Mid-term evaluation

Title of the programme: **Potential of biomass for development of advanced materials and bio-based products**
Acronym of the programme: **NMP**

S4 priority area: **Networks for the transition to the circular economy**

Evaluator:

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General:
The present report will follow closely the guidelines given, as indicated before each section.

The evaluator's task is to evaluate the progress made by specific **Research and development programme (RRP)** with regard to the objectives outlined in the project proposal, objectives set by the call as well as the future prospects of the programme's results of the research activities. The Report should not be shorter than 6 pages and not longer than 10.

1. **Introduction:** basic data on the project and mid-term evaluation

   The original proposal and associated mid-term report of the project under discussion were provided about a month before the date of the evaluation, held in Ljubljana, May 7 and 8, 2019. This provided ample time to read the matter in sufficient detail before the meeting. The project deals with a well-integrated project to assess and exploit the possibilities of biomass leading to raw materials for advanced functional materials and bio-based products. This is an important and timely objective for which no further arguments have to be given here. The interrelationships of the various parts are nicely illustrated with a scheme showing their dependencies. The aim and goal of the project was also clearly explained in the introductory presentation.

   Initially the program consisted of 19 partners of which 10 industrial, but 7 others (of which 6 industrial) joined the program. This also lead to the expenditure of 283 fte (instead of the 206 fte as foreseen in 2016). Concurrently, 53 researchers were employed, as compared to the targeted 21. In the meantime 12 theses have been completed and a considerable number of publications was issued

   A few general remarks. The project proposal as provided is rather extensive and from the logics of constructions, one is easily distracted from the red line. This is probably a result of the guiding lines given to write a proposal for this program. As I am not informed about that, I will not address this issue further. However, the mid-term evaluation report remedies this to a large extent by being, generally speaking, concise and to-the-point. At a certain number of places, the comments in the report are

relatively general, but that, on its turn, has been remedied quite adequately with the presentations during the mid-term evaluation meeting.

2. **Assessment** of the progress made with regard to the objectives outlined in the project proposal of the programme and it's research and development projects:

2.1. **General observations** with regard to mid-term report and visit

The mid-term report is generally clear, but sometimes somewhat superficial. However, missing information was provided quite adequately during my visit and also afterwards answering the (small) list of remaining questions. The atmosphere during the visit was relaxed and clear answers were provided during the discussions. I also liked that, at a few occasions, researchers did not agree with each other in my presence, which I consider as sign of strength. It should also be said that at one or two places a clear indication was given that a certain line of inquiry was (is) stopped. This is also a good sign in my view, as this type of reports try to provide all too often that "everything is alright", which is, of course, hardly ever the case.

The overall connections between the various parts of the program are clearly indicated in the schematic structure as provided in the proposal. Not everything is connected to everything (as sometimes is claimed at these occasions) but an adequate connection exists between many parts while a few "dangling ends" get a clear input from the more connected parts.

More of a suggestion for future reports, reading would become easier if, after the summary of what has been done, directly the results and associated discussion would have been presented. This is likely a matter of instruction to the researchers. At the same point, a request for an overview of papers published and presentations given should be included in the instructions.

2.2. **Key highlights:** which achievements stand out in your opinion

For bio-based raw materials there are generally a few rather important issues that have to be addressed. First, availability and purity of the raw materials. Natural materials tend to have a relatively large variation in chemical composition, impurity content and morphology. As modern materials and products require typically high quality, meaning constant composition combined with high purity, the use of bio-based raw materials (co-)depends crucially on their quality. Second, bio-based raw materials are generally more polar as compared to their synthetic counterparts. This often lead to a more hydrophilic behaviour as is desired. Third, aromatic building blocks are typically less abundant and using less of them typically leads to lower glass transition temperatures. This, fourth on its turn, influences generally the mechanical properties in the sense of yielding a lower modulus, a lower hardness and larger deformability.

Therefore the action to set up a data base with the appropriate properties of available materials and an indication of the required specifications is highly relevant to make proper choices. Furthermore, as lignin could be turned to a valuable source for aromatic compounds, this aspect is highly appreciated. The results on the bio-fibre based materials, such as the reinforced polymer (PE) showing comparable properties as compared to glass-fibre while introducing excellent recyclability and the isolation materials, I also consider as excellent. Another aspect worth mentioning, is the overall process and energetic analysis. For viable exploitation of the processes involved such an analysis is imperative in my view in such an integrated project. It has led to (more

than) prototype drying and combustion equipment showing considerable energy savings.

2.3. **Changes:** if any changes were made to the project, do you assess them as reasonable and sufficiently well elaborated

The work on the sensors on paper was stopped. The reason for that were already given in the report but have been elaborated somewhat further in the response to list inquiries afterwards. The arguments given are solid: they are related to the intrinsic moisture sensitivity of cellulose products and the unavoidable variations humidity under application conditions. I think the decision is a proper one.

2.4. **Work plan** till the end of the project (comment how realistic is its implementation)

The remainder of the work to be done until the end of the project was not specifically addressed for each of the work packages. However, from the results obtained so far and the related discussions, my impression is that a fair fraction of the results promised in the project proposal will be really obtained. Most of the things still to be done flow naturally from what has been achieved so far. Hence, I do not expect serious "surprises" in the remainder of the project time that will influence the overall performance of the project.

3. **Role of the partners** in the project: your assessment

Possibly the most important aspect of partners in a complex project such as the one presently discussed is that the partners trust each other. Although this is difficult to assess during a (short two day) meeting, there are certain signs that are indicative for a positive assessment. One of the good signs is that the different researchers do not always agree with each other during such a meeting. This was certainly the case for this evaluation meeting. Another good sign is providing adequate response to questions asked without beating around the bush. Also this was here the case, as addressed already at another of the items discussed in this report.

4. **Internal** (between the project partners) **and external communication:** assessment on the basis of evidence provided during the visit (if none, this deserves to be mentioned as well)

With respect to external communication, the report lacked a list of papers published and presentations given, but these were provided together with the response on the list in inquiries afterwards. As far as the list of publications published is concerned, the overall impression is that the resulting presentations, both nationally and internationally, are quite adequately. The impression also exist that the number of publications in solid scientific journals could be a bit larger.

With respect to the internal communication between the partners, this seems overall to be good. As "evidence" I like to recall that upon a few questions where a researcher addressed was not directly able to provide an answer, another researcher came to answer the issue raised, often in a break somewhat later. This indicates in my opinion clearly that the researchers trust each other and thus communicate, with as result the above. My feeling is that this will be done also without my presence.

5. **Assessment of dissemination and exploitation** of the project results in the phase TRL7-9 (during the duration of the programme and in the period after the completion of the research activities)

This aspect is already partially addressed in the previous section with respect to dissemination of the results. The exploitation of results is more difficult to assess, as I am not really aware of the technological and/or economic scenery of Slovenia. In my view the life-time cycle analysis should be an important tool in a project like this. While such an analysis is probably more valued in an industrial environment, nevertheless, from a number of examples discussed during the meeting I have the impression that all participants realise the importance of this aspect, including not only the, obviously more economically aware, industrial participants but also the more scientifically oriented researchers.

6. **Assessment of quality of main scientific achievements** (scientific excellence in line with planned, any special success stories)

This section will give first a brief overview of the main results obtained in the various work packages. It will follow the order of addressing the results of the mid-term evaluation meeting. Many items were discussed in some technical detail, which I will not address here again. Thereafter one or two specific remarks will be made.

WP 1: *Valorization of biomass potential and development of bio-based products*
This package contains several sub-packages. The first deals with" Biomass potential assessment for developing added-value products" and essentially deals with a database containing all sorts of relevant information. I am not aware of other attempts to realize such a database and, although the information is obviously "local", it is, as already stated, in view of the variability and purity of bio-based raw materials, crucial.

The second sub-package discusses the "Conventional and deep eutectic solvent (DES) use for biomass decomposition and cellulose (fibre) production". As "freeing" cellulose from biomass is one of the basic issues that have to be solved, it is proper that attention is given to this aspect and that is not is relied solely on knowledge available elsewhere. The realization of high quality methacrylate monomers, essentially having the same properties as their petroleum-based counterparts, is convincingly shown.

"Nano-cellulose production" is the third sub-project. Here the use of ultrasound to accelerate the process is an interesting aspect, also delivering heat to the system that otherwise might have to be provided another way.

WP 2: *Development of advanced and multifunctional materials with integrated nanocellulose and environmentally acceptable additives*
Two sub-packages exist. The first sub-package handles the "Preparation and incorporation of existing and new bio-based compounds for reaching improved/new functionalities". The modification of nanoparticles is highly relevant, both for processing and for final properties of the resulting composites. I expressed doubts upon a realistic chance to modify gypsum by incorporating other ions (see the section Concluding Remarks and Recommendations).

The second sub-package is directed to "Advanced materials and products made from lignocellulosic fibres-paper, cardboard and yarn". Here some interesting and

promising, but sometimes unexpected and unexplained, results with respect to the mechanical properties of paper were obtained. It was decided to stop the incorporation of sensor elements in paper in view of the moisture dependence leading unavoidable to unreliable results due to the (varying levels of) moisture always present.

WP 3: *Products with higher proportion of bio-based components and improved functionalities for different industries*
Although formally divided again two sub-packages, actually the activities comprise a range of related activities all related to the development of functional biomass-based (nano) composites. Here some non-woven filter materials were developed, of which the mechanical integrity might be questionable. However, I think that options exist to improve that. Another highly interesting topic is the development of alternative and promising insulation materials. The development of miscanthus fibre-based PE composites with excellent properties and recyclability is still another.

WP 4: *Advanced processes in waste treatment for new added value products*
In this case the division of the package in two sub-packages is realistic. The first attempts the "Development of processes for biological and mechanical processing of solid waste". The raw material is sludge which is treated with enzymes to upgrade the material by, amongst others, to reduce the heavy metal content.

The second sub-package is the "Development of prototypes of products based on solid waste following the principle of circular economy". The goal is to incorporate as much as possible (upgraded) sludge into building materials, like bricks. The results obtained look rather promising and were discussed within a realistic perspective.
As a lot of water is used in the various process involved, a go-between between work package 4 and 5 is the re-use of waste in other industries.

WP 5: *Production of energy from waste with a high water content*
Again a main division in two sub-packages, which also in this case are highly interrelated. Formally the first addresses the "Development of technologies for energy recovery from refused material flows", while the second deals with the "Development of prototypes for energy recovery from refused material flows". A thorough analysis of the various processes involved was presented leading to a drying system as well as a combustion system which incorporated the ideas resulting from the models developed. The potential gain in energy consumption reduction is large.

Some remarks
Apart from the overall assessment given above, there are one or two topics that render a remark necessary. First, on the modification of the gypsum to try to increase the refractive index, possibly by incorporating other ions. During the visit this was briefly discussed and I expressed then that I am sceptic about the prospects for a sufficient increase in refractive index. I remain at that position: the crystallographic structure will allow only a limited exchange of ions (leading to small changes in refractive index) or to another crystallographic phase (with probably a quite different refractive index). An option based on morphology would be using hollow particles (so as to maximize the refractive index difference) but is typically not really simple and also expensive, meanwhile leading to more fragile particles.

Second, the use of lignin as a possible source of aromatics seems to be a rather good opportunity to provide a somewhat wider diversity of aromatics from bio-based sources. It seems profitable to evaluate these possibilities a bit further.

7. **Cooperation** between public and private partners (assessment of synergies)

Overall, there is a nice balance in cooperation between public and private partners. This statement based on the contributions of the various partners as presented in the report as well during my visit. This cooperation also seems to be of a rather open nature, as occasionally during the meeting also the researchers started arguing about certain aspects.

8. **Concluding remarks and recommendations**

First of all, I should remark, as has been done during the mid-term evaluation meeting that the atmosphere during the presentations and subsequent discussions were open, pleasant, with answers given to question without evasive moves. I say this because this is not always the case during an evaluation as the one we are discussing. Second, a number of questions were posed after the discussions of the individual sub-projects during a general discussion at the end of the meeting. Also they were adequately addressed, for those questions where a representative could answer the questions, as a number of researchers had other obligations that day. The remainder of the question was repeated in a short questionnaire mailed to the organisers afterwards and rapidly answered in a mail within a few days. Also the powerpoint presentations and the full publication list (which for some reason or another was not provided in the report, most likely because the questions was not asked) was provided in that mail. This all implies that all responses were quickly and professionally provided, answering essentially all questions asked. I also have say that remarks made on my of mode of “interrogation” were pleasant to hear and appreciated.

Having said all this, there are few point that can be mentioned in a summary containing final recommendations and remarks. These are listed below in a bullet list in arbitrary order:

- In my view the possibilities of lignin to provide a wider range of aromatic compounds based on bio-based raw materials deserves further attention. One of the general problems of bio-based raw materials is the range of aromatic compounds that are provided. As they are an essential part of the modern application of polymer materials, a change towards bio-based materials providing a wider range of aromatics that can be realised is imperative can only really succeed if such compounds become available.
- Titania, or titanium oxide (in the rutile as well as anatase crystallographic form) is an almost indispensable compound for many applications. This not applies to white paints but also to tainted paints as they generally also contains a large amount of titania. Moreover, this material is also used in many other products, such as cosmetics and sun tan preventing and many other products. With present concerns and (either already installed or coming) European legislation the use of this material will be highly restricted, if not completely forbidden. Technically speaking this (most probably) will be an impossible task, but nevertheless many applications probably will allow alternatives, if not even just to avoid legal

problems and/or image building. This warrants the search for alternatives, both from an ecological as well as economical point of view. The program part dealing with issues is highly appreciated but solutions sought in the directions of modifying gypsum by incorporating other ions most likely will not lead seems to viable solution. The main problem is that the change in refractive index required is really large and is likely not to be reached with ionic substitution. Other approaches may be pursued, however, one of which is the realisation of hollow particles, so as to maximise the refractive index difference. I realise that this is a not only a difficult route, almost certainly leading to more complex technology, but it is, in my view, a more promising route.

- The life-time cycle analysis of the processes involved is a most valuable part of the whole project. It is realised, by the presenter during the meeting as well as by me, that such an analysis could be easily result in GIGO (Garbage In, Garbage Out) results, but that for a proper assessment of alternative and/or modified processes, such an analysis carried using the best knowledge available to all participants of the project is crucial for an honest appraisal of the process at stake. Therefore, as the results of the life-time cycle analysis in the report are somewhat scattered, although very clearly and honestly addressed by the presenter during the meeting, some more effort to this project is warranted. This is all the more important as the project as a whole is substantial and with, although seen as an advantage as indicated, several crucial interconnections that will influence the overall or total result.
- As an overall conclusion, I would to say that I think that the present project is well on its way with realistic prospects for incorporating (some of the) results in actual materials and processes. This is largely due to the well thought-over project proposal, as summarized in the scheme mentioned before, leading overall to integrated activities with realistic expectations about the results.