AN ASSESSMENT OF RESEARCH AND INDUSTRIAL NEEDS

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INTRODUCTION

The design and development of practical biomass conversion systems is complicated by the variability of chemico-physical properties, the huge number of chemical products, the interaction between chemical and physical processes and the need to control pollutants emissions. A comprehensive assessment about the actual scientific knowledge on thermochemical conversion processes is not available and the results achieved in one sector are unknown to the other despite the inter-relation.

Among the tasks of WP2F there is the collection of information about ongoing scientific research in biomass termochemical conversion and the assessment of industrial needs in this field. In order to achieve these objectives, a questionnaire has been prepared and distributed to researchers and idustries. The answers to each question have been collected and processed in order to produce statistical data representing research and industrial scenery. The framework of the questionnaire is outlined in paragraph "**APPLICATION FORM**". The main results are shown and discussed in paragraph "**RESULTS**", providing information about the technology of interest and the level of research ("***Technology and Level of Research***"), with details about the most important topics for each technology ("***Pyrolysis***", "***Gasification***", "***Combustion***"), according to scientists and industry, and funding sources ("***Funding***"). Finally, the most important results of the survey are summarized in paragraph "**CONCLUSIONS**".

APPLICATION FORM

As shown in Tables 1a-1d, the application form for scientists consists conceptually of four parts. In Table 1a general information is required about institution (name, address, contact person, phone and e-mail), technology (pyrolysis, gasification and combustion), level of research (fundamentals and laboratory experimentation, applied research and demonstration) and kind of funding (public and private). In Tables 1b, 1c and 1d scientists are asked about specific research topics in pyrolysis, gasification and combustion, respectively. Each topic represents a rather wide research area, thus scientists may provide further specifications.

The application form for industries (Table 2) consists of five sections. In the first, general information is required (Company name, address, contact person, phone and e-mail). In the following two sections they are asked to specify the technology of interest (pyrolysis, gasification

Scientist Information	Institution name, Institution address, Contact person(s), Contact's phone and e-mail
Technology	• Pyrolysis • Gasification • Combustion
Level of Research	• Fundamentals and laboratory experimentation • Applied research • Demonstration
Funding	• Public • Private

Table 1a. Application form for scientists – General information.

Specify (if appropriate)	
P1 Feedstocks	P10 Product upgrading
P2 Biomass components	P11 Biorefinery
P3 Pre-treatments	P12 Chemicals production/recovery
P4 Drying	P13 Natural or added catalysts
P5 Physical properties: feedstocks, char	P14 Dynamics of minor species: N, S, Cl, other
P6 Chemical kinetics	P15 Model development
P7 Carbonization Fast pyrolysis Co-pyrolysis Other	P16 Numerical simulation
P8 Plant optimization	P17 Economic aspects
P9 Chemical Characterization of liquid products	P18 Bio-oil combustion/gasification

Table 1b. Application form for scientists – Research topics about pyrolysis.

Specify (if appropriate)	
G1 Feedstocks	G10 Gas cleaning
G2 Pre-treatments	G11 Product upgrading
G3 Drying	G12 Natural or added catalysts
G4 Physical properties: feedstocks, char	G13 Dynamics of minor species: N, S, Cl, other
G5 Chemical kinetics	G14 Model development
G6 Fixed bed Fluidized bed Entrained bed Co-gasification Other	G15 Numerical simulation
G7 Plant optimization	G16 Economic aspects
G8 Char reactivity	G17 Life Cycle Assessment (LCA)
G9 Ash behaviour	G10 Gas cleaning

Table 1c. Application form for scientists – Research topics about gasification.

Specify (if appropriate)	
C1 Feedstocks	C10 Gas cleaning
C2 Pre-treatments	C11 Natural or added catalysts
C3 Drying	C12 Dynamics of minor species: N, S, Cl, other
C4 Physical properties: feedstocks, char	C13 Pollutants abatement
C5 Chemical kinetics	C14 Model development
C6 Fixed bed Fluidized bed Entrained bed Co-combustion Other	C15 Numerical simulation
C7 Plant optimization	C16 Economic aspects
C8 Char reactivity	C17 Life Cycle Assessment (LCA)
C9 Ash behaviour	

Table 1d. Application form for scientists – Research topics about combustion.

and combustion) and topics which need investigation. The last two sections are devoted to further suggested topics and specific issues. More than 200 questionnaires have been sent to well-known research groups and more than 50 to industries with expertise in the field of biomass thermochemical conversion processes by e-mails. Copies of the questionnaire have been also delivered through the ThermalNet newsletter. This has produced 41 forms filled in by scientists and 16 by industries.

Company Information	Company name, Company address, Contact person(s), Contact's phone and e-mail
Technology	Pyrolysis, Gasification, Combustion
Topics to be investigated	Feedstocks; Biomass components; Pre-treatments; Drying; Physical properties; Chemical kinetics; Carbonization; Fast pyrolysis; Co-pyrolysis; Fixed bed; Fluidized bed; Entrained bed; Co-gasification; Plant optimisation; Chemical characterization of liquid products; Char reactivity; Ash behaviour; Gas cleaning; Product upgrading; Chemicals production/recovery; Natural or added catalysts; Dynamics of minor species; Pollutants abatement; Model development; Numerical simulation; Economic aspects; Bio-oil combustion; Life Cycle Assessment
Suggested topics	
Specify issues to be investigated	

Table 2. Application form for industries.

RESULTS

Technology and Level of Research

The first question is about the thermochemical conversion technology. As shown in Fig.1a and Fig.1b, the percentage of interest for pyrolysis, gasification and combustion is of about 76, 83 and 66% for scientists and of about 31, 62 and 62% for industries, respectively. It is worth noting that percentages are evaluated with respect to the total number of questionnaires filled in. Results show that scientists are generally involved in two or all the three conversion technologies, in a larger extent with respect to industries (the sum of percentages is greater than 100 and higher for scientists than for industry). Moreover, the interest of scientists for the three conversion technologies is roughly the same (or slightly lower for combustion), whereas industrial research focuses more on gasification and combustion, rather than on pyrolysis.

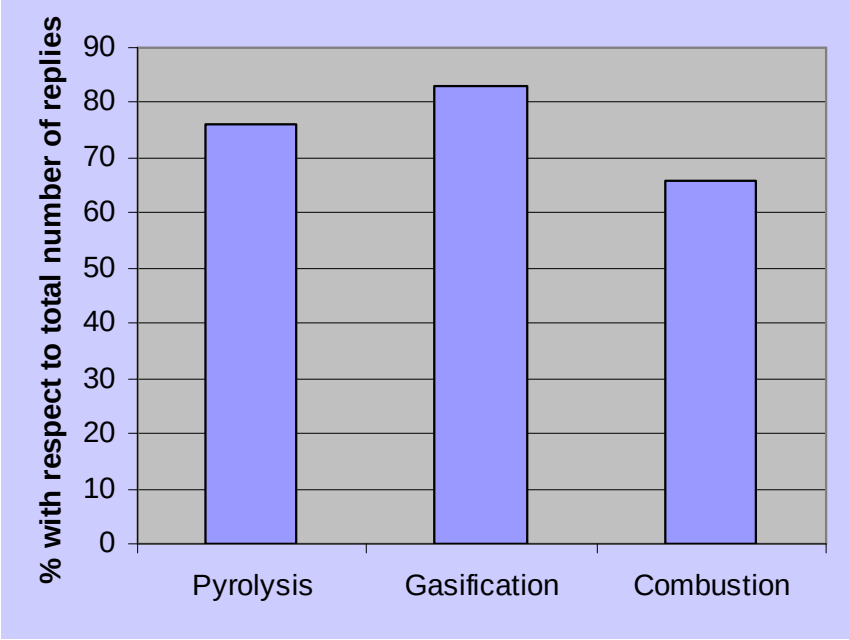

Fig.1a. Percentages of selection of each thermochemical conversion process (pyrolysis, gasification and combustion) with respect to the total number of replies of scientists.

With respect to each technology selected, scientists have been asked to provide information about the level of research ("Fundamentals and Laboratory Experimentation", "Applied Research" and "Demonstration"). Results (summarized in Fig.2) show that scientists are generally involved in two or all the three levels of research for all of the three conversion technologies (for each conversion technology the sum of percentages is again greater than 100). The main research areas for all the three technologies are "Fundamentals and Laboratory Experimentation" and "Applied Research", with percentages in the ranges 56-77% and 74-79%, respectively. Moreover, it is worth pointing out that research at "Demostration" level is roughly double for combustion with respect to

pyrolysis and gasification (percentages are 41, 19 and 24% for combustion, pyrolysis and gasification, respectively).

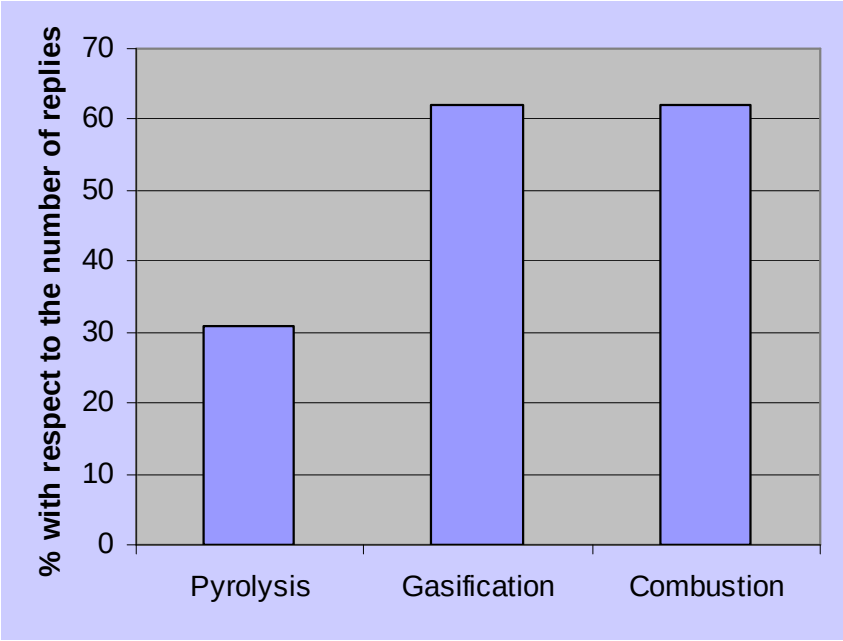

Fig.1b. Percentages of selection of each thermochemical conversion process (pyrolysis, gasification and combustion) with respect to the total number of replies of industries.

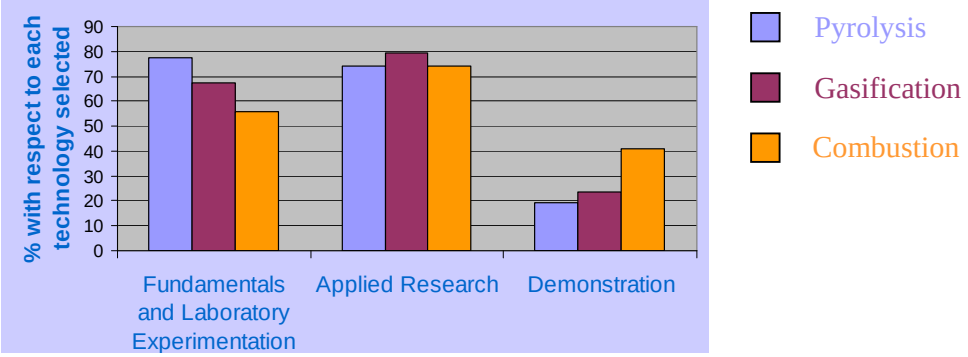

Fig.2. Percentages of selection of the level of research for each conversion technology according to scientists and industry.

Pyrolysis

For each technology selected, scientists have been also asked to select specific research topics and to provide, if appropriate, further information. In Figs.3a-3b the percentages of selection of each topic in pyrolysis (evaluated with respect to the number of scientists with research activities in thermochemical conversion process) are compared. Topics with percentages of selection larger than about 50% are “Feedstocks” (64%), “Chemical kinetics” (55%), ”Model development” (52%), “Fast pyrolysis” (52%), “Pre-treatments” (48%), “Numerical simulation” (48%) and “Product

Upgrading" (48%), and are further detailed below, with specifications given by the scientists. The percentage for "Physical properties" is of about 45%. This research topic include "feedstocks" and "char", selected by a percentage of 77% and 100%, respectively, with respect to scientists who select this topic.

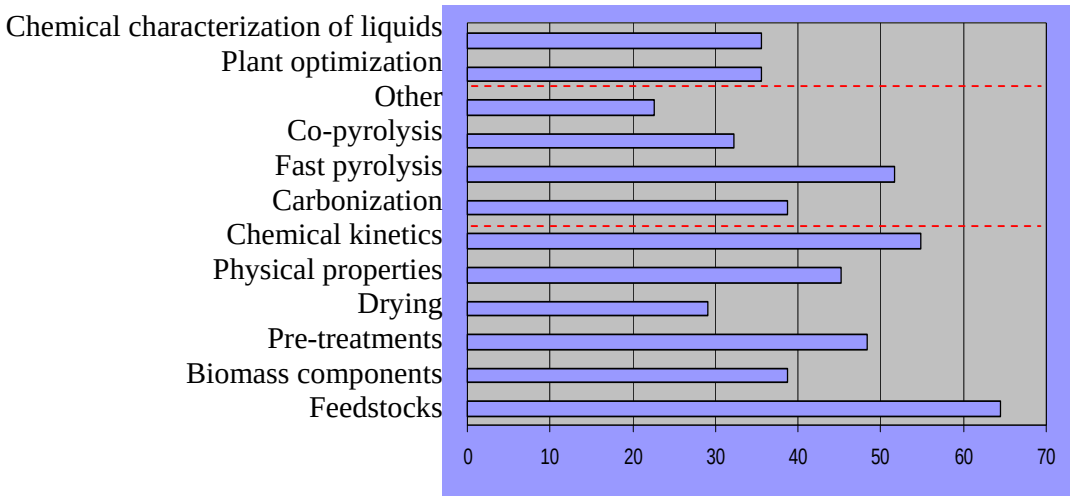

Fig.3a. Percentages of selection of research topics in pyrolysis.

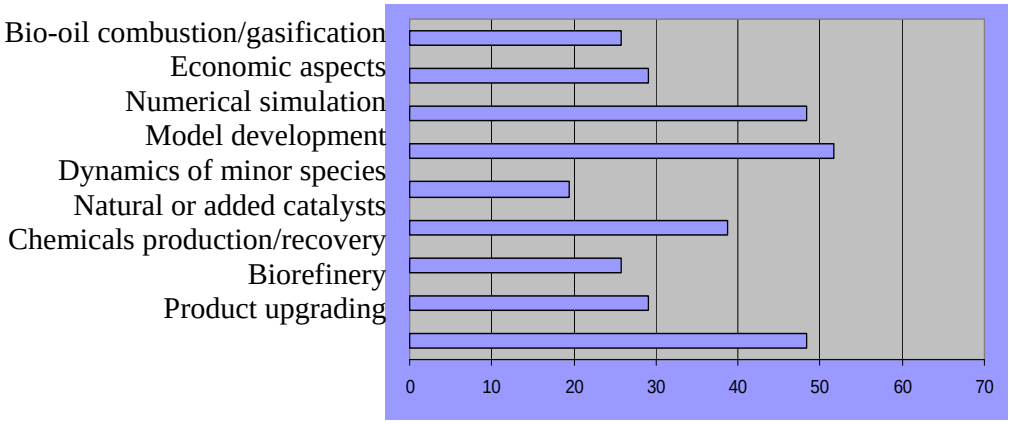

Fig.3b. Percentages of selection of research topics in pyrolysis.

Specifications about the research topic "Feedstocks" are provided by a percentage of 40% of scentists who select this topic, as shown in Fig.4a. Specifications, summarized in Fig.4b, regard the typology of biomass used as feedstocks. "Wood" is the most used biomass, with a percentage of 16%, followed by "Black liquor", "Agricultural residues", "Straw", "Waste" and "Any type of agricultural residues", with a percentage of (11%).

Specifications for the research topic "Chemical kinetics" are provided by a percentage of 24% of scientists who have selected this topic, as shown in Fig.5a. Specifications include typology of experimental apparatus ("TGA/DTG"), chemical species ("Influence of N-species in slow and

fast pyrolysis" and "Metal behaviour"), substratum ("Wood decomposition") and typology of chemical kinetics ("Kinetic schemes for biomass pyrolysis"). They are summarized in Fig.5b.

The topic "Model development" has been detailed by a percentage of 31% of scientists with activities on this topic, as shown in Fig.6a. Specifications are detailed in Fig.6b and refer to the features of the models ("Thermodynamic modelling", "Kinetic modelling" and "Biorefinery costs, in particular BTL and 2nd gen ethanol costs") or to physical system modelled ("Single particle", "Reactor" and "Different types of short residence time reactors"). "Single particle" and "Reactor" are the specifications with the largest percentages of selection (24%).

As shown in Fig.7a, a percentage of about 62% of scientists with research activities on "Fast pyrolysis" are also interested in other processes. Fig.7b shows that 50% of researchers with activities on "Fast pyrolysis" and other processes are interested in "Carbonization" or "Co-pyrolysis", whereas a percentage of 40% in other processes classified as "Other". Specifications for "Other" refer essentially to "Slow pyrolysis".

Specifications for the topic "Pre-treatments" are provided by a percentage of 47% of scientists with research activities on this topic, as shown in Fig.8. Specifications include mechanical, physical, thermal and chemical specifications, as detailed in Table 3. Percentages are not given because each specification is provided the same number of times.

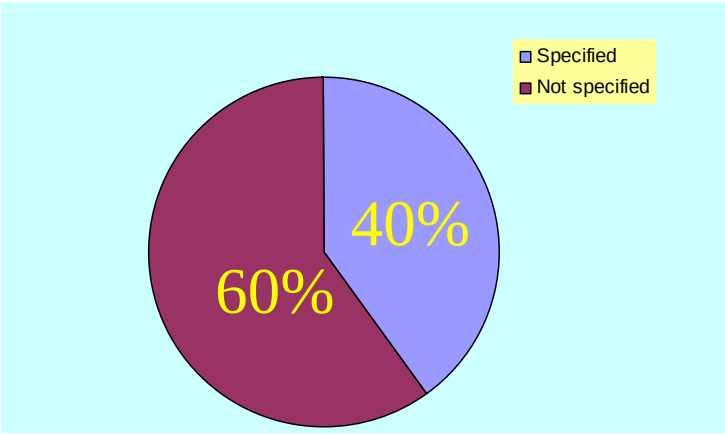

Fig. 4a. Percentages of scientists who select the topic "Feedstocks" and provide (blue colored sector) or do not provide (wine colored sector) further specifications, in the field of pyrolysis.

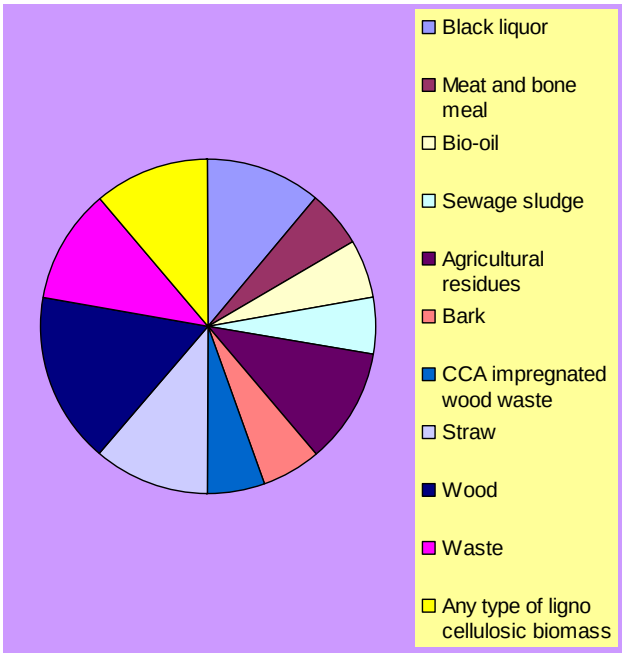

Fig.4b. Percentages of specifications provided for the research topic "Feedstocks" (percentages are evaluated with respect to the number of specified aspects), in the field of pyrolysis.

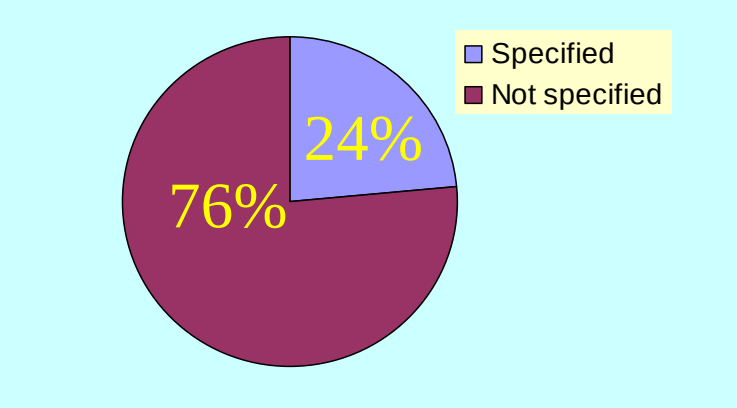

Fig.5a. Percentages of scientists who select the topic "Chemical kinetics" and provide (blue colored sector) or do not provide (wine colored sector) further specifications, in the field of pyrolysis.

Specifications for the topic "Product upgrading" are given by 43% of researchers with activities on this topic, as shown in Fig.10. Specifications, detailed in Table 5, show that the upgrading process refers to both char and bio-oil. "Hydrogenation of bio-oil" is the specification with the largest percentage of selection (25%, with respect to the total number of specification on this topic).

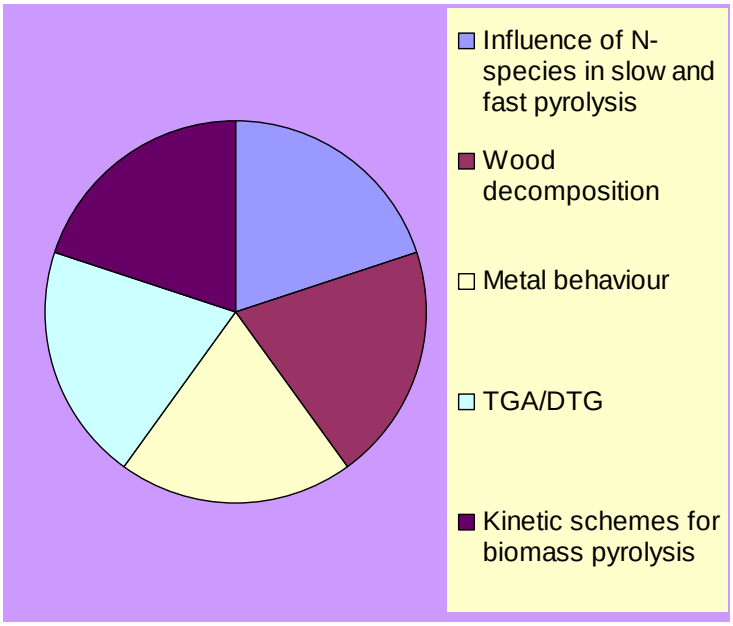

Fig.5b. Percentages of specifications provided for the research topic "Chemical kinetics" (percentages are evaluated with respect to the number of specified aspects) in the field of pyrolysis.

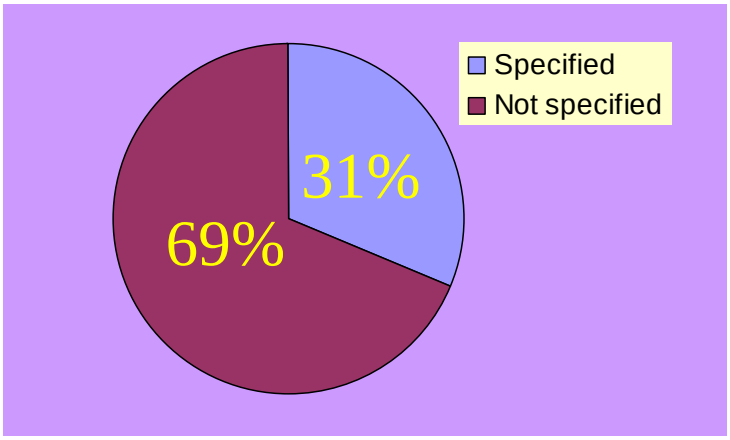

Fig.6a. Percentages of scientists who select the topic "Model development" and provide (blue colored sector) or do not provide (wine colored sector) further specifications in the field of pyrolysis.

The main topics suggested by industry as worth to be investigated in the field of pyrolysis are "Fast Pyrolysis", "Product upgrading", "Plant Optimization", "Economic Aspects", "Pre-treatments", "Chemical characterization of liquids" and "Bio-oil combustion/gasification". Figure 11 shows a comparison between the percentages of selection of these topics by industry and by scientists. It can be noticed that topics of interest for industry are only partially studied by scientists. In particular, the percentages of selection are roughly double for industry, apart from the topic "Pre-treatments", for which the percentages of selection are rather close (48% for scientists and 60% for industry).

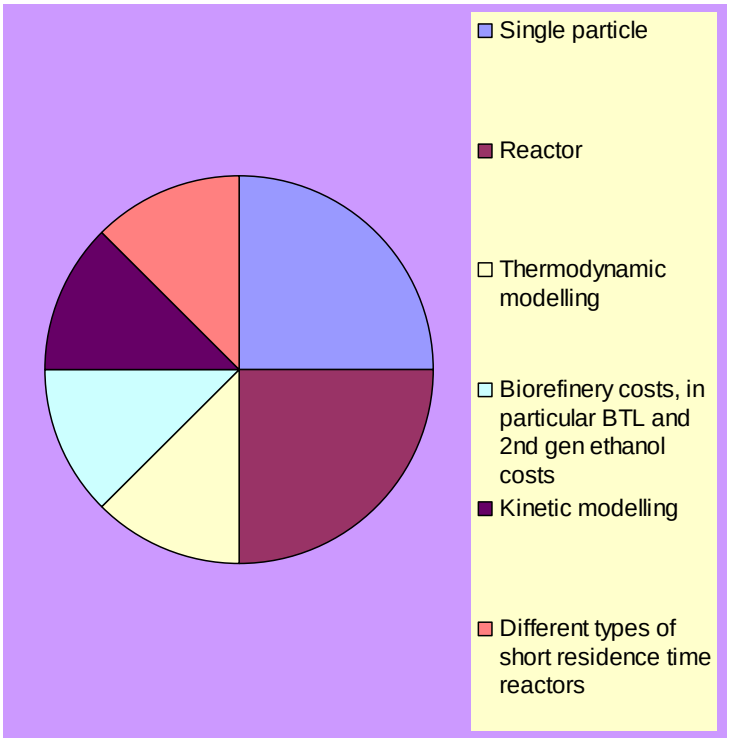

Fig.6b. Percentages of specifications provided for the research topic "Model development" (percentages are evaluated with respect to the number of specified aspects) in the field of pyrolysis.

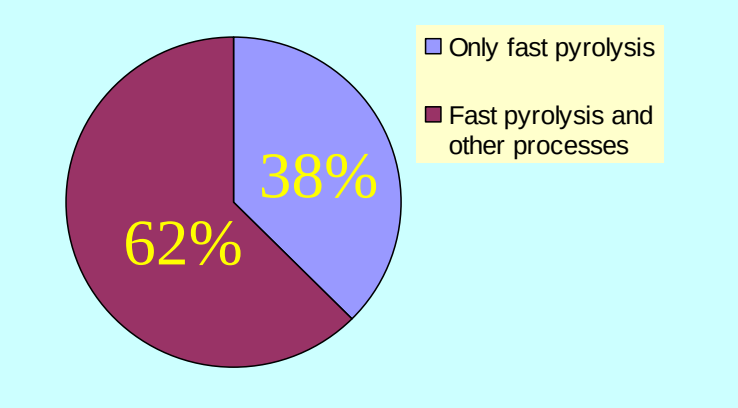

Fig.7a. Percentages of scientists with research activities on "Fast pyrolysis" and other processes (wine colored sector) and only "Fast Pyrolysis" (blue colored sector), in the field of pyrolysis.

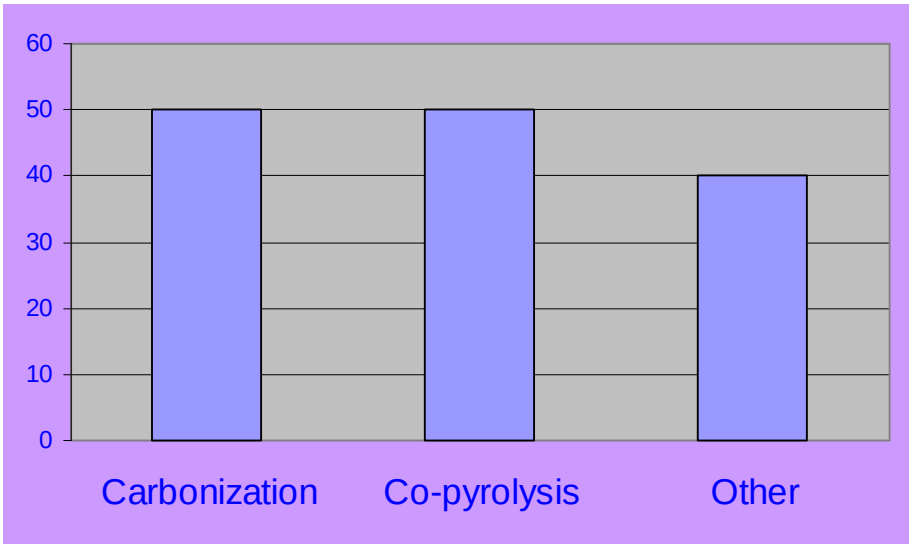

Fig.7b. Percentages of selection of other conversion processes among scientists with research activities on "Fast Pyrolysis" and other processes in the field of pyrolysis.

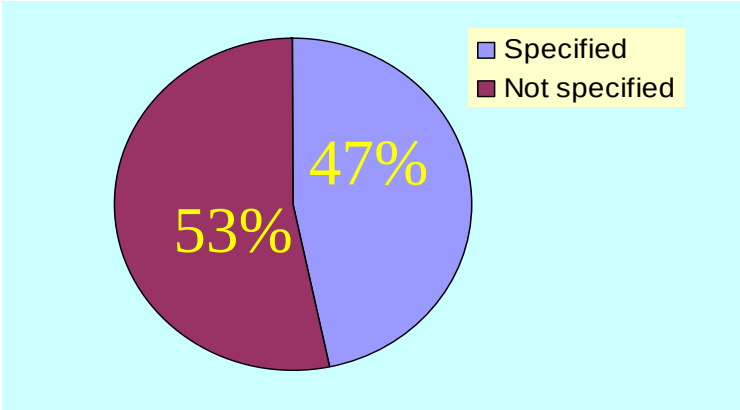

Fig.8. Percentages of scientists who select the topic "Pre-treatments" and provide (blue colored sector) or do not provide (wine colored sector) further specifications, in the field of pyrolysis.

Specifications
Densification technologies
Impregnation
Washing
Leaching
Impregnation with different inorganic catalysts
Energetical densificaton
Briquetting
Agglomeration
Comminution

Table 3. Specifications provided by scientists with research activities on "Pre-treatments" in the field of pyrolysis.

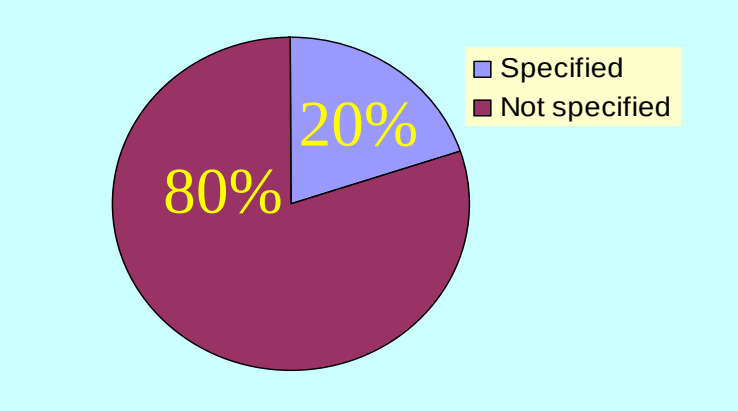

Fig.9. Percentages of scientists who select the topic "Numerical simulation" and provide (blue colored sector) or do not provide (wine colored sector) further specifications in the field of pyrolysis.

Specifications
Aspen Plus
Own code
Different types of short residence time reactors

Table 4. Specifications provided by scientists with research activities on "Numerical modelling" in the field of pyrolysis.

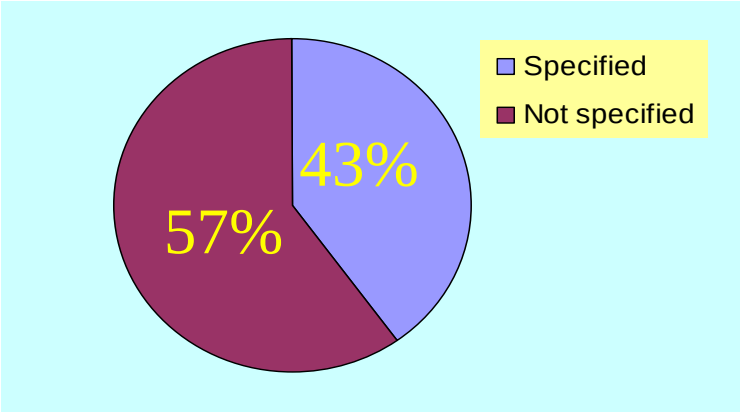

Fig.10. Percentages of scientists who select the topic "Product upgrading" and provide (blue colored sector) or do not provide (wine colored sector) further specifications, in the field of pyrolysis.

Specifications
In situ filtration of vapours
Hydrodeoxygenation of bio-oil
Fractionation
Separation of char in pure carbon and metals
Upgrading of bio-oils
Thermal stability and transformation of condensible vapours
Char dust briquetting and agglomeration

Table 5. Specifications provided by scientists with research activities on "Product upgrading", in the field of pyrolysis.

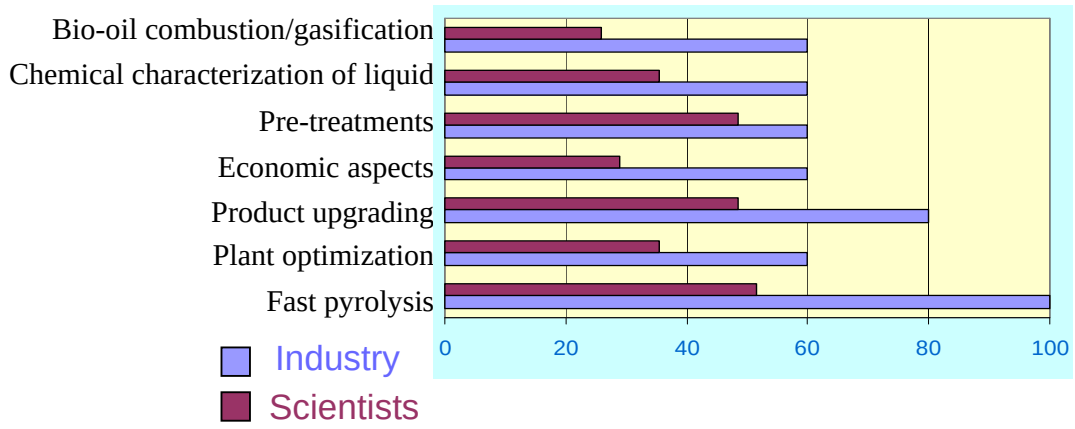

Fig.11. Comparison between percentages of selection of the main research topics suggested by industry, as evaluated by industry and by scientists, in the field of pyrolysis.

According to industry the following issues need to be investigated:

- Ablative pyrolysis.
- Change of product quality depending on type of feedstock pre-treatment. Economic aspects.
- Product treatments to achieve bio oil specification/composition as required for further utilization in conventional refineries. Economic aspects.
- Various feedstocks, physical oil upgrading, combustion in Diesel engine.
- ATEX requirements and legislative compliance for thermal processes.
- LCA of carbon sequestration potential of pyrolysis chars.
- Quick assessment of tars in producer gas that can be done in minutes onsite, not in a remote lab.

Gasification

In Figs.12a-12b the percentages of selection of each topic in gasification (evaluated with respect to the number of scientists with research activities in gasification) are compared. Topics with a percentage of selection of about 50% or larger are “Gas cleaning” (59%), “Model development” (59%), ”Fluidized bed” (53%), “Char reactivity” (50%), “Feedstocks” (47%) and “Numerical simulations” (47%). Further specifications provided by scientists on these topics are detailed below. Research activities on “Physical properties” (41%) include feedstocks and char, each one with a percentage of selection of 86% evaluated with respect to the number of scientists with activities on this topic.

Specifications for the topic “Gas cleaning” are provided by a pecentage of 25% of scientists with activities on this topic, as shown in Fig.13. The list of specified aspects is given in Table 6. It

includes details about the process, pollutants and procedure. “High temperature gas filtration” is the specification with the largest number of selections (22% with respect to the total number of specifications on this topic).

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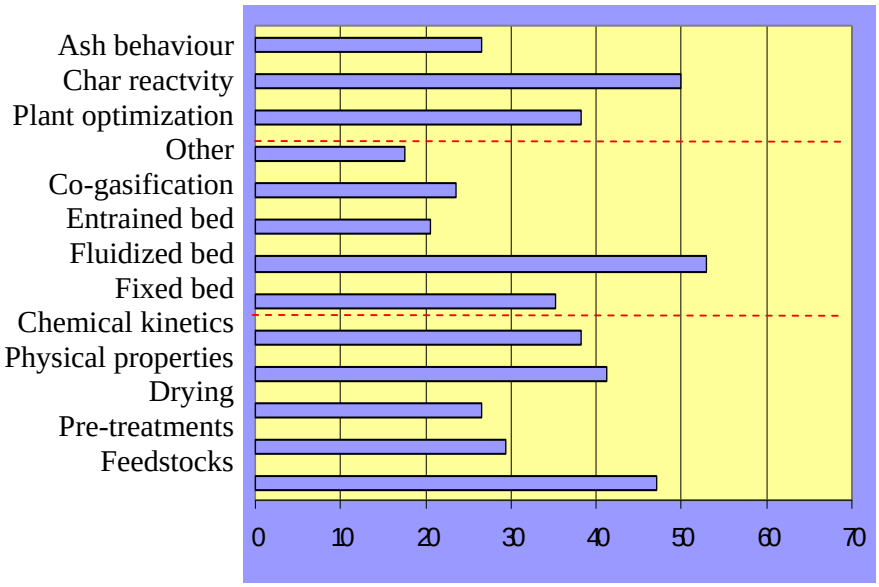

Fig.12a. Percentages of selection of research topics in gasification.

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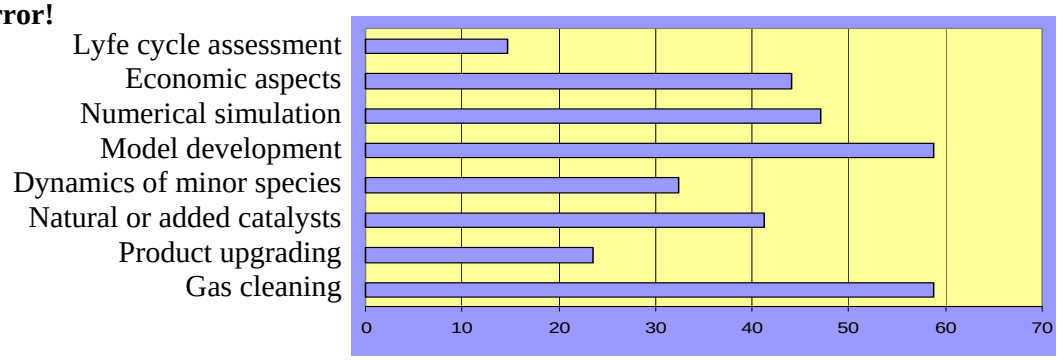

Fig.12b. Percentages of selection of research topics in gasification.

Specifications for “Model development” are given by 30% of scientists with research activities on this topic, as shown in Fig.14. Table 7 collects the specified aspects, which refer to the types of models, the typology of chemical reactor and to the features of code properties.

As shown in Fig.15a, a percentage of about 83% of scientists with research activities on “Fluidized bed” are also interested in other reactors/processes. Fig.15b shows that 47% of researchers with activities on “Fluidized bed” and other processes are interested in “Co-gasification”, 33% in “Fixed bed” and “Entrained bed”, whereas a percentage of 7% in other (not specified) processes.

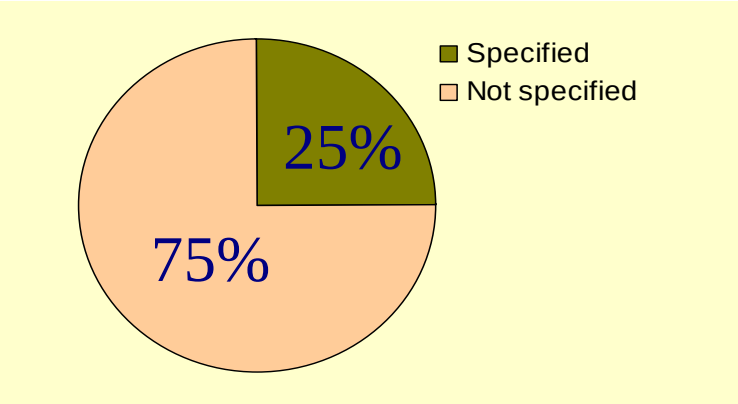

Fig.13. Percentages of scientists who select the topic "Gas cleaning" and provide (green sector) or do not provide (pink sector) further specifications, in the field of gasification.

Specifications
High temperature gas filtration
Cold gas cleaning
Developments on OLGA tar removal
Selection of catalytic processes
Sorbent selection/testing for S and Cl
Thermal cracking – methods of vapours traces analysis
Gas cleaning for syntesis reactors (Fischer-Tropsch and methanation)
Technology assessment for removal of particles and tars

Table 6. Specifications provided by scientists with research activities on "Gas cleaning" , in the field of gasification.

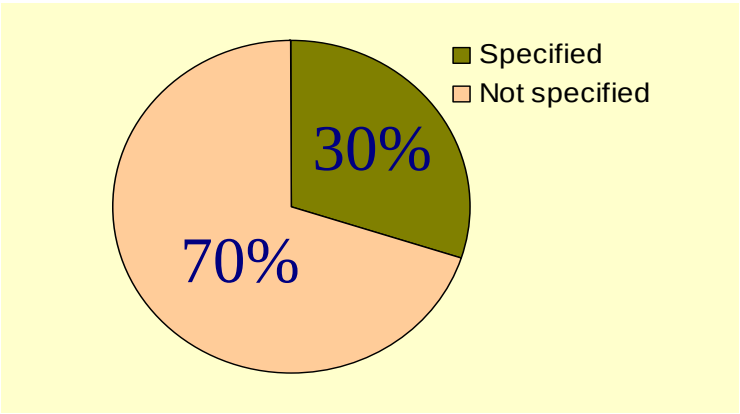

Fig.14. Percentages of scientists who select the topic "Model development" and provide (green sector) or do not provide (pink sector) further specifications, in the field of gasification.

Specifications
CFBG modeling
Atomization of a bio-oil into a plasma
Hydrothermal biomass gasification models
Kinetic modelling
Different types of short residence time reactors
Own made models
Research in connection with industry scale fluidized bed

Table 7. Specifications provided by scientists with research activities on "Model development" in the field of gasification.

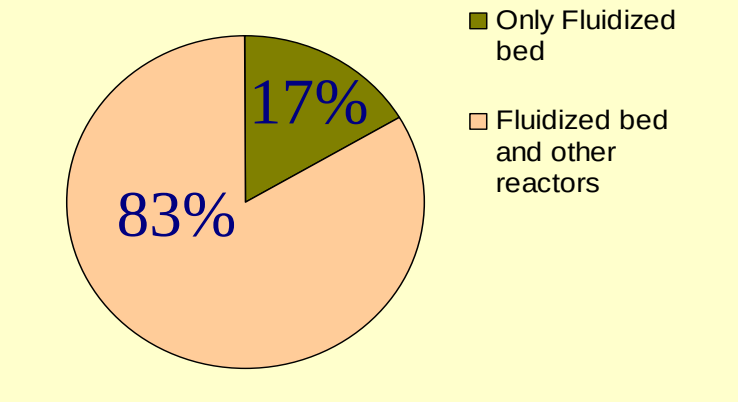

Fig. 15a. Percentages of scientists with research activities on "Fluidized bed" and other processes/reactors (pink sector) and only "Fluidized bed" (green sector) in the field of gasification.

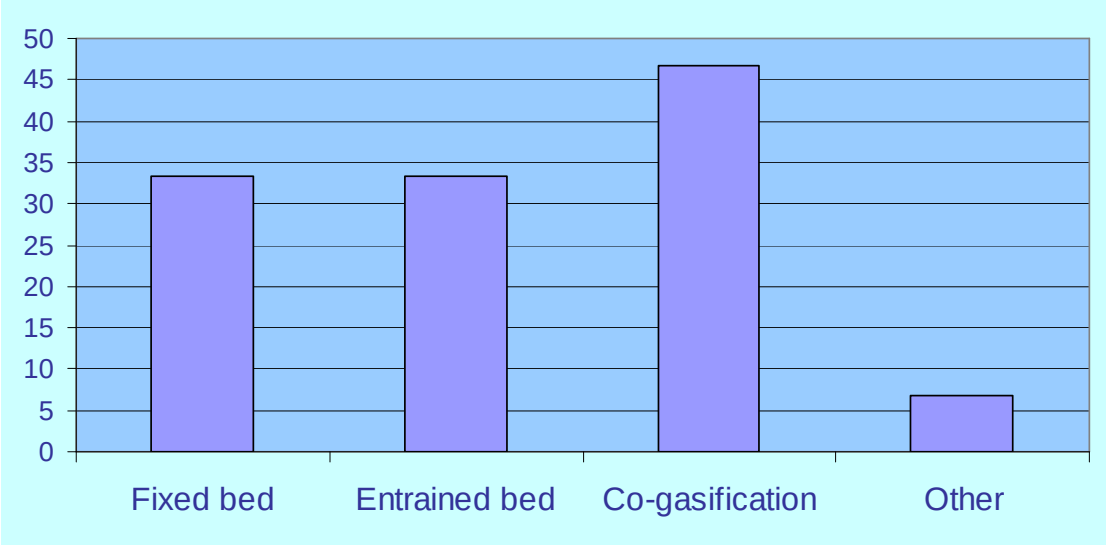

Fig.15b. Percentages of selection of other conversion processes/reactors with respect to "Fluidized bed" among scientists with research activities on "Fluidized bed" and other processes/reactors in the field of gasification.

Specifications for the topic "Char reactivity" are provided by a percentage of 12% of scientists with research activities in this field, as shown in Fig.16. Specifications refer only to the experimental apparatus, as detailed in Table 8.

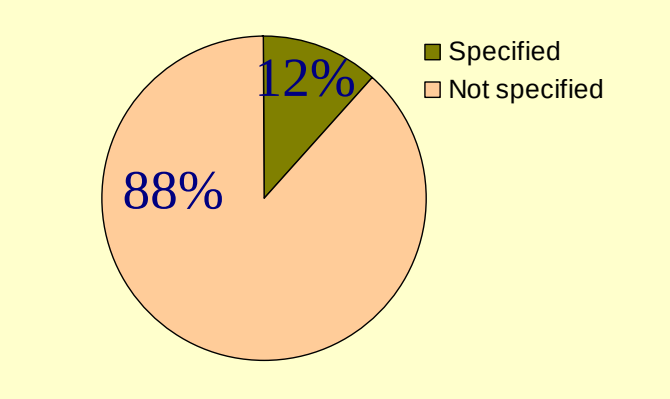

Fig.16. Percentages of scientists who select the topic "Char reactivity" and provide (green sector) or do not provide (pink sector) further specifications, in the field of gasification.

Specifications
TGA/DTG
Research in connection with industry scale fluidized bed

Table 8. Specifications provided by scientists with research activities on "Char reactivity" in the field of gasification.

A percentage of 44% of scientists with activities on "Feedstocks" specify this topic, as shown in Fig.17. Specifications, as detailed in Table 9, refer not only to the kind of biomass used, but also to other activities concerning the feedstocks, such as characterization and strategic aspects.

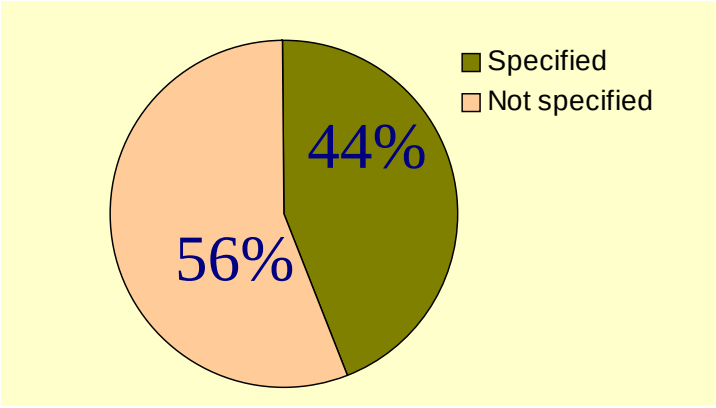

Fig.17. Percentages of scientists who select the topic "Feedstocks" and provide (green sector) or do not provide (pink sector) further specifications, in the field of gasification.

Specifications
Lignocellulosic biomass and residues
Wood
Sewage sludge
Meat and bone meal
Straw
Wet biomass with low ash content
Supply strategies
Physical and chemical characterization, ash analyses
Research in connection with industry scale fluidized bed

Table 9. Specifications provided by scientists with research activities on “Feedstocks” in the field of gasification.

Specifications for the topic “Numerical simulation”, as shown in Fig.18, are provided by a percentage of 24% of researchers with activities on this topic. Specifications are summarized in Table 10 and include details about the simulated chemical reactor and the numerical code used.

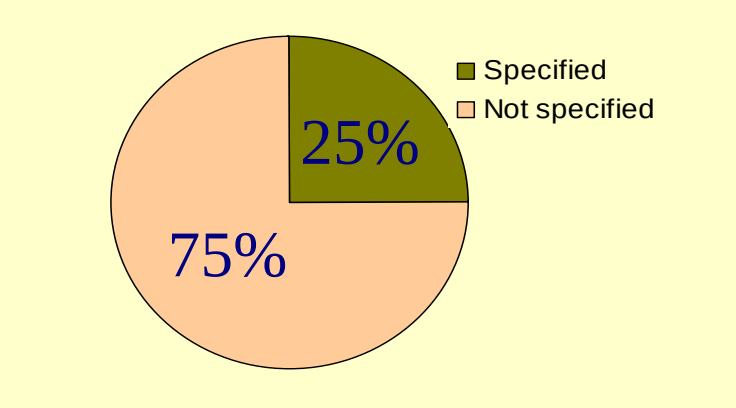

Fig.18. Percentages of scientists who select the topic “Numerical simulation” and provide (green sector) or do not provide (pink sector) further specifications, in the field of gasification.

Specifications
CFBG modeling
Aspen Plus
Formation in a plasma-aided gasifier
Continuous flow supercritical biomass gasification reactor
Different types of short residence time reactors
Research in connection with industry scale fluidized bed

Table 10. Specifications provided by scientists with research activities on “Numerical simulations" in the field of gasification.

The main topics suggested by industry worth to be investigated in the field of gasification are “Plant optimization”, “Gas cleaning”, “Fluidized bed”, “Economic aspects”, “Pre-treatments”

and “Product upgrading”. Fig.19 shows a comparison between the percentages of selection of these topics by industry and scientists. It is possible to remark that the difference between industrial needs and topics of interest for scientists is lower in gasification than in pyrolysis. However the topics “Plant optimization”, “Pre-treatments” and “Product upgrading” require further investigation by scientists (the percentages of selection are 70, 40 and 40% for industry and 38, 29 and 24% for scientists, respectively).

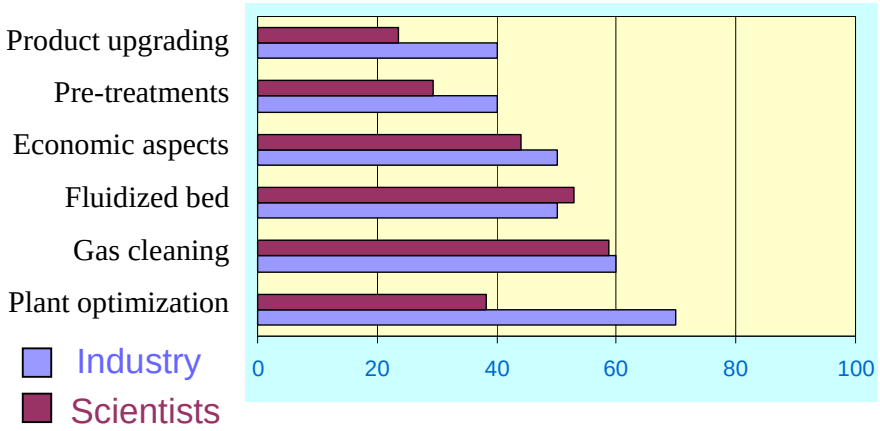

Fig.19. Comparison between percentages of selection of the main research topics suggested by industry, as evaluated by industry and by scientists in the field of gasification.

According to industry the following issues need to be investigated:

- Multistage gasification with external direct dryer, external pyrolysis, partial tar combustion and char gasification,
- Technical, environmental and health aspects of by-products: (i.e. ashes),
- Emissions,
- Ash behaviour and composition, fusion temperatures, bed agglomeration, etc.,
- ATEX requirements and legislative compliance for thermal processes,
- LCA of carbon sequestration potential of gasification chars,
- Gas/air mixing for gas engines running on producer gas – no good commercial suppliers of systems for gasification,
- Quick assessment of tars in producer gas that can be done in minutes onsite, not in a remote lab,
- Tar and char conversion using air and riched air, heat recover from syngas, clean minimazing liquid waste production, define economic aspects and LCA.

Combustion

In Figs.20a-20b the percentages of selection of each topic in combustion (evaluated with respect to the number of scientists with research activities in combustion) are compared. Topics with a percentage of selection of about 50% or larger are “Numerical simulations” (67%), “Model development” (63%), “Feedstocks” (59%), “Pollutants abatement” (56%), “Gas cleaning” (48%), and “Fixed bed” (48%). Further specifications provided by scientists on these topics are detailed below. Research activities on “Physical properties” (33%) include feedstocks and char, each one with a percentage of selection of 89%, evaluated with respect to the number of scientists with activities on this topic.

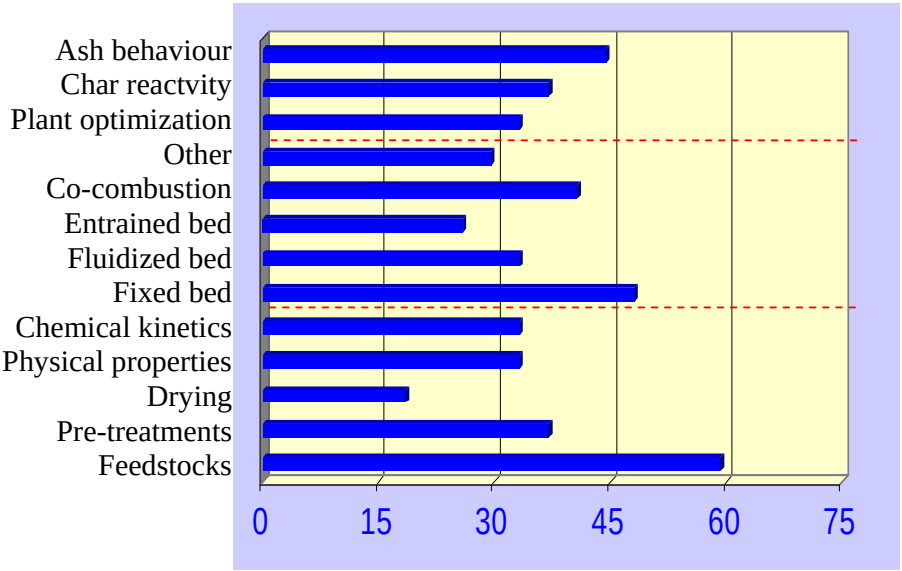

Fig.20a. Percentages of selection of research topics in combustion.

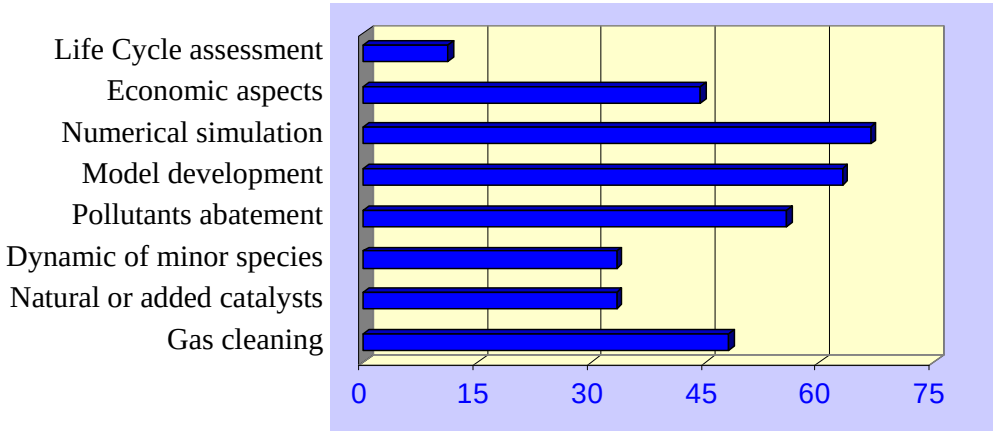

Fig.20b. Percentages of selection of research topics in combustion.

The topic “Numerical simulations” is specified by a percentage of 17% of researchers who select it, as shown in Fig.21. Specifications provide details about the simulated processes and are collected in Table 11.

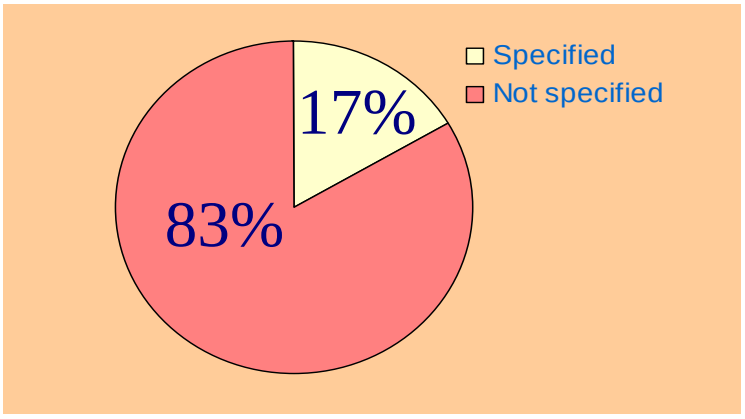

Fig.21. Percentages of scientists who select the topic “Numerical simulation” and provide (yellow sector) or do not provide (pink sector) further specifications in the field of combustion.

Specifications
Biofuel oxidation and turbulent combustion
Kinetic model and particle model
Optimization of combustion design by CFD modeling

Table 11. Specifications provided by scientists with research activities on “Numerical simulation” in the field of combustion.

Specifications for the topic “Model development” are provided by a percentage of 24% of scientists with activities on this topic, as shown in Fig.22a. Such specifications, summarized in Fig.22b, refer to the scale and the physical and chemical conditions of the system modelled. The largest number of specifications is for “kinetic models”, with a percentage of 44% (with respect to the total number of specified issues for this topic).

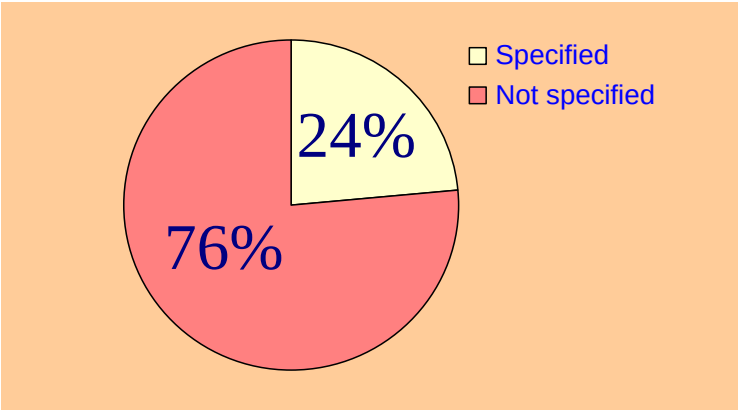

Fig.22a. Percentages of scientists who select the topic "Model development" and provide (yellow sector) or do not provide (pink sector) further specifications in the field of combustion.

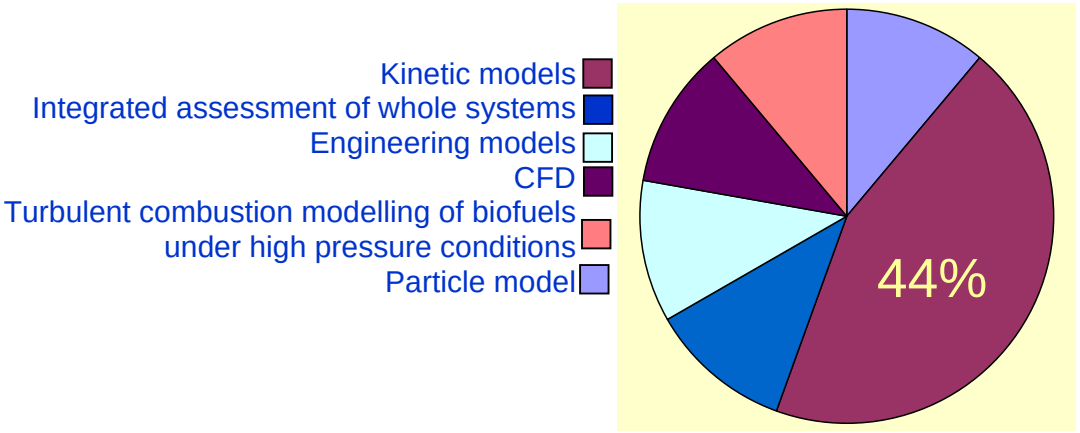

Fig.22b. Specifications provided for the topic "Model development" with corresponding percentages of selection (evaluated with respect to the total number of specified aspects for this topic) in the field of combustion.

A percentage of 31% of scientists with activities on "Feedstocks" specify this topic, as shown in Fig.23. Specifications, as detailed in Table 12, refer not only to the kind of biomass used, but also to other activities concerning the feedstocks, such as characterization and strategic aspects. "Wood" is the most specified topic, with a percentage of 22% (with respect to the number of specified aspects).

Specifications for the topic "Pollutants abatement" are provided by 47% of scientists with research activities on this topic, as shown in Fig.24a. Specified aspects are collected in Fig. 24b and include details about chemical species to be abated, experimental apparatus and abatement techniques. Topics with the largest degree of selection are "Nox", "CO" and "Primary measures" with percentages 29, 12 and 12%, respectively (with respect to the number of specified aspects).

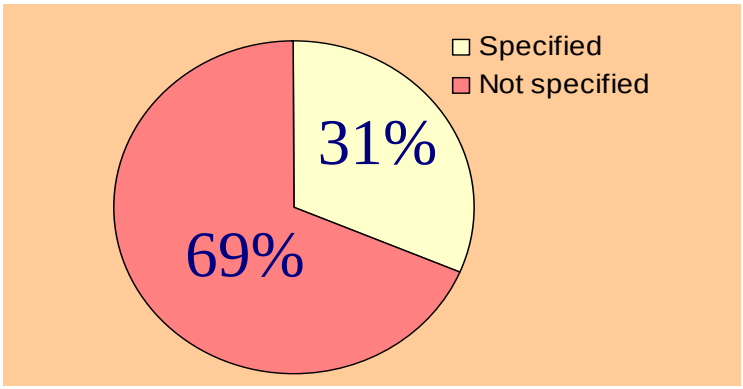

Fig.23. Percentages of scientists who select the topic "Feedstocks" and provide (yellow sector) or do not provide (pink sector) further specifications, in the field of combustion.

Specifications
Wood
Straw
Waste
Coal
Coke
Integrated assessment of whole systems
Physical and chemical characterization with ash analyses
Supply strategies

Table 12. Specifications provided by scientists with research activities on "Feedstocks" in the field of combustion.

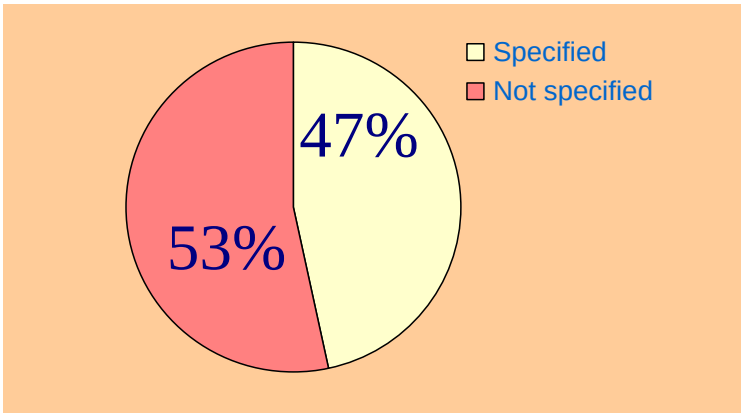

Fig.24a. Percentages of scientists who select the topic "Pollutants abatement" and provide (yellow sector) or do not provide (pink sector) further specifications in the field of combustion.

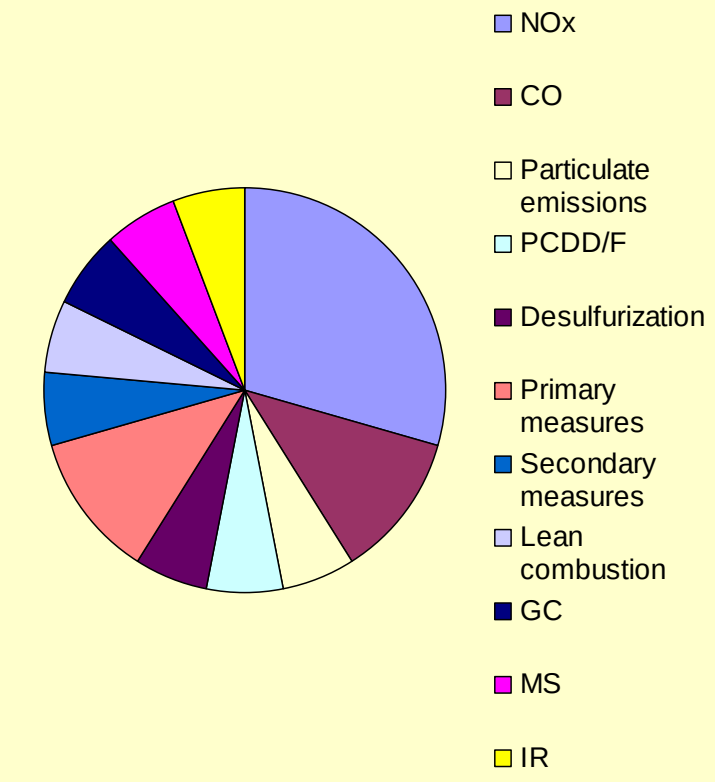

Fig.24b. Specifications provided for the topic "Pollutants abatement" with corresponding percentages of selection (evaluated with respect to the total number of specified aspects for this topic) in the field of combustion.

Only a percentage of 15% provide specifications for the topic "Gas cleaning", as shown in Fig.25. Specifications, detailed in Table 13, refer to cleaning techniques and to species to be removed.

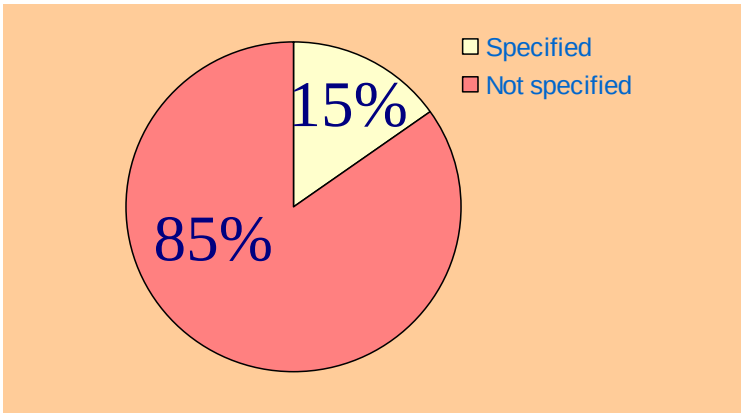

Fig.25. Percentages of scientists who select the topic "Gas cleaning" and provide (yellow sector) or do not provide (pink sector) further specifications in the field of combustion.

Specifications
Desulfurization
Catalyzed and non catalyzed NO reduction, fundamentals of SNCR and SCR
PM abatement: Fundamentals of particle characteristics and particle removal technologies

Table 13. Specifications provided by scientists with research activities on "Gas cleaning" , in the field of combustion.

As shown in Fig.26a, a percentage of about 85% of scientists with research activities on "Fixed bed" is also interested in other reactors/processes. Fig.26b shows that 73% of researchers with activities on "Fixed bed" and other processes are interested in "Co-combustion", 54% in "Fluidized bed", and 45% in "Entrained bed" and "Other" (not specified). It is worth noting that most of fixed bed reactors are grate furnaces.

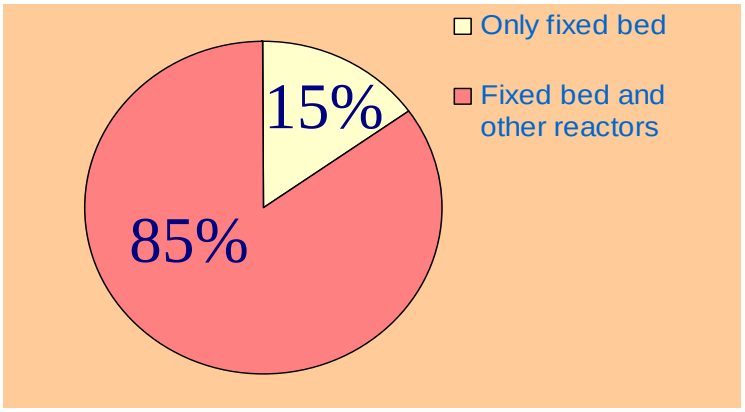

Fig. 26a. Percentages of scientists with research activities on "Fixed bed" and other processes/reactors (pink sector) and only "Fixed bed" (yellow sector) in the field of combustion.

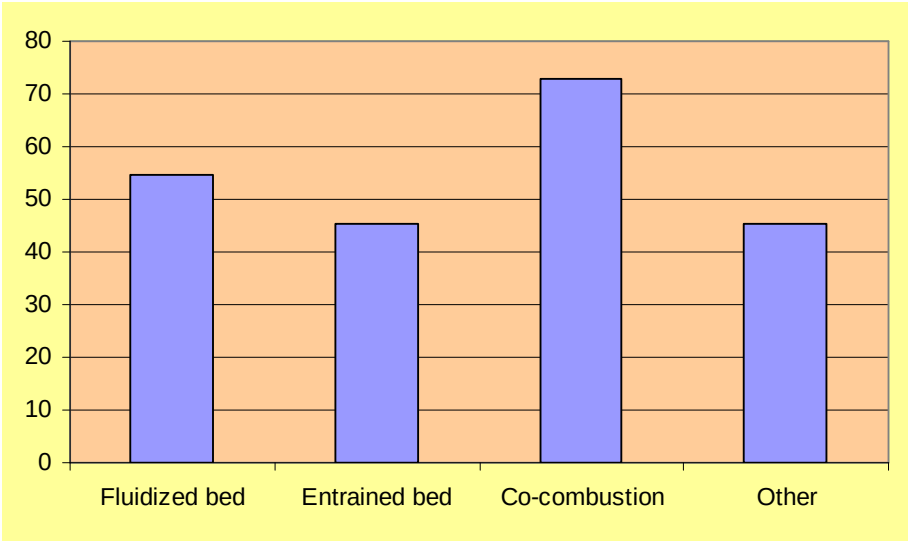

Fig.26b. Percentages of selection of other conversion processes/reactors with respect to fixed bed among scientists with research activities on "Fixed bed" and other processes/reactors in the field of combustion.

The main topics suggested by industry as worth to be investigated in the field of combustion are “Plant optimization”, “Gas cleaning”, “Fixed bed” and “Ash behaviour”. Fig.27 shows a comparison between the percentages of selection of these topics by industry and by scientists. It is possible to remark that some topics of interest for industry require further investigation by scientists, in particular “Plant optimization” and “Gas cleaning” (the percentages of selection are 90 and 70% for industry and 33 and 48% for scientists, respectively).

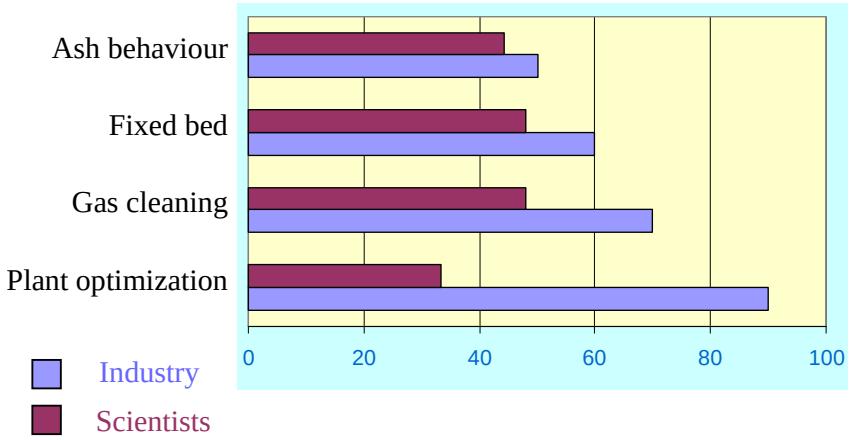

Fig.27. Comparison between percentages of selection of the main research topics suggested by industry, as evaluated by industry and by scientists, in the field of combustion.

According to industry the following issues need to be investigated:

- Emissions,
- Formation of particles in biomass combustion,
- Characterization of aerosols with respect to precipitation design optimization with modeling of flow dynamics and kinetics

  a) with respect to particle reduction

  b) with respect to Nox reduction
- Development and implementation of advanced control technologies, technical, environmental and health aspects of by-products: (i.e. ashes),
- Drying and milling of biomass,
- Advanced co-firing in large coal boilers,
- Biomass ash behaviour and mixed coal/biomass ash behaviour boiler tube,
- Corrosion due to co-firing,
- Combustion of the solid residues from biofuel production processes,
- Particulate matter analysis.

Funding

For each technology scientists have been asked if they have public or privete financing and in what percentage. As shown in Fig.28, a percentage between 10-15% do not answer to this question. Data provided, summarized in Fig.29, show that public funding prevails clearly over private funding. It is also possible to notice that private funding seems to favour gasification and combustion. In fact, for these technologies, the percentages of public funding is 24 and 23%, respectively, against 19% for pyrolysis.

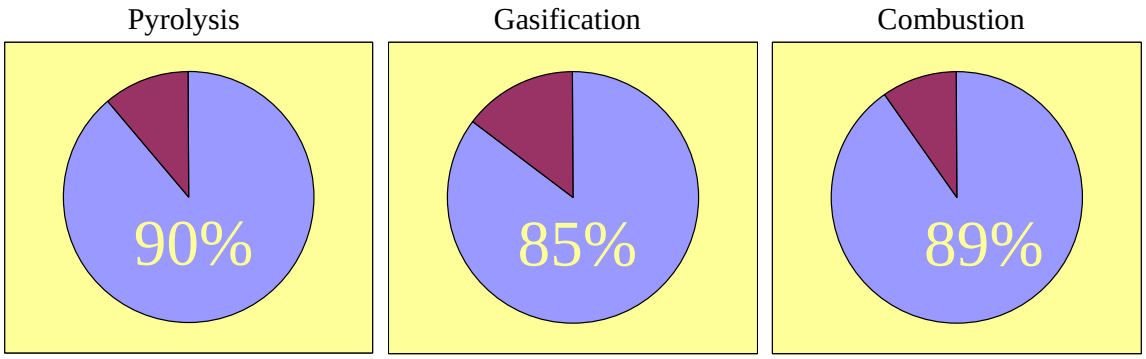

Fig.28. Sharing between useful answers (blue sectors) and data not provided (red sectors) to the question about funding for each technology.

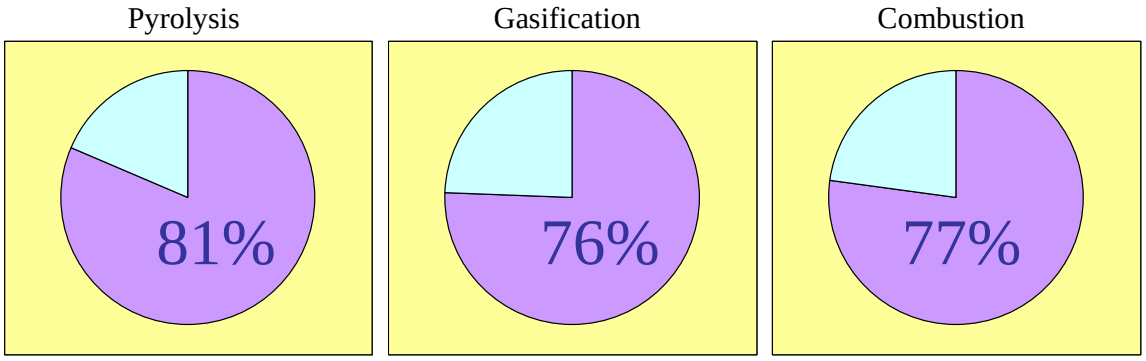

Fig.29. Sharing between public (violet sectors) and private (cyan sectors) funding for each technology.

CONCLUSIONS

- A questionnaire has been prepared and distributed to researchers and industries for the collection of information about ongoing research and the assessment of industrial needs.
- The interest of scientists for the three conversion technologies is roughly the same.
- The main research levels for all the three technologies are:

  a) Fundamentals and Laboratory Experimentation;

  b) Applied Research.
- Research at a demonstration level is larger for combustion with respect to pyrolysis and gasification.

- The principal research topics for pyrolysis are: “Feedstocks”, “Chemical kinetics”, “Model development”, “Fast pyrolysis”, “Pre-treatments”, “Numerical simulations” and “Product Upgrading”.
- The principal research topics for gasification are: “Gas cleaning”, “Model development”, “Fluidized bed”, “Char reactivity”, “Feedstocks” and “Numerical simulations”.
- The principal research topics for combustion are: “Numerical simulations”, “Model development”, “Feedstocks”, “Pollutants abatement”, “Gas cleaning” and “Fixed bed”.
- Most of research is funded by public financing.
- Private funds seem to favour the gasification and combustion technologies.
- Industrial research focuses more on gasification and combustion, rather than on pyrolysis.
- The following topics need to be further investigated by research groups:

  Pyrolysis: “Fast Pyrolysis”, “Product upgrading”, “Plant Optimization”, “Economic Aspects”, “Pre-treatments”, “Chemical characterization of liquids” and “Bio-oil combustion/gasification”.

  Gasification: “Plant optimization”, “Pre-treatments” and “Product upgrading”.

  Combustion: “Plant optimization” and “Gas cleaning

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CombNet/GasNet/PyNe

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