



Innovation for Climate chAnge mitigation:  
a study of energy R&d, its Uncertain  
effectiveness and Spillovers

# Icarus expert elicitation reports

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Biofuel technologies

Short Technical Report from the  
ICARUS survey on the current state  
and future development

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## **Biofuel technologies**

### **Short Technical Report from the ICARUS survey on the current state and future development**

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Thank you again for the time you have devoted to the ICARUS survey. It is greatly appreciated as it has allowed us to collect a wealth of information, which will prove very useful in assessing the potential of biofuel technologies

*Table 1: List of experts participating in the survey*

<b>Name and Surname</b>	<b>Affiliation</b>	<b>Country</b>
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)	UK
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	UK
Raphael Slade	Imperial College London	UK
Philippe Shild	European Commission	Germany
Henrik Thunman	Chalmers University of Technology	Sweden

*Please note that the numbers associated to the experts in the paper are randomly assigned*

## Introduction

The present document provides a preliminary analysis of the results of the expert elicitation survey, carried out as part of a 3-year ERC-funded project on innovation in carbon-free technologies (ICARUS - Innovation for Climate chAnge mitigation: a study of energy R&D, its Uncertain effectiveness and Spillovers - [www.icarus-project.org](http://www.icarus-project.org)).

Figure 1 provides a graphical representation of the main biofuel technologies which have been assessed as part of the expert elicitation process.

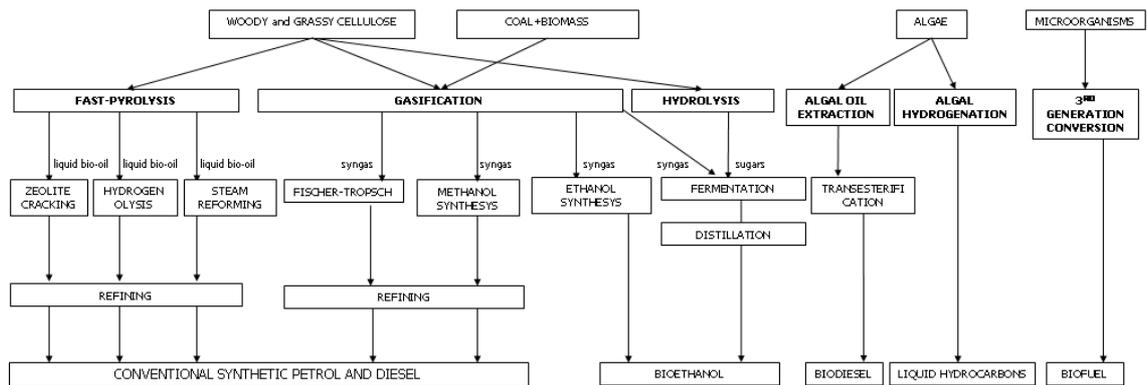


Figure 1: Technology paths that have been assessed in the interviews with the experts

Figure 2 illustrates the origin of the experts participating in the study and shows the heterogeneity of the cluster of experts, which was composed by 7 experts from institutions, 5 from universities and 3 from the private sector.

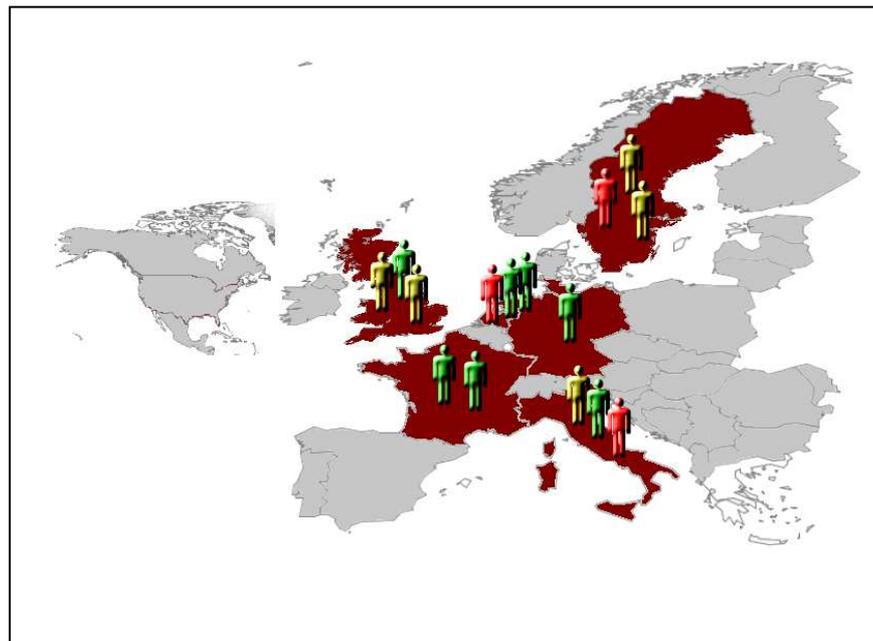


Figure 2: Geographical map of the area of origin of the experts and their professional sector. The individual figures over each country indicate the number of experts per country, while the colours highlight their professional sector: green = institution, yellow = academia, red = private.

The level of expertise of the selected experts, using the self-evaluation exercise within the elicitation survey, is shown in Figure 3. The scatter plot area can be read as follows: (i) the high/left quadrant, identifies experts with lower coverage across the different types of technology and a high level of specialisation, (ii) the high/right quadrant, includes experts with high coverage and high specialisation; (iii) the low/right quadrant, includes experts with high coverage and relatively scarce specialisation; and (iv) the low/left quadrant includes experts characterized by low coverage and low specialisation. The ordination shows that most experts have a high degree of specialisation (Specialization Index > 50%) and a high level of coverage (CI>50%).

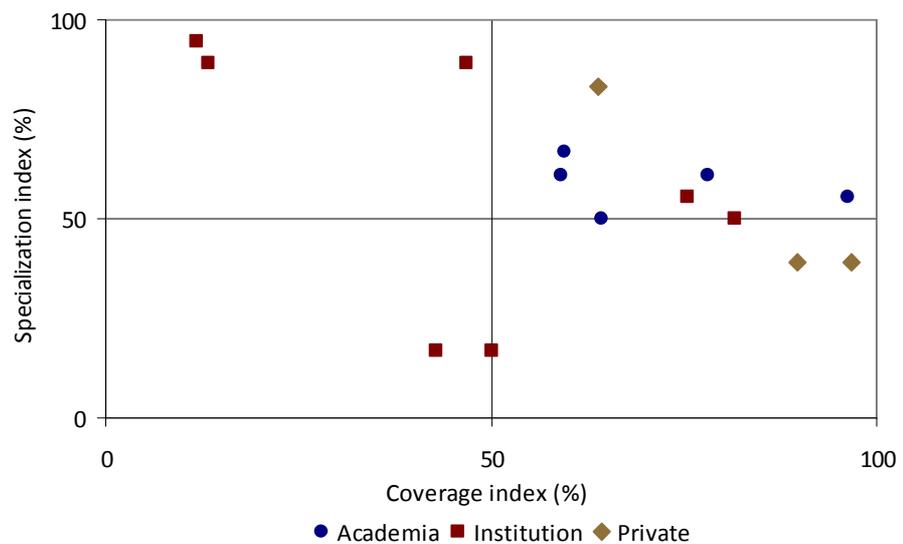


Figure 3: Direct ordination of the 15 experts based on the Coverage Index and the Specialisation Index.

Figure 4 shows the level of expertise across all experts for each technology. With the exception of 3<sup>rd</sup> generation feedstock, all of the processes are covered by at least one expert declaring a high level of expertise. The highest levels of expertise tend to be concentrated on the refining processes, whereas many experts declared a medium or low expertise among feedstocks; this is probably due to the fact that the majority of the experts have a background related to engineering, rather than agriculture.

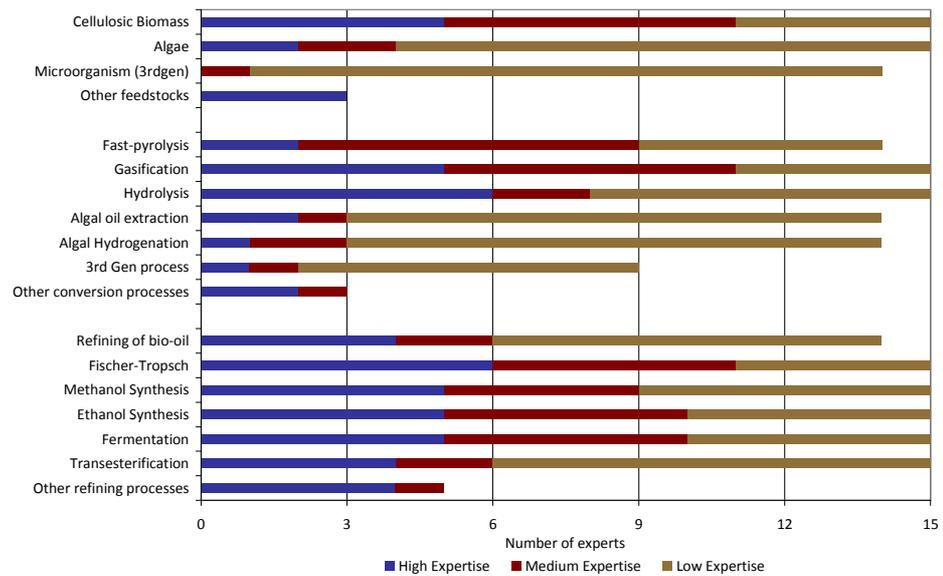


Figure 4: Distribution of the experts in three classes of expertise (High expertise: max level of knowledge >3; medium expertise: max level of knowledge =3; Low expertise: max level of knowledge <3) among all the technological paths.

## Technical potential of biofuel technologies

The assessment of the possible drivers for future variations in the cost of biofuels started with an analysis of the current technical characteristics of each feedstock, conversion and refining processes. The experts provided important insights on the specific conditions, which would lead biofuel technologies to commercial success, and also identified the stages of the RD&D process which had to be improved to overcome existing bottlenecks. Figure 5 shows how each expert evaluated the status of each technology: the bigger the circle, the higher the need for improvements. Precisely, experts were asked to evaluate the status of a technology by assigning a value from 1 (current level is excellent) to 3 (substantial advances are needed). The highest requirements for improvements are for the emerging technologies: algae and 3<sup>rd</sup> generation processes. Other feedstocks and processes are generally evaluated as also needing advancement.

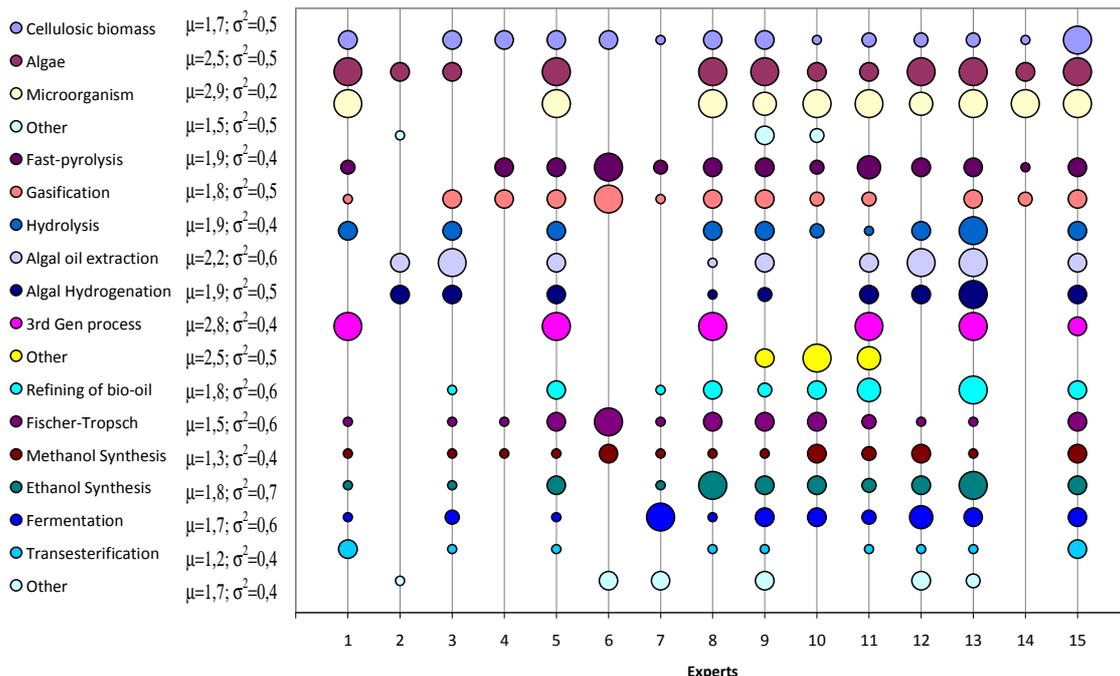


Figure 5: Current maturity level of the different feedstocks, conversion and refining processes (row) assigned by each expert (column). Both the average and variance are provided.

To identify the most important drivers of the variations in the costs of biofuels, we asked each expert to comment on the current level of technical development of the proposed technological options. Experts were asked to identify the main bottlenecks which currently represent barriers to cost reductions and to specify what type of RD&D would be most needed. Table 2 reports keywords that were mentioned by at least four experts when discussing barriers and issues connected to each of the technological options. Market barriers were indicated by many experts as the main difficulty for several biomass sources (cellulosic biomass, energy crops, waste oils) to become a significant feedstock for energy processes.

Table 2: Keywords mentioned by at least 4 experts

Cellulosic Biomass	Economic barriers to the market Logistics issues
Algae	Energy intensity Up scaling of the process Production costs
Fast pyrolysis	Up-grading 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 C5 sugar fermentation

Experts were asked to define their optimal allocation of the RD&D budget over the 2010-2030 period in order to make biofuel technologies

commercially successful in 2030. The budget was conventionally expressed in 100 chips that the experts had to distribute among the different biofuel technologies (results are reported in Figure 6). The highest allocations of this budget were devoted to improving innovative technologies, such as algae and cellulosic biomass, and to the improvement of gasification, considered a promising technology but still needing substantial advances.

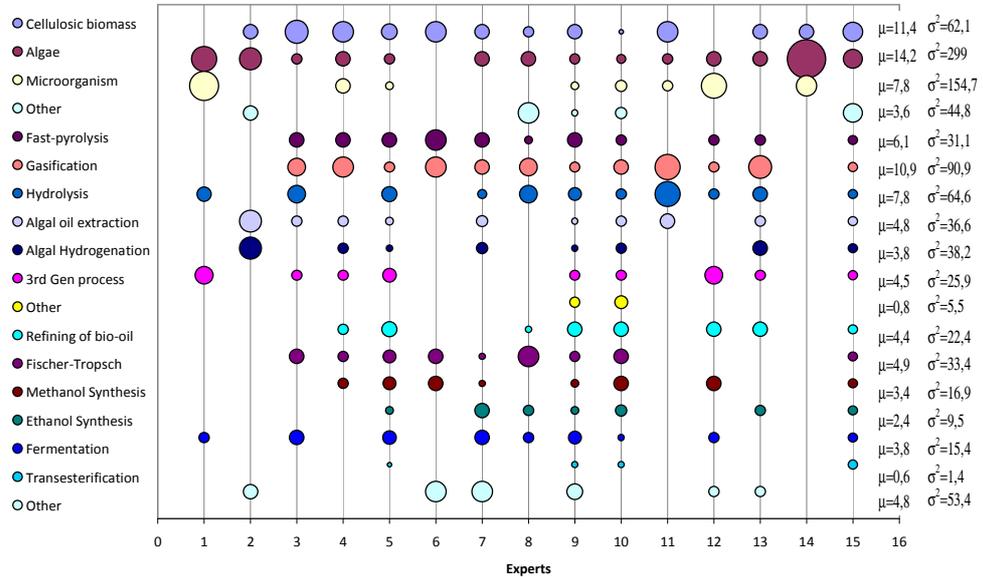


Figure 6: Allocation of the RD&D budget over the 2010-2030 period to make biofuel technologies commercially successful in 2030. The budget is conventionally expressed in 100 “chips” per expert (column), to be distributed among the different technologies. For each technology (row) both the average and variance in chips allocation are provided.

Figure 7 provides information about the suggested type of RD&D needed between basic, applied and demonstration RD&D. We report aggregated figures as no substantial differences across experts were reported. For algae, the budget should be devoted to basic and applied research, while for cellulosic biomass, whose status is closer to success, applied research and demonstration activities are dominant. It should be noted that most of experts believe demonstration activities are now crucial for a wide array of technologies.

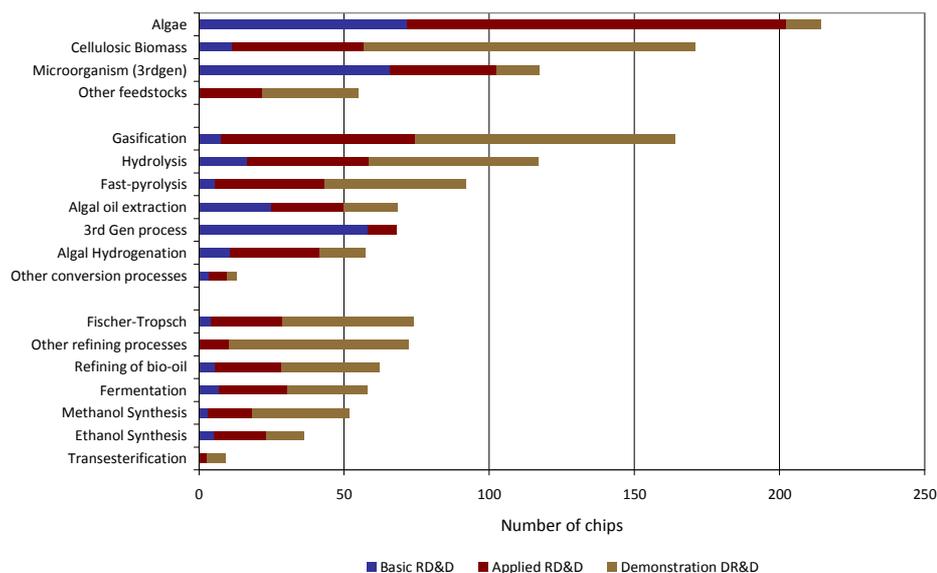


Figure 7: Sum of the RD&D allocated by all experts among different technologies and subdivision of the budget between basic, applied and demonstration RD&D.

## RD&D effectiveness on future biofuels cost

Figure 8 reports experts' expected costs in 2030 (90<sup>th</sup> percentile, 10<sup>th</sup> percentile and "best guess") for 3 different RD&D scenarios. In the first scenario the current annual level of RD&D would not change until 2030. In the second scenario, the investment in RD&D for biofuel technologies would increase by 50% until 2030, and in the third scenario the investment in RD&D would increase by 100% in the next 20 years.

Estimates of the expected cost per litre of gasoline equivalent in 2030 (Figure 8) indicate a high degree of uncertainty and variance among the experts. Most estimates are comprised between 0.5 and 2 dollars per litre of gasoline equivalent (\$/lge). Few experts provide much higher expected costs, limited to 4 \$/lge. According to many experts, the uncertainty doesn't consistently decrease with higher RD&D investment scenarios.

According to the IPCC SRREN report<sup>1</sup>, the projected production cost of biofuel 2020-2030 is expected to range from 0.2 to 1.02 \$/lge (shaded area in Figure 8). The IEA<sup>2</sup> projects that in 2030 production costs of second generation biofuels will be between 0.8 and 1.0 \$/lge. There is thus agreement at least in the high range of the IPCC and IEA projections. Under the current level of RD&D funding, only 4 experts provided a biofuel cost

<sup>1</sup> 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, 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.

<sup>2</sup> IEA – International Energy Agency, 2011. Technology roadmap: Biofuels for transport, Paris, OECD/IEA.

below 1.0 \$/lge; the number of experts increases to 7 under the 50% scenario and to 11 under the 100% scenario.

The majority of the experts provided the estimate of these expected costs of biofuel for a mix of technologies. Six experts, on the other hand, provided the estimates for a technology that they considered more promising. Specifically, experts 5, 8 and 12 in Figure 8 indicated cellulosic ethanol and experts 4, 6, 7 and 8 indicated gasification.

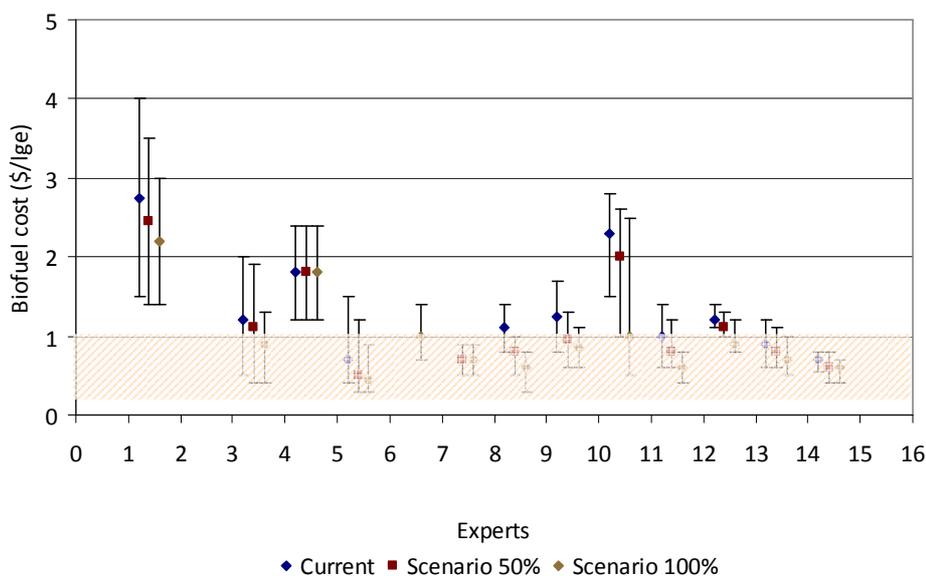


Figure 8: Estimates of the cost of litre of gasoline equivalent (lge) from biofuel technologies in 2030, under three different R&D funding scenarios. The shaded area represents the 2020-2030 projected production cost range as reported in the IPCC SRREN Report.

## Diffusion of biofuels

In the fourth section of the questionnaire, we asked the experts to indicate which geographical area of the world had the highest probability of being the first to reach commercial success. According to the experts' assessment the first area to reach the breakthrough in biofuel technologies would be the USA (as indicated by 9 experts), followed by countries within the European Union (6 experts), Brazil (3 experts) and China (1 expert).

The experts then considered how the dynamics of technology transfer between countries and regions of the world could affect the choice to support internal RD&D programs. The majority of the experts (12) 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 program in order to develop absorptive capacity and therefore to be ready to adopt breakthrough technologies developed by other countries.

### Negative externalities

Experts were asked to identify the potential negative externalities on the environment and society as a whole which might derive from the diffusion of

biofuel technologies. Many experts (9) expressed concern about the sustainability of biomass supply. With respect to biomass supply, the main issues that emerged are related to: the competition of land use for energy vs. food, equity issues between developed countries (that would import biomass) and developing countries (that would produce biomass), biodiversity conservation, water use and water pollution (due to the use of fertilizer for energy crops). However, the remaining five experts stated that these issues are much more relevant (if not only) for first generation biofuels and, therefore, they do not expect these externalities from second and third generation biofuels, whose primary feedstock should be residues. One expert pointed out that since biomass feedstocks are a limited resource, they should be used in the conversion technologies that maximize the reduction of greenhouse gases emissions. Therefore, they should be used in heat and electricity applications rather than for liquid biofuels. Finally, one expert observed that they do not expect great life-changing innovations coming from biofuels since 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 the emission of pollutants and traffic congestion. Only one expert provided some examples of positive externalities, such as agricultural and rural development and job creation.

### **Non-technical barriers to diffusion**

The last section of the questionnaire assessed the crucial role of market diffusion for the success of biofuel technologies and their competitiveness with fossil fuel energy technologies. Experts were asked to discuss and evaluate the importance of a set of potential barriers and then suggest other barriers they considered relevant. Figure 9 shows all the identified barriers and provides a ranking of their importance together with the suggested solution.

Almost all experts acknowledged that the most important barrier would be the competition for land for food vs. energy use, closely followed by the presence of environmental externalities. This is in line with what was highlighted upon discussing potential negative externalities. Policy interventions are by far the preferred way to overcome such barriers. In fact, during the interviews, certification systems were often recalled as a possible way of providing and tracing sustainable feedstock. A few of the experts also acknowledged that this issue is vast and regards primarily the eradication of poverty and the improvement of agricultural productivity. As ways to overcome this barrier, experts also suggested: the design of systems which co-produce feed and bioenergy feedstock from the same land, the design of a supply chain where feedstock supply and the conversion plant are connected, the provision of CO<sub>2</sub> biological sequestration on some land, and the design of conversion plants which allow for feedstock diversification.

Barriers related to economic and finance 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.

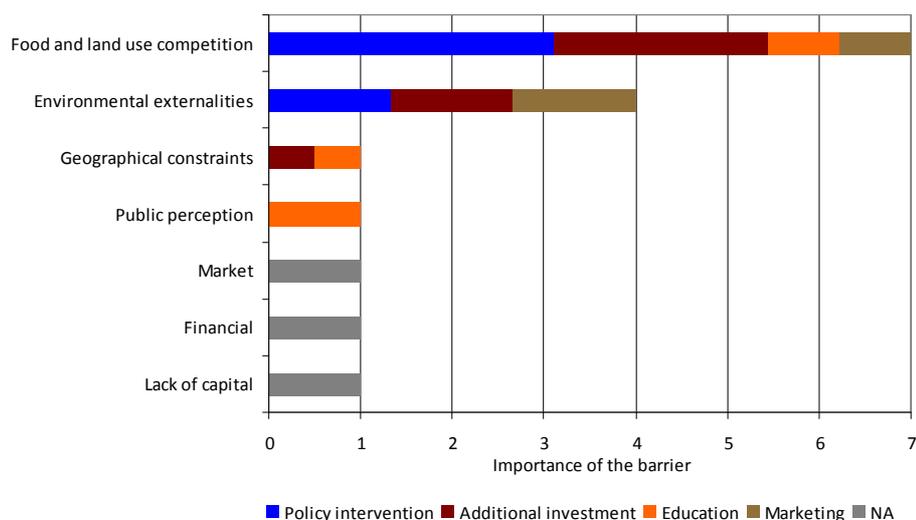


Figure 9: Factors which could represent non-technical barriers to the diffusion of biofuel technologies and potential solutions to overcome the barriers.

### Diffusion trends

Assuming that in 2030 biofuel technologies would be technically ready to compete with conventional fossil fuels, we asked the experts to provide a probability of three specific penetration rates of biofuels. Specifically, we asked the experts to provide the probability associated to three scenarios corresponding to three penetration rates (20, 50 and 70%) for vehicles in the private vehicle market, which run on biofuels. Moreover, we asked to distinguish between OECD, fast growing and developing country groups. There is a lot of variance among the answers provided by the experts. From the three graphs in Figure 10, the following patterns emerge: the 20% diffusion scenario is the one with the highest probability of occurring, the 50% scenario has a lower probability of occurring, and the 70% diffusion scenario has a very low probability associated to it. For OECD countries, the majority of experts assign highest probability to the lowest diffusion scenario (20%), even though there is one expert who is much more confident in the success of biofuel diffusion. For fast growing countries, the five experts who answered assign a probability of between 50 and 75% for the realisation of the lowest diffusion scenario (20%). In the case of developing countries, experts generally agree that the low diffusion scenario is the one with highest probability.

We also asked what experts thought could be the ceiling to the diffusion trend of biofuel technologies. On average, a 40% ceiling was indicated, but with very high variations among the experts who indicated figures such as 10% (1 expert), 25-35% (5 experts), 50% (3 experts) and 100% (1 expert). The remaining 3 experts did not respond to this question. This upper limit to biofuel contribution is due to limitations in feedstock availability. However, even the presence of other technologies (e.g., electric vehicles) and other conditions (e.g., a general decrease in the use of vehicles) will limit the diffusion of biofuels. One expert stated that biomass should be used where it allows for the greatest contribution to carbon mitigation, such as in the replacement of heavy oil and coal used for heat and electricity production.

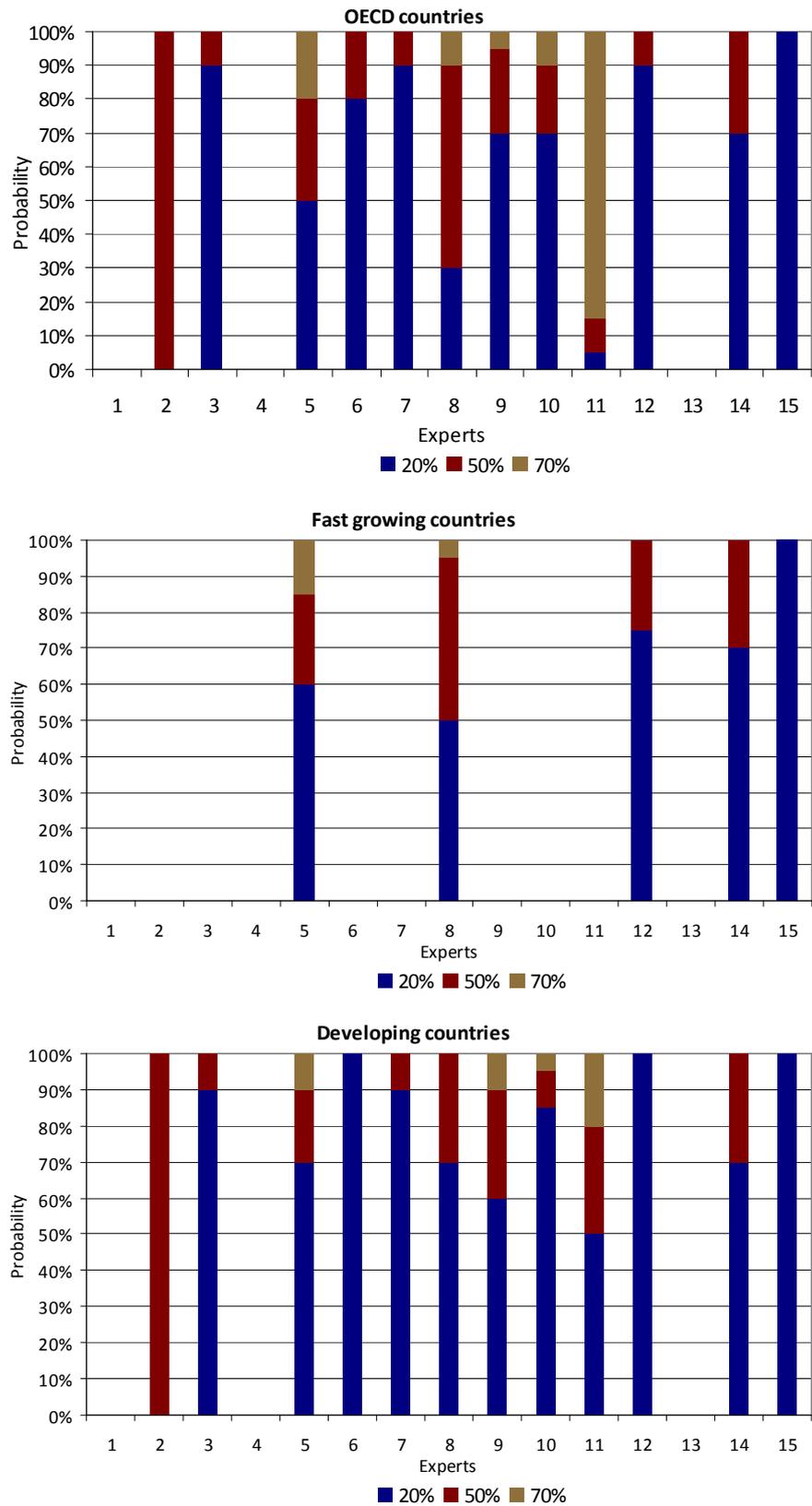


Figure 10: Probability of 3 different penetration rates for biofuel technologies in 2050 (OECD, fast growing and developing countries).