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Summary
This paper illustrates the main results of an expert elicitation survey on advanced (second and third generation) biofuel technologies. The survey focuses on eliciting probabilistic information on the future costs of advanced biofuels and on the potential role of RD&D (Research, Development and Demonstration) efforts in reducing these costs and in supporting the deployment of biofuels in OECD and non-OECD countries. Fifteen leading experts from different EU member states provide insights on the future potential of advanced biofuel technologies both in terms of costs and diffusion. This information results in a number of policy recommendations with respect to public RD&D strategies and is an important contribution to the integrated assessment modelling community.

Keywords: Expert Elicitation, Research, Development and Demonstration, Biofuels

JEL Classification: Q42, Q55

The research leading to these results has received funding from the European Research Council under the European Community's Seventh Framework Programme (FP7/2007-2013) / ERC grant agreement no. 240895 – project ICARUS "Innovation for Climate Change Mitigation: a Study of energy R&D, its Uncertain Effectiveness and Spillovers". This paper, like Bosetti et al. (2012a), is part of the systematic collection of experts' estimates for Europe carried out within ICARUS. We thank the participating experts listed in Table 1, as well as Agostino Gambarotta (Università di Parma) and Paolo Magni (Fondazione Politecnico di Milano), who helped us with the pilot tests. We also wish to thank Erin Baker (University of Massachusetts) and Jacopo Crimi, Barbara Racah, Thomas Longden and Stergios Athanassoglou (FEEM) for their contribution and assistance.

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Advanced Biofuels: Future Perspectives from an Expert Elicitation Survey

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ABSTRACT: This paper illustrates the main results of an expert elicitation survey on advanced (second and third generation) biofuel technologies. The survey focuses on eliciting probabilistic information on the future costs of advanced biofuels and on the potential role of RD&D (Research, Development and Demonstration) efforts in reducing these costs and in supporting the deployment of biofuels in OECD and non-OECD countries. Fifteen leading experts from different EU member states provide insights on the future potential of advanced biofuel technologies both in terms of costs and diffusion. This information results in a number of policy recommendations with respect to public RD&D strategies and is an important contribution to the integrated assessment modelling community.

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1 Introduction

Biofuels are a viable substitution for oil-derived fuels in the transport sector. They do not require changes in car engines, nor in the re-fuelling process, thus simplifying their adoption. For these reasons, biofuels are seen as one important option to mitigate CO_2 emissions and reduce dependency on oil. Indeed, as transport is responsible for 23% of CO_2 emissions (IEA, 2011a), many countries have been setting policy targets in the last decade for the introduction of biofuels (Sorda et al., 2010). With respect to Europe, in 2003 the European Commission set the goal of reaching a 5.75% share of renewable energy in the transport sector by 2010 (Directive 2003/30/EC), and in 2009 modified it to a minimum of 10% by 2020 (Directive 2009/28/EC).

This notwithstanding currently marketed (first generation) biofuels represented only around 3% of global road transport fuels in terms of energy in 2010 (IEA, 2011b), with great variance between countries.[1] For example, in 2011, 86% of the production of ethanol, the most common biofuel in use, was concentrated in the USA and Brazil (74.5 billion litres) while the EU accounted for a mere 5% (around 4.5 billion litres) (Renewable Fuels Association, 2012).

This very limited diffusion of biofuels is partly due to a set of concerns we briefly review below. First, potential competition with food crops for the use of fertile land and water has raised the issue of sustainability of an increasing demand for biofuels (Rathmann et al., 2010). Competition for land also has potential effects on deforestation and, in turn, on biodiversity and emissions from changes in land use (Berndes et al., 2011; Dale et al., 2010; Wise et al., 2009). Second, their ecological and social sustainability has been largely questioned (for an overview, see Tilman et al., 2009). Third, expected net savings of greenhouse gases (GHG) emissions with respect to conventional fossil fuels are smaller than what was previously thought when the whole life cycle is accounted for (Hill et al., 2006; Farrell et al., 2006; Searchinger et al., 2009). Finally, and most prominently, first generation biofuels are almost always not cost-competitive with fossil fuels.

Advanced generation biofuels can, in principle, overcome the main shortcomings associated with first generation technologies (*Nature,* 2011). However, advanced biofuels still have to overcome many barriers, ranging from high investment and feedstock costs to enhancing conversion efficiency and developing entirely new conversion processes, before they can become a real contributor to the energy market (Chum et al., 2011). Of particular importance is the increase in biomass availability and the move from food-derived feedstocks to residues and non-food biomasses. This shift would also improve the GHG balances and mitigate the land competition with food products.

This paper sheds light on the future prospects of advanced biofuels technologies. We developed an expert elicitation protocol to collect probabilistic information on the future costs of biofuels, how biofuels will be affected by EU public RD&D programmes, and which non-technical barriers to diffusion should be considered when designing renewable energy policies.

The next section of the paper briefly reviews the current status of biofuel technologies. Section 3 describes the expert elicitation process. In Section 4 the experts' assessment of the current status of the investigated technologies is presented. Section 5 illustrates the experts' projections of biofuels costs under three RD&D funding scenarios. Section 6 discusses the likely diffusion of biofuels in the market, the regions that will most likely first achieve cost-competitiveness, the potential barriers to biofuel success, their possible negative externalities and the dynamics of knowledge spillover and technology transfer. The last section of the paper concludes and discusses the main findings of the study.

2 Biofuels today

The combination of an increasingly policy-driven demand for biofuels and the concerns that currently available technologies are falling short of expectations has increased the pressure for the development of second generation (cellulosic ethanol, biomass-to-liquids, pyrolysis oil, dimethyl ether) and third generation (algal-biodiesel, biofuels from third generation processes) biofuel technologies. Most of these technologies are at an early stage of development. Little data on current advanced biofuel costs are available due to confidentiality and scarce experience: one of the first commercial plants commenced construction in 2010 and is not yet operative (The Biofuels TP, 2012). The potential for success and cost reductions are thus surrounded by large uncertainties. We

[1] Brazilian sugarcane ethanol represents roughly 25% of transport fuel demand in the country (Poppe and Horta Nogueira, 2009) and is also exported to the global market (ANP, 2011). In 2010, 4% and 3% of the road transport fuel demand was met by ethanol in the United States and in the EU, respectively (IEA, 2011b). Within Europe, the main consumers of biofuels are Germany, France, Spain, Italy and the United Kingdom. Together these countries consume about 70% of all EU biofuel (9.7 over 13.9 Mtoe) (IEA, 2011b).

address this gap in the literature by providing data on expected costs of third generation and advanced biofuel production. The IEA roadmap (IEA, 2011b) puts the current cost of cellulosic ethanol at 1.1 USD per litre of gasoline equivalent (lge). It also underlines that the cost estimates of advanced biofuels, as well as their parity with conventional fuels, are largely uncertain, due to key factors such as the scale of the plant, technology complexity, and feedstock costs. If the lowest fixed and variable costs were to be achieved, the cost of cellulosic ethanol in 2030 could be in the range of 0.8–0.95 USD/lge, where the variation mainly depends on the influence on the feedstock costs of future uncertain oil prices.

The IPCC SRREN projections (Chum et al., 2011) provide wider cost ranges for a wider set of technologies: estimates are as low as 0.41 and as high as 1.19 USD/lge. Edwards et al. (2008) analyse the future costs of advanced biofuels in the EU and show a fairly different perspective, claiming that advanced biofuels have no chance of being competitive with fossil fuels by 2030, due to the high costs and limited availability of feedstock.

Within Europe, the development of advanced production plants is fostered through the 7th Framework Programme and the European Biofuels Technology Platform. The total public RD&D budget devoted to bioenergy (liquids, solids and biogas) increased from about 100 million USD in 2002 to roughly 300 million USD in 2010 (with a peak at 450 million USD in 2009) (IEA, 2011c). In the period 2002–2010, on average, 25% of the public budget was specifically allocated to applications for heat and electricity, 23% to the production of liquid biofuels, 13% to the production of solid biofuels, 12% to other biofuels and only 1% to biogases (the remainder is not specifically allocated).

With respect to Europe, a main concern for policy makers is to ensure the coordination of effort at the EU and national levels to make advanced biofuels a commercially viable option, thus reaching the goals set by the European Commission. A core focus of this strategy is higher RD&D investments (IEA, 2011b; EC, 2009a). Critical components of technology development in all energy technologies are successful demonstration and early deployment. Such concerns are particularly relevant for biofuel (and more in general biomass), for which the European Commission identifies the need to demonstrate the technology at the appropriate scale, whether pilot, pre-commercial demonstration or full industrial scale plant (EC, 2009a). RD&D funding is crucial in this respect as well. This is in sharp contrast with the historical trend in EU public investments, which so far has been focused on funding early stages of research and development as opposed to demonstration activities. For example, in 2007, 71% of public RD&D for transport biofuels went to research and development, while only 9% of the investments went to demonstration activities (EC, 2009b).

3 The expert elicitation survey

The use of expert judgments has become increasingly commonplace in recent years to make up for the lack of data, to assess risk and to support decision-making processes (Hogarth, 1980; Morgan and Henrion 1990; Cooke, 1991). Applications range from nuclear engineering (Cooke and Goossens, 1999) to climate change issues (Morgan and Keith, 1995). Carefully structured elicitation processes can provide useful insights regarding many important uncertainties in policy analysis.

We structured our analysis considering and complementing the existing applications of expert elicitation to low-carbon energy technologies, which has begun only recently. Baker et al. (2009a), Chan et al. (2011), Baker et al. (2009b), Curtright et al. (2008), Bosetti et al. (2012a) and Baker and Keisler (2011) use expert elicitation to investigate the uncertain effects of RD&D investments on the prospect of success of carbon capture and storage, solar PV technologies and cellulosic biofuels.

Figure 1 provides a graphical representation of the biofuel technologies that have been assessed in the survey.

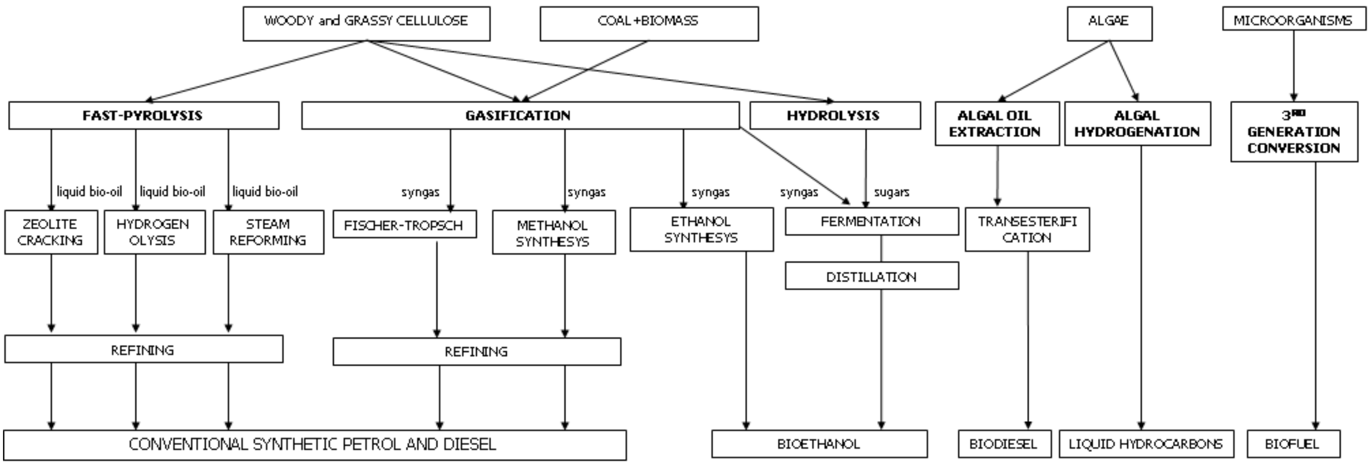

Figure 1: Technology paths of second- and third-generation biofuel technologies assessed in the interviews with the experts

We applied the techniques suggested in the vast literature on decision analysis (Clemen and Reilly, 2001; Keeney and von Winterfeldt, 1991; Meyer and Booker, 1991; Morgan and Henrion, 1990; O'Hagan et al., 2006; Phillips, 1999) to minimise the risks of errors or biases in the experts' estimates. We carefully chose the elicitation situation, structuring specific questionnaires and submitting them in face-to-face interviews. We tested the whole process during pilot interviews, and subsequently revised parts of the questionnaire. During each interview, the experts were briefed on the project's purpose and then warned about the occurrence of specific heuristics or biases in the estimates.

We carefully gathered a set of experts with strong scientific backgrounds and sound empirical knowledge, covering different biofuel technologies, background knowledge and sectors (academia, institutions, private sector). We refer the reader to Bosetti et al. (2012a) for a detailed description of the protocol, the survey structure and the selection of the experts.

The experts that participated in the survey are listed in Table 1. All answers are anonymously reported in the rest of the paper and the order of the experts does not reflect the one in Table 1.

The self-evaluation exercise proposed to the selected experts at the beginning of the questionnaire, whose results are summarised in Figure 2, confirmed the heterogeneity of the cluster. Experts were asked to state their expertise with respect to all the technologies considered in Figure 1 on a scale from 1 (low) to 5 (high). The highest levels of expertise concentrate on refining processes. The majority of experts declared medium or high expertise for cellulosic feedstocks, while for highly innovative processes such as algae and third-generation biofuels only few experts presented a high/medium expertise.

Table 1: List of experts participating in the survey

Name and Surname	Affiliation	Country
David Chiaramonti	Università degli Studi di Firenze	Italy
Jean-Francois Dallemand	Joint Research Centre (Ispra)	France
Ed De Jong	Avantium Chemicals BV	The Netherlands
Herman den Uil	Energy Research Centre of the Netherlands (ECN)	The Netherlands
Robert Edwards	Joint Research Centre (Ispra)	United Kingdom
Hans Hellsmark	Chalmers University of Technology	Sweden
Carole Hohwiller	Commissariat à l'énergie atomique et aux énergies alternatives (CEA)	France
Ingvar Landalv	CHEMREC	Sweden
Marc Londo	Energy Research Centre of the Netherlands (ECN)	The Netherlands
Fabio Monforti-Ferrario	Joint Research Centre (Ispra)	Italy
Giacomo Rispoli	Eni S.p.A.	Italy
Nilay Shah	Imperial College London	United Kingdom
Raphael Slade	Imperial College London	United Kingdom
Philippe Shild	European Commission	Germany
Henrik Thunman	Chalmers University of Technology	Sweden

Surveys were carried out between 2010 and 2011. Following up on the interviews allowed us to check the elicited information, to deepen the discussion with each of the experts, and, when necessary, to correct for possible inconsistencies. More information on the pool of experts and on their expertise with respect to the analysed technologies is provided, together with the whole survey, in Bosetti et al. (2012b).

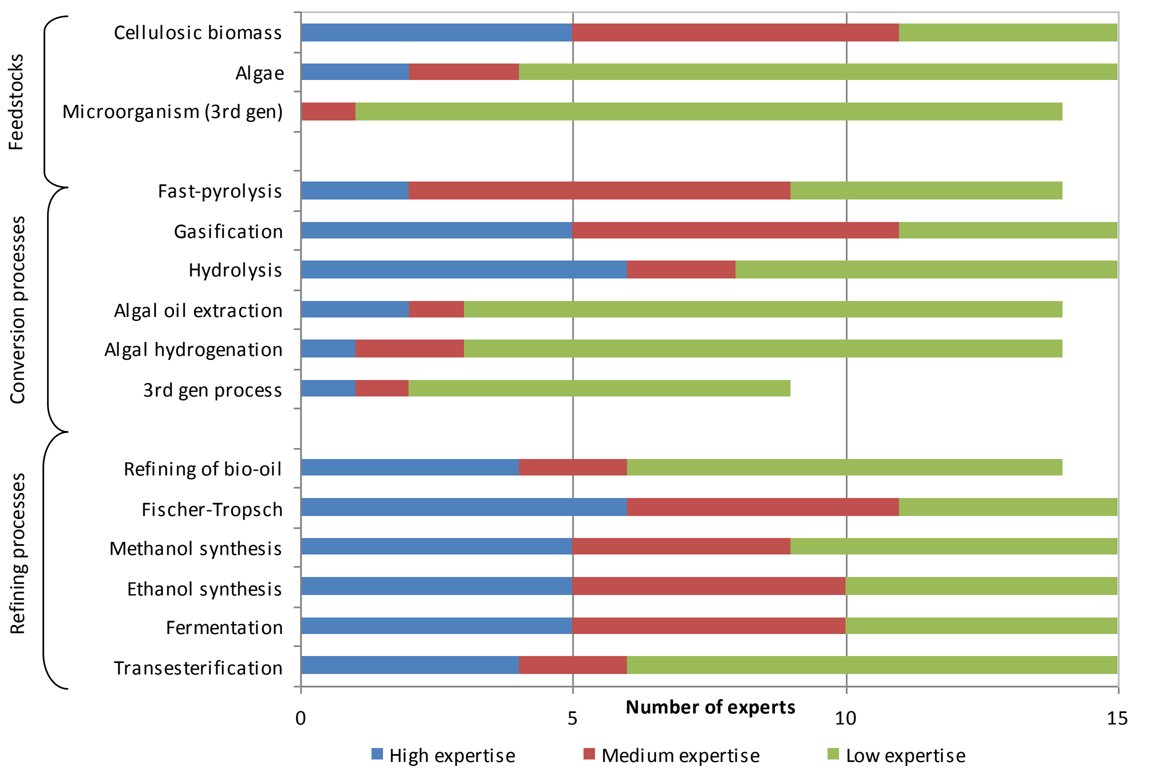

Figure 2: Distribution of the experts with respect to the investigated technologies. High expertise: max level of knowledge >3; medium expertise: max level of knowledge =3; low expertise: max level of knowledge <3

4 Technical barriers to advanced biofuels technologies

Given the great variety of technological options currently under development (Table 1), and their different level of maturity, each technology will likely require a different focus when it comes to basic research, applied research or demonstration activities. The first part of our survey asked the experts to identify the main RD&D needs for second and third generation biofuels. Experts assessed the level of maturity of each technological option and listed the main technical barriers hindering its development. Finally, they indicated what kind of research activity would be required to overcome the technical bottlenecks. Figure 3 summarises the results. Feedstocks and conversion processes are at a less mature stage than refining processes, which are mostly considered at a good level of development.

Some experts did not feel at ease evaluating all the proposed technologies. In particular, the highest number of no responses is associated to the more innovative technological paths of third-generation biofuels. This is consistent with a generally lower level of expertise in these technologies (Figure 2).

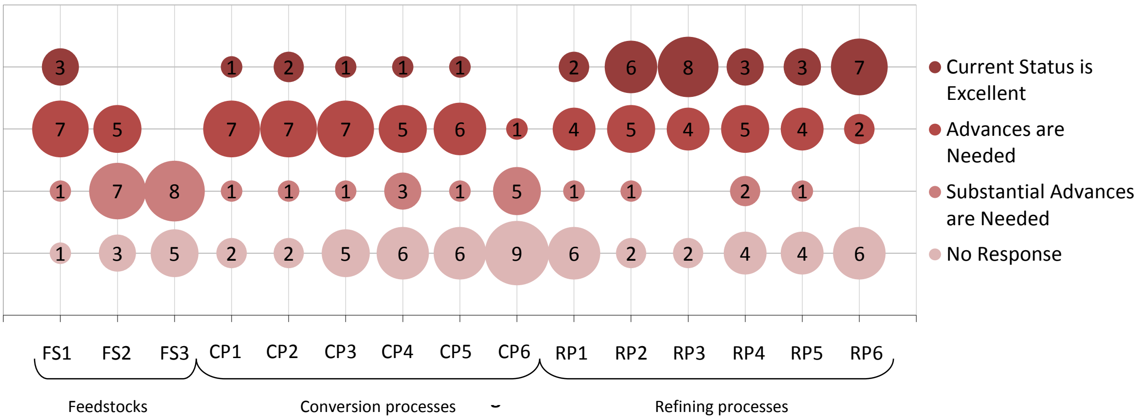

Figure 3: Experts' assessment on the level of technological development of second and third generation biofuel technologies. Acronyms stand for: FS1: Cellulosic biomass; FS2: Algae; FS3: Microorganism; CP1: Fast-pyrolysis; CP2: Gasification; CP3: Hydrolysis; CP4: Algal oil extraction; CP5: Algal hydrogenation; CP6: Third generation process; RP1: Refining of bio-oil; RP2: Fischer-Tropsch; RP3: Methanol synthesis; RP4: Ethanol synthesis; RP5: Fermentation; RP6: Transesterification.

The main technical barriers singled out by experts for each of the technological options considered are listed in Table 2. As expected, several issues emerged concerning feedstocks, not only with respect to innovative technologies (algae and microorganism), but also with respect to more mature ones, such as cellulosic biomass. Cellulosic biomass is characterised by difficulties in the procurement and logistic costs of feedstocks. Along the same lines, growing algae in large amounts is very costly, both in terms of money and energy. For this reason, research on algae should focus on scaling up the processes and increasing energy efficiency. Conversion technologies could benefit from RD&D investments targeted at bio-oil upgrading in fast-pyrolysis, gas cleaning in gasification and enzymes selection in hydrolysis. As for algal oil extraction, improvements are needed to increase the energy efficiency of the process.

While the majority of experts characterise the status of several refining processes (Fischer-Tropsch, methanol synthesis and transesterification) as excellent, these technologies still face a few important barriers (with the exception of transesterification, which is considered ready for commercialisation). For example, improvements in the catalyst and in the purity of the syngas are needed for Fischer-Tropsch technologies. A general call for improved efficiency characterises all technologies considered, in particular sugar fermentation.

Capital costs are also seen as a barrier for further development of refining processes. Methanol synthesis and ethanol synthesis plants are currently very expensive. Conversely, in the case of Fischer-Tropsch, funds for large-scale plants are needed to foster economies of scale and learning-by-doing, which are instrumental for successful development. All remaining refining processes, namely refining of bio-oil, ethanol synthesis and fermentation, are characterised as not yet mature and in need of further advancement.

Table 2: Keywords mentioned by at least four experts

Cellulosic biomass	Economic barriers to the market Logistics issues
Algae	Energy intensity Up-scaling of the process Production costs
Fast-pyrolysis	Upgrading of the bio-oil
Gasification	Gas cleaning
Hydrolysis	Cost of the process Enzymes
Algal oil extraction	Energy intensity
Fischer-Tropsch	Catalyst Scale of the process
Methanol synthesis	Plant costs
Ethanol synthesis	Plant costs
Fermentation	Efficiency of C_5 sugar fermentation

Experts were subsequently asked to identify the optimal RD&D budget allocation for 2010–2030 needed to maximise the probability of reaching cost-competitiveness by 2030. Each expert was assigned 100 chips, which represented the current annual level of public RD&D investments, around 160 million[2] 2007USD (IEA, 2011c), and they were asked to distribute them among the different biofuel technologies presented in Table 1.

The answers provided by all experts are reported in Figure 4. First, it is important to notice that the majority of experts (9 out of 15) assigned some budget, even if it was low, to 10 or more technologies. The budget allocated by these nine experts (900 chips) is fairly divided among feedstock (29%), conversion processes (39%) and refining processes (32%). On the contrary, those experts (6 out of 15) who decided to focus their budgets on fewer technologies (6 or fewer) concentrated their budgets (in total 600 chips) on feedstocks and conversion processes, 49% and 39% respectively, and allocated the remaining 13% to refining processes. This reflects the discussion on the main existing bottlenecks. In light of their relative immaturity, feedstock and conversion processes were allocated 38% each of the experts' budgets. Conversely, refining processes received 24% of the budget.

Within feedstocks, algae and microorganisms, being very innovative (Figure 4), received on average 14 and 8 chips, respectively. For algae, variations in the allocations are high between experts, and the high average resulted from the choice of a few specialised experts who devoted most of their budgets to this feedstock. This is also true for microorganisms, which received very high allocations from only three experts. Cellulosic biomass also received a high RD&D allocation, with 11 chips on average. For this feedstock, the variation within experts' allocation is lower than in the previous two cases, indicating a general agreement on the need to improve the feedstock and its procurement. All these considerations once again stress the importance of assuring that biomass is supplied to the energy conversion processes.

[2] On the basis of IEA definitions, we assume that RD&D for liquid biofuels is calculated as the sum of the RD&D allocated to "production of liquid biofuels", "production of solid biofuels", "other biofuels" and "unallocated biofuels". We define the current EU RD&D budget by evaluating the average yearly expenditure over the period 2004–2009 in order to smooth out the recent slowdown in investments due to the economic crisis. Numbers were presented both in euros and dollars. We also define the constant RD&D budget up to 2030 as a constant share of GDP.

Among conversion processes, gasification, hydrolysis and fast-pyrolysis, which were identified as relatively more mature (Figure 4), received the highest average contributions: 10.9, 7.8 and 6.1 chips, respectively. Gasification was supported by the largest number of experts and received the highest average allocation. However, variance is also high. The two processes related to the conversion of algae in fuels are much more controversial: they received a low average amount, with few exceptions.

As already mentioned, refining processes collected much lower numbers of chips than feedstocks and conversion processes. First, a number of experts allocated no budget to these technologies. Among those who did allocate money, the variance was great. Fischer-Tropsch process, for example, attracted on average 4.9 chips but with contributions ranging from 2 to 20. This mirrors the information about the maturity of technology shown in Figure 4, where experts were almost equally divided between those considering it mature and those considering it to need advances. Similar observations can be made for the refining of bio-oil derived from pyrolysis, even though they attracted a lower number of chips (4.4 on average).

Conversely, there was agreement among the experts in allocating a small share of the budget to fermentation, methanol and ethanol synthesis (3.9, 3.5 and 2.4 chips, respectively). Among those, fermentation is supported by the largest number of experts, while methanol and ethanol synthesis did not receive any contributions from the majority of experts. Finally, transesterification received, unanimously, less than one chip on average, most citing the commercial status of the technology even when using algae as feedstock.

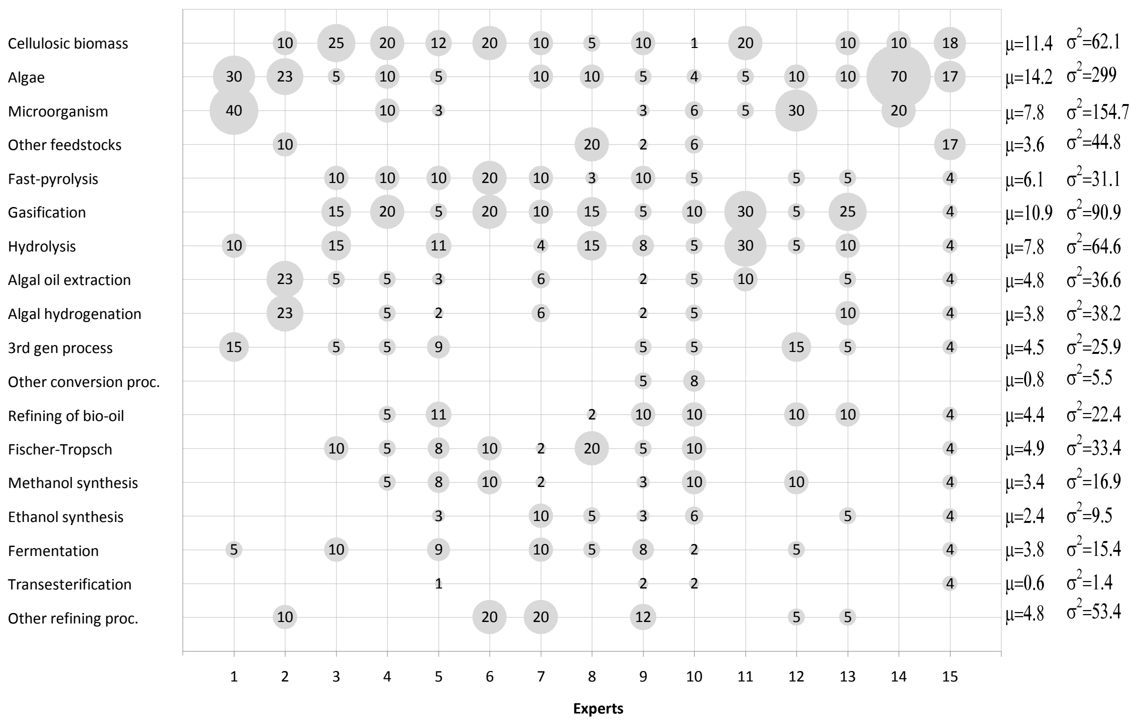

Figure 4: Allocation of the RD&D budget over the 2010-2030 period to make biofuel technologies commercially successful in 2030. Mean and variance for each technological unit is reported. The budget is conventionally expressed in 100 “chips” per expert (column), to be distributed among the different technologies. For each technology (row) both the average and variance in chip allocation are provided.

Quite mature processes, such as ethanol from cellulosic biomass and gasification, received large budget allocations, while less mature technologies, such as algae and microorganisms, received much lower amounts. Some light can be shed on this apparent contradiction by considering the kind of RD&D investment the experts had in mind. Funding for demonstration activities should account for the largest economic part of RD&D expenditures in these technologies, as shown in Figure 5. The importance of funding for demonstration activities is particularly emphasised for all conversion and refining processes. Conversely, experts called for more basic and applied research with respect to less mature feedstocks and related conversion technologies. In general, experts would limit the risk of failure linked to the development of more innovative biofuel technologies, and would instead speed up the deployment and demonstration process of mature technologies, which are deemed closer to commercial success.

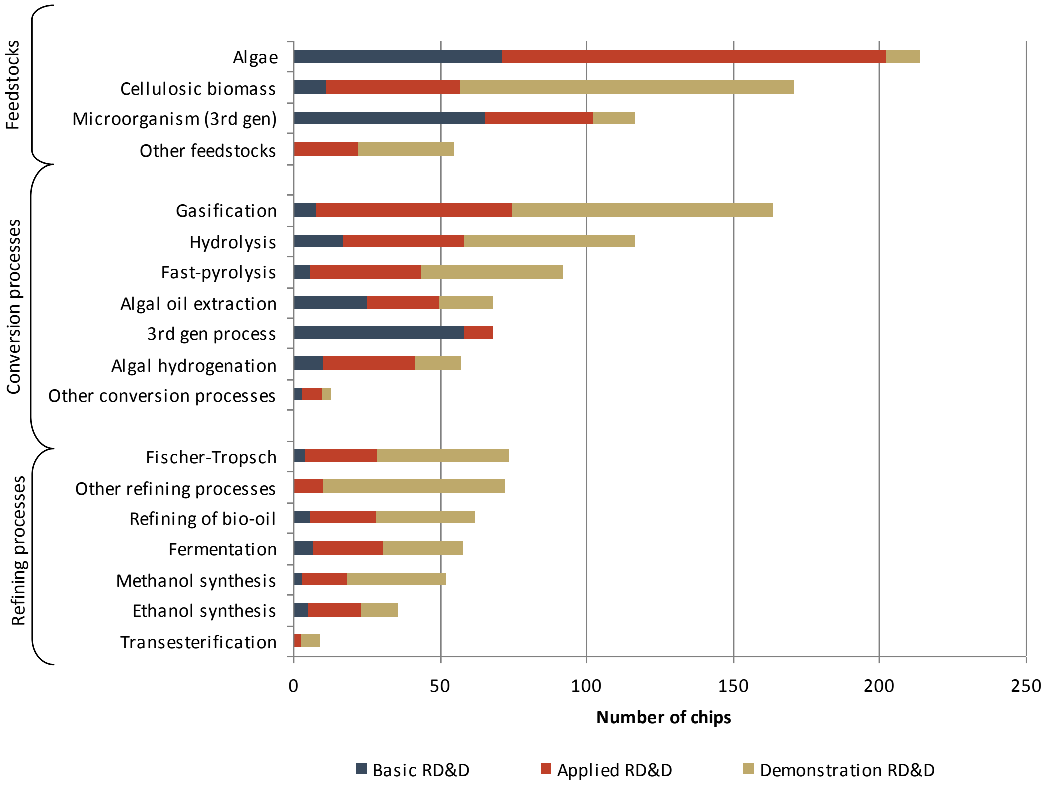

Figure 5: Sum of the funding allocated by all experts among different technologies and subdivision of the budget between basic and applied research and demonstration activities

5 RD&D and future costs

The core of the survey was to assess whether, and under what conditions, advanced biofuels would eventually become cost-competitive with conventional fossil fuels. To do so, we elicited the experts' assessment of the probabilistic cost of advanced biofuels in 2030 and how these distributions would be affected by changes in the EU public RD&D strategy.

In particular, the cost assessment was based on three RD&D scenarios: (1) a current scenario, where the current annual level of public investment in RD&D (160 million 2007USD[2]) is kept constant up to 2030; (2) a +50% RD&D scenario, where current funding is increased by 50% from now to 2030; and (3) a +100% RD&D scenario, where funding is doubled starting now and up to 2030.

We explicitly illustrated to experts the three scenarios so that the only element that distinguished them was the level of public EU RD&D funding from now to 2030, while private funding and other countries' RD&D programmes would remain the same across scenarios. Incentives and subsidies would also remain equal to zero across all scenarios.

To avoid anchoring effects, we first asked the experts to provide the 10th, 50th and 90th percentiles of the expected cost in 2030 under the three RD&D investment scenarios. We then checked the consistency of responses and challenged potential overconfidence in the experts' responses by asking a subsequent question where experts had to estimate the probability that the cost of biofuels in 2030 would be lower than 0.73, 0.40 or 0.20 USD/lge, again based on the three funding scenarios.[3,4] This allowed us to ask the same information to each expert twice, but with a different focus. As a result, we were able to carry out consistency checks and help experts thinking about their assessments thoroughly.

Thirteen out of fifteen experts provided estimates of the expected costs of advanced biofuel technologies. Seven did it for an unspecified mix of technologies, while six assessed costs of specific technologies that they considered more promising. Specifically, experts 8, 9 and 10 indicated gasification, experts 11 and 12 considered cellulosic ethanol, and expert 13 focused on Fischer-Tropsch liquids and cellulosic ethanol.

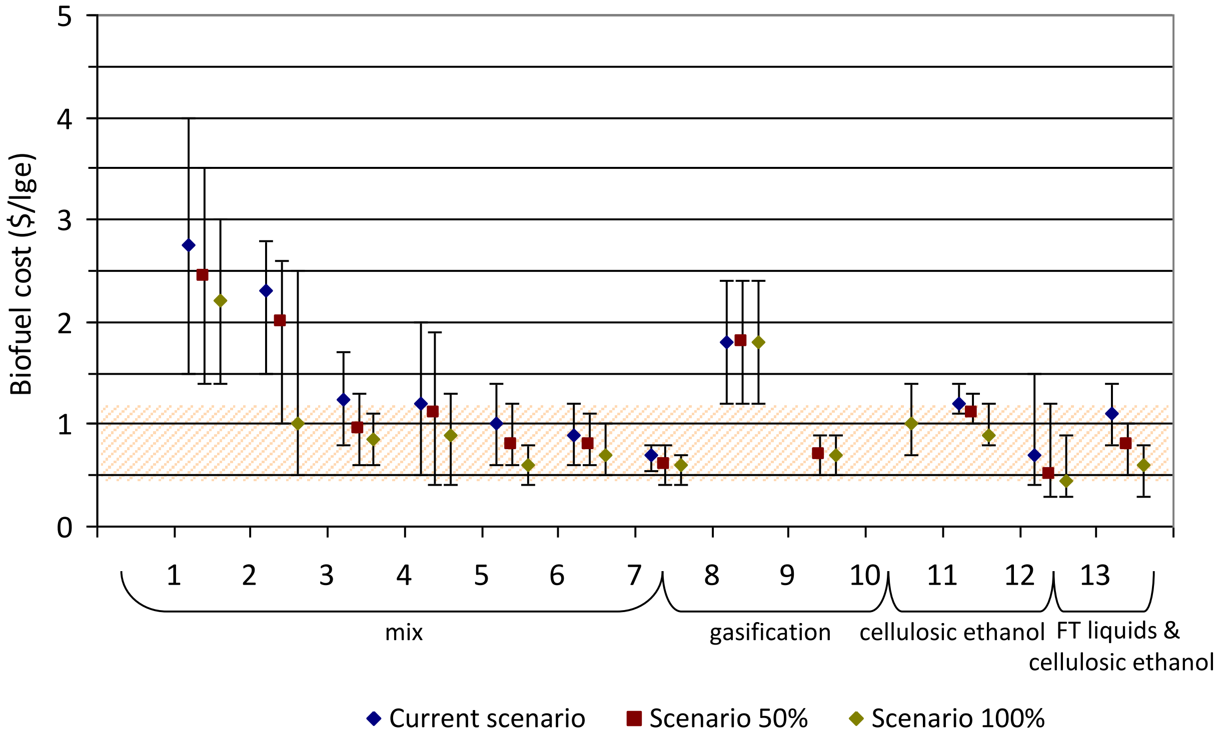

Figure 6: Estimates of the cost of one litre of gasoline equivalent (lge) from biofuel technologies in 2030, under three RD&D funding scenarios. The shaded area represents the 2020–2030 projected production cost range as reported in the IPCC SRREN Report (Chum et al., 2011).

By 2030, under the current RD&D public funding scenario, experts expected that the cost of biofuels would range from as low as 0.7 to as high as 2.75 USD/lge (blue marker in Figure 6). Despite the breadth of this range, the majority of experts provided an expected cost around 1 USD/lge, while only three experts provided a value higher than 1.8 USD/lge. In particular, according to 7 experts, the most likely cost in 2030 will be between 0.7 and 1.25 USD/lge. The same experts expected an average reduction in costs of 15% with a +50% increase in RD&D funding, and of 29% with a doubling of the investments. Three experts reported much higher estimates (2.75, 2.3 and 1.8 USD/lge) under current RD&D funding. Only one of these three experts (expert 2) expected an impact of increased levels of RD&D (in particular the 100% increase scenario) that would bring the reported estimates in line with the majority of other experts. The

[3] The three "breakthrough" cost levels proposed to the experts correspond to projections of the costs of conventional petroleum gasoline in 2030: an upper level of 0.73 USD/lge, which simulates the presence of a carbon price in line with a 550 ppmCO_2 stabilization scenario, and two lower levels of 0.40 USD/lge and 0.20 USD /lge. These three values allow us to span a wide range of future evolution of the price of oil.

[4] Since experts typically think in terms of technological endpoints and not in terms of costs, we provided them with a formula to derive the cost of biofuels from specific technical factors, such as feedstock costs, efficiency, capital costs and operational and maintenance cost, see Bosetti et al. (2012b) for a detailed description. Experts who did not feel at ease with directly providing monetary estimates were free to use the formula to estimate how improvements in technical factors would result in lower monetary costs.

other two experts (experts 1 and 8) were very pessimistic about the capacity of biofuels to be competitive with conventional fuels in 2030. Expert 1 was also convinced that a more efficient use of biomass feedstock is in the co-production of electricity and heat.

Figures on cost reductions based on increased levels of EU public RD&D funding are provided in Table 3. All but two experts agreed on a positive effect of RD&D on the 50th percentile cost estimates. Experts 8 and 9 represent an exception, as they did not see any potential effect of RD&D, at least in the range of values encompassed by the three scenarios.

The experts' opinions varied with respect to the effect of RD&D on the uncertainty, which we measure as the length of the bar in Figure 6. According to 11 out of 13 experts, a 50% increase of public RD&D would reduce or maintain the level of uncertainty surrounding cost projections. The same is true when a further increase of public funding is assumed (+100% scenario), with the exception of one expert, who showed an increase in the uncertainty of the estimate. Only two experts indicated a higher degree of uncertainty in evaluating departures from the status quo. According to the ancillary information collected during the interviews, this might be due to higher investments in less mature technologies, whose success have a higher degree of uncertainty.

A comparison with other available estimates of future costs puts our results into perspective. According to the IPCC SRREN report (Chum et al., 2011), the projected production cost of biofuel between 2020 and 2030 is expected to range from 0.41 to 1.19 USD/lge (shaded area in Figure 6). The IEA (2011b) 2030 projections of second generation production costs range between 0.8 and 1.0 USD/lge. Finally, the European Biofuels Technology Platform's (2008) aspirational goal for biofuel is lower than 0.6 USD/lge. Under the current level of RD&D funding, only four experts provided a cost estimate lower than 1 USD/lge. Under the +50% RD&D scenario, the estimates of seven experts are within the IPCC 2030 expected range of costs. This number increases to 11 experts under the +100% RD&D scenario.

Table 3: Costs of biofuels (USD/lge) in 2030 under the current RD&D scenario and expected reductions under a 50% and a 100% increase in RD&D funding (experts 9 and 10 did not provide any estimation for the current scenario)

Expert	Technology	Current scenario 50th percentile	% reduction (wrt current scenario 50th percentile)	
			Scenario 50%	Scenario 100%
1	Mix	2.75	10.9	20.0
2	Mix	2.3	13.0	56.5
3	Mix	1.25	24.0	32.0
4	Mix	1.2	8.3	25.0
5	Mix	1	20.0	40.0
6	Mix	0.9	11.1	22.2
7	Mix	0.7	14.3	14.3
8	Gasification	1.8	0.0	0.0
9	Gasification	-	-	-
10	Gasification	-	-	-
11	Cellulosic ethanol	1.2	8.3	25.0
12	Cellulosic ethanol	0.7	28.6	35.7
13	FT liquids and cellulosic ethanol	1.1	27.3	45.5

6 Diffusion of biofuels

The conclusive part of the elicitation focused on the market diffusion of biofuels and non-technical barriers that are likely to hamper their success. Experts commented on the likelihood of three 2050 alternative scenarios characterised by low (20%), medium (50%) and high (70%) proportions of vehicles running on biofuels over the total private vehicles market. As there might be substantial differences in the potential for advanced biofuel diffusion in different regions, the likelihood of these alternative penetration scenarios was evaluated separately for OECD, fast-growing and developing countries. Results are reported in Table 4. For OECD countries, eight experts believe that the 20% penetration scenario is very likely to happen (probabilities between 70% and 100%), while two experts assigned a high probability (60% and 100%) to the 50% diffusion scenario. Only one expert foresaw a diffusion rate of 70% with a probability of 85%.

Also, in the case of fast-growing countries, the majority of experts who answered the question (four out of five) believe that there is a high possibility of achieving a 20% penetration rate of biofuels (60–100% probability). However, the low rate of response to this question underlies a great uncertainty surrounding the biofuel market in fast-growing countries. Experts agreed that the low diffusion scenario was going to be the most likely one in developing countries as well: nine experts assigned to it a probability higher than 66%.

Table 4: Probability of three different penetration rates for biofuel technologies in 2050 (OECD, fast-growing and developing countries)

Expert	OECD countries			Fast-growing countries			Developing countries		
	Low	Medium	High	Low	Medium	High	Low	Medium	High
1	-	-	-	-	-	-	-	-	-
2	70	20	10	-	-	-	85	10	5
3	70	25	5	-	-	-	60	30	10
4	90	10	0	-	-	-	90	10	0
5	5	10	85	-	-	-	50	30	20
6				-	-	-	-	-	-
7	70	30	0	70	30	0	70	30	0
8	-	-	-	-	-	-	-	-	-
9	90	10	0	-	-	-	90	10	0
10	80	20	0	-	-	-	100	0	0
11	90	10	0	75	25	0	100	0	0
12	50	30	20	60	25	15	70	20	10
13	30	60	10	50	45	5	70	30	0
14	0	100	0	-	-	-	0	100	0
15	100	0	0	100	0	0	100	0	0
Average	**62**	**27**	**11**	**71**	**25**	**4**	**74**	**23**	**4**

Experts then indicated the possible ceiling to the diffusion of vehicles running on biofuels in the private market in 2050. Most experts (eight) believe that biofuels will account for 25% to 50% of private transport, but estimates range from 10% to 100%, showing a general lack of consensus. According to several experts, the ceiling to biofuels will be caused by limitations in feedstock availability and by substitution with other technologies (e.g., electric vehicles).

Experts also discussed the importance of a set of potential barriers to the diffusion of biofuels technologies. These are listed and ranked, together with proposed solutions, in Figure 7. The most important barrier is the competition for the use of land, food vs. energy, closely followed by the presence of environmental externalities. Policy interventions are by far the preferred means to overcome such barriers. Certification systems were often recalled as a possible way of providing and tracing sustainable feedstock. A few experts also pointed out that this issue is key and primarily concerns the eradication of poverty and the improvement of agricultural productivity. Experts then suggested further solutions to this barrier, such as the design of systems that co-produce food and bioenergy feedstock from the same land, the design of a supply chain where the feedstock supply and conversion plant are connected, the provision of CO_2 biological sequestration on some land, and finally the design of conversion plants that allow for feedstock diversification.

Barriers related to economic and financial issues were considered less relevant than those related to environmental and sustainability issues. Only one expert specifically stated that financing is the biggest issue and that it is necessary to invest in the process and finance demonstration.

To further investigate the diffusion process, experts indicated the geographical areas of the world with the highest probability of reaching commercial breakthrough. Nine of them indicated that the USA would reach cost-competitiveness first, six chose the EU, three Brazil and one China.

Experts also commented on how the nature of knowledge will affect the support of national RD&D programmes. Twelve affirmed that the current conditions reflect a relatively successful cooperation among different countries, which results in important knowledge spillovers. However, they agreed on the binding need for each country to invest in its own RD&D programme to develop absorptive capacity and therefore to be ready to adopt breakthrough technologies developed by other countries.

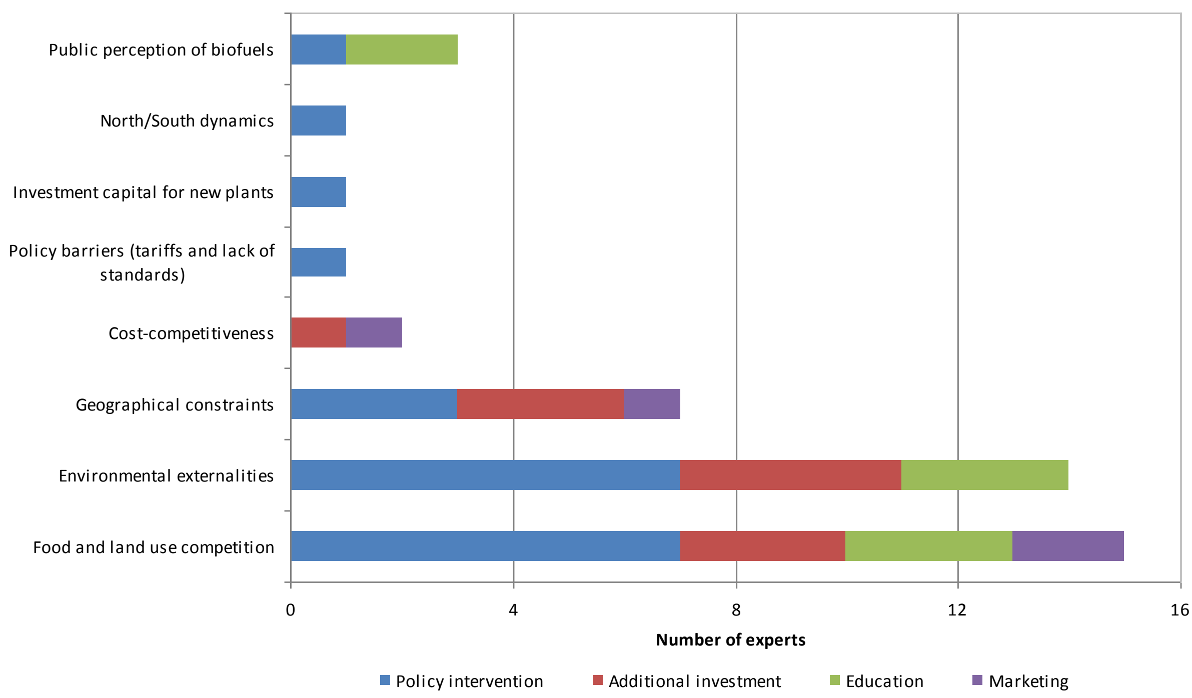

Figure 7: Factors that could represent non-technical barriers to the diffusion of biofuel technologies and potential solutions to overcome these barriers

Finally, experts identified the potential negative externalities on the environment and society that might be associated with the diffusion of biofuel technologies. Most experts (nine) expressed concern about the sustainability of biomass supply, in particular the competition of land use for energy vs. food, which was already mentioned as an important non-technical barrier to deployment. Equity issues between developed countries (that would import biomass) and developing countries (that would produce biomass) were also mentioned. The same experts also underlined the importance of considering environmental issues like biodiversity conservation, water use and water pollution (due to the use of fertiliser for energy crops). Conversely, the remaining five experts stated that the above-listed issues are much more relevant for first generation biofuels, and are not to be expected from second and third generation biofuels, whose primary feedstock should be residues.

One expert pointed out that, because biomass feedstocks are a limited resource, they should be used in the conversion technologies to maximise the reduction of greenhouse gas emissions. Therefore, they should be applied to heat and electricity applications to replace heavy oil and coal, rather than for the production of liquid biofuels. Finally, another expert observed that great life-changing innovations are not expected from biofuels because they are a way of preserving our existing way of life by substituting fossil fuels. In particular, biofuels will not improve two important issues related to the transport sector, such as emission of pollutants and traffic congestion. Only one expert provided some examples of positive externalities, linked to agricultural and rural development and job creation.

7 Conclusions and policy recommendations

Biofuels represent a concrete and promising solution to reduce the dependence on fossil fuels in the transport sector, and to meet climate change policy targets while ensuring reliable fuel supply. Significant progress has been made in the last years with respect to research and technical improvements. However, some technical barriers and market dynamics still hinder the commercial success of these technological options.

Assessing the potential to overcome these barriers, the RD&D effort necessary to promote this process as well as the future of biofuels costs are key steps to support policy makers in drafting appropriate and efficient energy policies. The expert elicitation survey that we carried out uses a robust elicitation protocol that collects novel evidence on the current status and future developments of biofuel technologies. Its results and policy implications are of great relevance for the current debate on renewable energy technologies in Europe, as well as worldwide.

The first conclusion clearly emerging from this study is that most of the selected technologies already present a good potential to overcome technical bottlenecks by 2030, but will not likely be cost-competitive with fossil fuels unless a climate policy is in place. The role of RD&D investments is considered crucial to ensure technological advances, and the portfolio of investments should be diversified among different technological processes. First of all, refining processes such as methanol synthesis, transesterification and Fischer-Tropsch, are technically mature, and should be allocated a relatively small amount of RD&D, mainly targeted at enhancing demonstration activities. Conversely, the success of biofuels mainly depends on investments in applied research and demonstration for conversion processes, in particular gasification and hydrolysis. Indeed, these results point to the overall complexity of conversion processes applied to biofuels production with respect to fossil fuels.

Furthermore, RD&D is needed to guarantee the supply of feedstocks, as well as to provide effective solutions for logistic and economic issues. Innovative third generation feedstocks, such as algae and microorganisms, could reach substantial improvements but would probably require a larger time horizon (i.e., beyond 2030) to gain in competitiveness. With the exception of these highly innovative technologies, which would mainly require basic RD&D funding, experts agree on the need to distribute investments among all phases of the RD&D process. This is in contrast with the historical breakdown of EU public investments, which has concentrated on the earlier stages of the research activity.

Assuming the current level of annual RD&D investments until 2030, most experts' best guesses of biofuels costs lay within the 0.7–1.8 USD/lge range. The average expected cost is 1.35 USD/lge, due to the presence of outliers with estimates around 2.5 USD/lge. Without any variation in RD&D funding over the next 20 years, there is much disagreement on the possibility to abate costs below even the highest fossil fuel projected cost (0.73 USD/lge). Lower-costs scenarios appear extremely unlikely for the time range under consideration.

Increases in RD&D investments generally lead to a decrease in the expected costs of biofuels. In particular, increasing funding by 50% lowers the expected costs by roughly 15% (1.14 USD/lge), while a doubling of public investments leads to a 29% reduction (0.96 USD/lge). When increasing by 50% and then by 100% the RD&D investment, there is a positive effect on cost reduction and a higher probability of reaching 0.73 USD/lge. However, biofuels will hardly be competitive with traditional fossil fuels without a carbon tax, even if investments are doubled. Increasing public funding for biofuel technologies generally results in lower divergence of experts' estimates.

Consistent with its public policy of strong support of biofuel technologies, the United States emerges as the first country that will potentially reach commercial success. However, experts recognise that other countries (both developed, such as EU members, and fast-growing, such as Brazil and China) also have a high probability of producing cost-competitive biofuel technologies. Although technology transfer could play a major role in the success of these technologies, experts emphasized the need of a well-designed EU RD&D strategy to keep up with more advanced countries. Experts acknowledged that technical maturity and cost-competitiveness are key for the success of biofuels, but that non-technical issues and barriers could slow down their worldwide diffusion and consequently their success. The main obstacles to market diffusion and large-scale deployment are the energy vs. food competition for land, environmental externalities and geographical constraints. In addition to the large share of the RD&D budget that experts suggest devoting to feedstock, ad-hoc policies should probably be put in place to ensure that these external costs are internalised.

When assessing the likelihood that biofuels will represent 20%, 50% or 70% of fuels used in the private vehicle market in 2050, experts generally agree on the 20% scenario for OECD countries. The 20% scenario is also the most likely in developing and in fast-growing countries, even though the latter are characterised by higher uncertainty. Experts show little consensus on this issue. Most experts justified their uncertainty and low estimates by highlighting the fact that the contribution of biofuels will be limited by feedstock availability, by the competition for land use for energy or food purposes, and also by the competition for the use of biomass in the production of heat and electricity.

References

ANP – National Agency of Petroleum, Natural Gas and Biofuels (Brazil) (2011), Oil, Natural Gas and Biofuels Statistical Yearbook / Agency of Petroleum, Natural Gas and Biofuels – ANP, Rio de Janeiro.

Baker, E. and J. Keisler (2011), Cellulosic Biofuels: Expert Views on Prospects for Advancement, Energy, 36(1), 595–605.

Baker, E., H. Chon and J. Keisler (2009a), Advanced solar R&D: Combining economic analysis with expert elicitations to inform climate policy, Energy Economics, 31, 37–49.

Baker, E., H. Chon and J. Keisler (2009b), Carbon capture and storage: combining economic analysis with expert elicitations to inform climate policy, Climatic Change, 96, 379–408.

Berndes, G., N. Bird and A. Cowie (2011), Bioenergy, land use change and climate change mitigation, IEA Bioenergy.

Bosetti, V., M. Catenacci, G. Fiorese and E. Verdolini (2012a), The future prospect of PV and CSP solar technologies: An expert elicitation survey, Energy Policy, 49, 309-317.

Bosetti, V., M. Catenacci, G. Fiorese and E. Verdolini, 2012b. ICARUS survey on the current state and future development of biofuel technologies. ICARUS Report 4, Milan.

Chan, G., L. Diaz Anadon, M. Chan and A. Lee (2011), Expert Elicitation of Cost, Performance, and RD&D Budgets for Coal Power with CCS, Working Paper, Energy Procedia, 4, 2685–2692.

Chum, H., A. Faaij, J. Moreira, G. Berndes, P. Dhamija, H. Dong, B. Gabrielle, A. Goss Eng, W. Lucht, M. Mapako, O. Masera Cerutti, T. McIntyre, T. Minowa and K. Pingoud (2011), Bioenergy. In IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation [O. Edenhofer, R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S.

Kadner, T. Zwickel, P. Eickemeier, G. Hansen, S. Schlömer, C. von Stechow (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Clemen, R.T. and T. Reilly (2001), Making Hard Decisions with Decision Tools, Duxbury Thomson Learning, Pacific Grove, CA.

Cooke, R.M. (1991), Experts in Uncertainty, Oxford University Press.

Cooke, R.M. and L.J.H. Goossens (1999), Procedures guide for structured expert judgements, Project Report to the European Commission, EUR 18820.

Curtright, A., G.W. Morgan and D.W. Keith (2008), Expert Assessments of Future Photovoltaic Technologies, Environmental Science and Technology, 42(24), 9031–9038.

Dale, V.H., K.L. Kline, J. Wiens and J. Fargione (2010), Biofuels: Implications for Land Use and Biodiversity, Biofuels and Sustainability Reports, Ecological Society of America.

Directive 2003/30/EC (2003), Directive 2003/30/EC of the European Parliament and of the Council of 8 May 2003 on the promotion of the use of biofuels or other renewable fuels for transport.

Directive 2009/28/EC (2009), Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC (Text with EEA relevance).

EC (2009a). Commission Staff working document, accompanying document to the Communication from the Commission to the European Parliament, the Council, the European economic and social committee and the committee of the regions on investing in the development of low carbon technologies (set-plan), A Technology Roadmap, {COM(2009) 519 final}, http://setis.ec.europa.eu/about-setis/technology-roadmap/?searchterm=roadmap

EC – European Commission (2009b), R&D Investment in the Priority Technologies of the European Strategic Energy Technology Plan, Commission Staff Working Document SEC(2009)1296.

Edwards R., S. Szekeres, F. Neuwahl and V. Mahieu (2008), Biofuels in the European Context: Facts and Uncertainties, JRC – European Commission, http://www.jrc.ec.europa.eu/

European Biofuels Technology Platform (2008), Strategic Research Agenda & Strategy Deployment Document.

Farrell A.E., R.J. Plevin, B.T. Turner, A.D. Jones, M. O'Hare and D.M. Kammen (2006), Ethanol Can Contribute to Energy and Environmental Goals, Science, 311, 506–508.

Hill J., E. Nelson, D. Tilman, S. Polasky and D. Tiffany (2006), Environmental, economic, and energetic costs and benefits of biodiesel and ethanol biofuels, PNAS, 103(30), 11206–11210.

Hogarth R.M. (1980), Judgment and choice, Wiley, New York, NY.

IEA – International Energy Agency (2011a), CO_2 emissions from fuel combustion – Highlights, OECD/IEA, Paris. http://www.iea.org/co2highlights/co2highlights.pdf

IEA – International Energy Agency (2011b), Technology Roadmap, Biofuel for Transport, OECD/IEA, Paris.

IEA – International Energy Agency (2011c), RDD budget database, accessed November 2011.

Keeney, R.L. and D. von Winterfeldt (1991), Eliciting probabilities from experts in complex technical problems, Transaction on Engineering Management, 38, 191–201.

Meyer, M.A. and J.M. Booker (1991), Eliciting and Analysing Expert Judgment: A Practical Guide, London: Academic Press Ltd.

Morgan, G. and D. Keith (1995), Subjective Judgments by Climate Experts, Environmental Science & Technology, 29(10), 468–476.

Morgan, G. and M. Henrion (1990), Uncertainty: A guide to dealing with uncertainty in quantitative risk and policy analysis, New York: Cambridge University Press.

Nature (2011), Biofuels, Nature, 474 Suppl, S1–S25.

O'Hagan, A., C.E. Buck, A. Daneshkhan, J.R. Eiser, P.H. Garthwaite, D.J. Jenkinson, J.E. Oakey and T. Rakow (2006), Uncertain Judgments: Eliciting Experts' Probabilities, John Wiley & Sons, Ltd.

Phillips L.D. (1999), Group elicitation of probability distributions: Are many heads better than one?, In J. Shanteau et al. (eds.), Decision Science and Technology: Reactions on the Contributions of Ward Edwards (pp. 313–330). Norwell, MA: Kluwer Academic Publishers.

Poppe, M. and L.A. Horta Nogueira (2009), Le bioéthanol: de l'expérience brésilienne à la formation d'un marché global, Revue de l'Énergie, 591, 1–10.

Rathmann, R., A. Szklo and R. Schaeffer (2010), Land use competition for production of food and liquid biofuels: An analysis of the arguments in the current debate, Renewable Energy, 35(1), 14–22.

Renewable Fuels Association (2012), Accelerating Industry Innovation – 2012 Ethanol Industry Outlook, Renewable Fuels Association, http://ethanolrfa.3cdn.net/d4ad995ffb7ae8fbfe_1vm62ypzd.pdf

Searchinger, T.D., S.P. Hamburg, J. Melillo, W. Chameides, P. Havlik, D.M. Kammen, G.E. Likens, R.N. Lubowski, M. Obersteiner, M. Oppenheimer, G.P. Robertson, W.H. Schlesinger and D. Tilman (2009), Fixing a Critical Climate Accounting Error, Science, 326, 527–528.

Sorda G., M. Banse and C. Kemfert (2010), An overview of biofuel policies across the world, Energy Policy, 38, 6977–6988.

The Biofuels TP (2012), Cellulosic Ethanol (CE), www.biofuelstp.eu

Tilman, D., R. Socolow, J. Foley, J. Hill, E. Larson, L. Lynd, S. Pacala, J. Reilly, T. Searchinger, C. Sommerville and R. Williams (2009), Beneficial Biofuels – The Food, Energy, and Environment Trilemma, Science, 325, 270–271.

Wise M., K. Calvin, A. Thomson, L. Clarke, B. Bond-Lamberty, R. Sands, S.J. Smith, A. Janetos and J. Edmonds (2009), Implications of Limiting CO_2 Concentrations for Land Use and Energy, Science, 324, 1183–1186.

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