanol costs of Fig. 9 might be lower than those shown in Fig. 5.

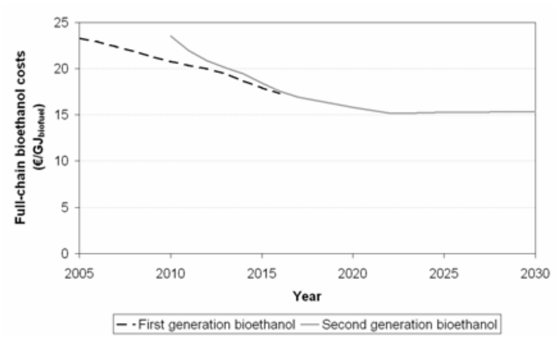

Figure 9: Full-chain bioethanol costs of the variant shown in Fig. 8.

4.5 Realizable cost reduction

Without explicit policy measures stimulating second generation biofuels production, it is expected that first generation biofuels will continue to play an important role in the biofuels production. The transformation of potential cost reduction, are reminded in Table II, into realizable cost reduction is not beforehand to be made. Not only does it depend on future policy choices, but also will the initial entrance of second generation biofuels be interesting. Currently, the differences are too close to estimate which second generation biofuel has the best chances. The fuel that enters the commercial market first might secure that market.

Table II: Potential cost reductions, preliminary results.

Gen.Biofuel	Costs in 2010	Costs in 2030
1. Biodiesel	100 (index)	101
1. Bioethanol	156	132
2. Bioethanol	188	115
2. Bio-DME	166	124
2. Bio-Fischer-Tropsch	152	109
2. Bio-SNG	186	143

4.6 Impact of import

One choice within the Biofuel Directive is whether one should create a biofuel production obligation, or a biofuel consumption obligation. A consequential choice might also be what and if, to what extent, imported biofuels from outside the Directive competence zone counts for the target obligation: should Europe encourage or discourage e.g. bioethanol from Brazil?

As far as the impact of biofuels import on the learning potential of second generation biofuels, BioTrans' results give a hint. The model run in which bioethanol import is allowed up to quota of 13 Mton/year at constant costs, results in Fig.10.

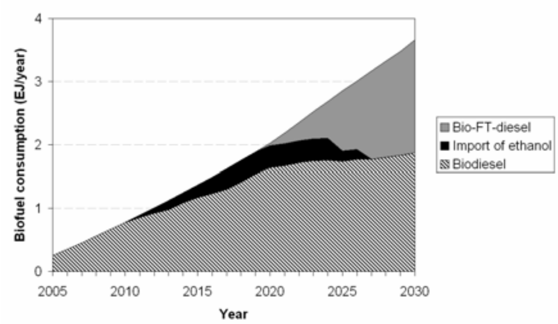

Figure 10: Biofuel production mix with a limited amount of import allowed to count for the biofuel target.

Apparently, biofuel import is only temporarily cost effective method to comply with the biofuel target. However, it seems only to delay the inevitable introduction of second generation biofuel. Thus, second generation biofuel will have a shorter time to learn and reduce costs, see also Fig.11.

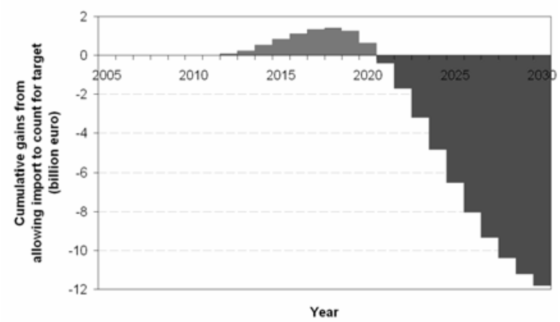

Figure 11: Total benefits of allowing imports to count for biofuel target as compared to disallowing import.

4.7 Greenhouse gas emissions

Second generation biofuels will generally have lower full-chain greenhouse gas emissions than common first generation biofuels. In the High case, one could observe a partial introduction of second generation biodiesel into the biofuel mix, mainly due to oil crop potential limitations. The introduction of second generation biodiesel in the mix is also apparent in Fig.12, where the average greenhouse gas emissions per $MJ_{biofuel}$ are shown. Consequently, should one wish to encourage second generation biofuels, one can also consider placing a greenhouse gas emissions cap on biofuels.

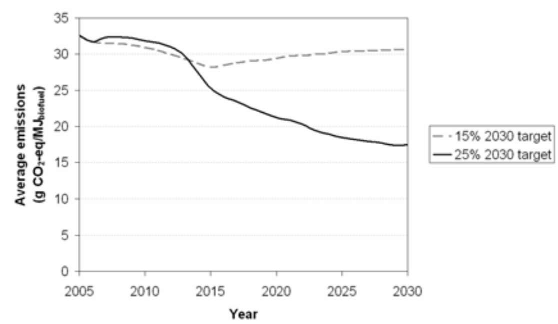

Figure 12: Average relative greenhouse gas emissions of the Low case and the High case.

5 CONCLUSIONS

Full-chain cost reductions of second generation biofuels in the period 2010-2030 are expected to range between the 20% and 40%. For the conversion process cost, as part of the full-chain costs, these ratios are larger with a range of 30% to 60%. Generally, diesel substitute options are seen by the model as more cost effective than gasoline substitute (bioethanol) options.

Within the diesel substitute market, biodiesel from oil crops will run out of potential if an ambitious biofuel target is set. Thus, an ambitious biofuel target is an implicit encouragement for second generation biofuels. First generation biodiesel will most likely remain the cheapest option for a significant part of the supply. Within the bioethanol market, however, a cost lock-in is in place favouring bioethanol from sugar and starch crops above lignocellulosic bioethanol. Bioethanol from woody and grassy crops does have the potential to become cheaper than first generation ethanol.

Several policy measures have been evaluated: setting high biofuel targets, setting subtargets for second generation biofuels, setting greenhouse gas emission caps on biofuels. These seem all different means to the same end: favouring second generation biofuels. Contrary, setting low biofuel targets or allowing imports from outside Europe to count for the European biofuel target, have a discouraging effect for second generation biofuels.

This paper shows preliminary results from the REFUEL study. One is advised to contact the authors before quantitatively referring to this paper.

5.1 References and selected literature

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