Unclassified **ENV/JM/MONO(2013)17**

Organisation de Coopération et de Développement Économiques
Organisation for Economic Co-operation and Development **06-Aug-2013**

English - Or. English

ENVIRONMENT DIRECTORATE
JOINT MEETING OF THE CHEMICALS COMMITTEE AND
THE WORKING PARTY ON CHEMICALS, PESTICIDES AND BIOTECHNOLOGY

ENV/JM/MONO(2013)17
Unclassified

ENVIRONMENTALLY SUSTAINABLE USE OF MANUFACTURED NANOMATERIALS
Workshop held on 14 September 2011 in Rome, Italy

Series on the Safety of Manufactured Nanomaterials
No. 39

JT03343364

English - Or. English

OECD Environment, Health and Safety Publications

Series on the Safety of Manufactured Nanomaterials

No. 39

Environmentally Sustainable Use of Manufactured Nanomaterials - Workshop held on 14 September 2011 in Rome, Italy

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ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

Paris, 2013

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FOREWORD

As part of its Programme on the Safety of Manufactured Nanomaterials, OECD held a workshop on the *Environmentally Sustainable Use of Manufactured Nanomaterials*. This event took place on 14 September 2011 in Rome, Italy. It was hosted by the Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA)

The objective of this event was to initiate an international dialogue between the OECD Working Party on Manufactured Nanomaterials (WPMN) and experts from the scientific, policy and regulated communities with experience in Life Cycle Assessment (LCA). Many of the experts have had experience with nanomaterials in the field of life-cycle aspects of manufactured nanomaterials, through the analysis of the potential positive and negative impacts on the environment and human health of nano-enabled applications at different stages of their use and development.

This document presents the report of the Workshop, which includes a number of conclusions relevant for current and future OECD activities, especially those focused on (LCA) and nanomaterials; including: i) basic structure and characteristics of LCA; ii) LCA application to nanomaterials at the research, scale-up, regulation and market level; as well as iii) on nanomaterials data availability, reliability, comparability and its generation.

This document is being published under the responsibility of the Joint Meeting of the Chemicals Committee and the Working Party on Chemicals, Pesticides and Biotechnology, which has agreed that it be declassified and made available to the public. It is presented in two parts: i) the main body of the report [ENV/JM/MONO(2013)17]; and ii) an addendum [ENV/JM/MONO(2013)17/ADD] which includes the programme of the workshop (Annex I), the presentations (Annex II) as well as the list of participants (Annex III).

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EXECUTIVE SUMMARY

As part of its Programme on the Safety of Manufactured Nanomaterials, OECD held a workshop on the **Environmentally Sustainable Use of Manufactured Nanomaterials**. This event took place on 14 September 2011 in Rome, Italy.

The objective of this event was to improve the international dialogue between the OECD Working Party on Manufactured Nanomaterials (WPMN) and the scientific, policy, and regulated communities with a focus on LCA experts having experience with nanomaterials in the field of life-cycle aspects of manufactured nanomaterials, through the analysis of the potential positive and negative impacts on the environment and health of nano-enabled applications at different stages of development. This document presents the report of the Workshop, which includes a number of conclusions relevant for ongoing and future OECD activities, especially those focused on Life Cycle Assessment (LCA) and nanomaterials; including: i) basic structure and characteristics of LCA; ii) LCA application to nanomaterials at the research, scale-up, regulation and market level; as well as iii) on nanomaterials data availability, reliability, comparability and its generation.

The main overall conclusions are as follows:

(a) Life cycle analysis (LCA) is an important tool and framework to evaluate the negative and positive environmental implications of a product, process or technology. It can also be employed to evaluate the impacts of nanomaterials. However, nano-LCA must be applied thoughtfully, taking into account particularities of the specific nano-enabled application in order to provide answers that will be useful to decision-makers.

(b) It is key to establish linkages between LCA and risk assessment to provide decision-makers with the full picture of negative and positive implications and because any LCA working group will need risk assessment information to complete an LCA. As there is no concept of a functional unit in risk assessment, such linkages can only be established if both LCA practitioners and risk assessors share the LCA objectives or problem formulation and iterative results with each other.

(c) In line with other nano-LCA workgroups, the ISO 14040/44 framework is a suitably harmonised and validated framework applicable to nanomaterials and nanotechnology.

ENVIRONMENTALLY SUSTAINABLE USE OF MANUFACTURED NANOMATERIALS

Background and Objectives

1. The workshop on the Environmentally Sustainable Use of Manufactured Nanomaterials addressed potential positive and negative impact on human health and the environment of certain nano-enabled applications at different stages of development. Hence, its basic objective was to further improve the international scientific dialogue in the field of life-cycle aspects of manufactured nanomaterials through, the analysis of nanomaterials based on their potential positive and negative impacts on human health and the environment. This was in line with the scope of the OECD Programme of Work on the Safety of Manufactured Nanomaterials, in particular, its work focused on the environmentally sustainable use of manufactured nanomaterials.

Introduction

2. The OECD Workshop on Environmentally Sustainable Use of Manufactured Nanomaterials was hosted by the Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA), and took place on 14th September 2011 at ENEA headquarters in Rome, Italy.

The Workshop was chaired by Achim Boenke (EC) and Kristan Markey (US). There were twenty four participants from OECD member countries, as well as participants from the scientific community, industry, regulators, and experts in LCA and nanomaterials, and the OECD Secretariat.

Presentations and Discussions

Session 1: General Presentations on Environmentally Sustainable Use of Manufactured Nanomaterials: Setting the Scene

3. Following the welcoming address by Giovanni Lelli, Commissioner of ENEA, this workshop started with general presentations which set the scene for the discussion on the importance of assessing positive and negative impacts of nano-enabled applications and addressing the Life Cycle Analysis of manufactured nanomaterials.

4. Participants were updated on current activities within the OECD related to LCA, especially work undertaken by the OECD Working Party on Manufactured Nanomaterials (WPMN)[1], which followed the conclusions reached at the OECD Conference on the "Potential Environmental Benefits for Nanotechnology: Fostering Safe, Innovation-Led Growth" (July 2009 – see Conference Background Paper on http://www.oecd.org/env/chemicalsafetyandbiosafety/safetyofmanufacturednanomaterials/43284399.pdf)

[1] http://www.oecd.org/env/nanosafety

and the understanding of Life-Cycle Assessment in terms assessing both positive and negative impacts of nano-enabled applications. In addition, participants were also updated on the work of the OECD Working Party on Nanotechnology (WPN)[2], which addresses a number of activities such as: i) regulatory frameworks for nanotechnology in food and medical products; ii) assessing the economic impact of nanotechnology; iii) using nanotechnology in consumer products, for green growth and sustainable development; iv) integration of nanotechnology in converging technologies; and v) social dimensions of nanotechnology.

Session 2: Case Study Presentations and Discussion

5. During the workshop, three different case studies were presented that analysed the potential positive and negative impacts of nanomaterials including: i) Carbon Nanotubes (CNTs) in semiconductors; ii) concrete hardening accelerators; and iii) nano zero-valent iron for environmental remediation. For each case study, the individual presenters informed workshop participants about their individual conclusions. These case studies and their corresponding conclusions served as essential inputs for the discussions held in the different breakout groups.

Carbon Nanotubes (CNTs) in semiconductors

6. Michael Steinfeldt (University of Bremen, Germany) presented “Environmental relief effects of nanotechnology-based applications, through the example of CNT materials”.

7. Through examination of the two applications of nanomaterials: i) conductive Plastic Foil with Multi-Walled Carbon Nanotubes (MWCNTs) in the semiconductor industry; and ii) CNT composite material - Next Generation CNT composite material as carrier tray for electronics components, he concluded that:

- the potential and prospects for reducing environmental load by nanotechnological products and processes depends on the type and level of innovation (nanotechnology generation, incremental vs. radical, end-of-pipe vs. integrated);
- a varying potential for gains in resource efficiency could be shown and quantified based on the life cycle assessment approach, but also highlighted a lack of toxicity, eco-toxicity and different exposure data;
- while most nanotechnology-based applications on the market are incremental innovations, many applications with higher level of innovation are still under the development; and
- (prospective) LCA-Studies need basic data on the nanotechnology-based manufacturing processes, toxicity, eco-toxicity and different types of exposure.

Concrete hardening accelerators

8. Martin Möller (Oeko-Institut e.V. - Institute for Applied Ecology, Freiburg,Germany) presented “Concrete Hardening Accelerator: A case study of the Nano Sustainability Check”. He introduced the “nano sustainability check” as a self evaluation tool for enterprises to analyze nano products regarding their concrete benefits in terms of sustainability. The Nano Sustainability used an analysis scheme with

[2] www.oecd.org/sti/nano

Key Performance Indicators (KPEs) as a core element and **S**trengths, **W**eaknesses, **O**pportunities, and **T**hreats-(SWOT)-analysis as a compass for strategic optimization for a sustainability assessment.

9. KPEs of the SWOT analysis included: Product Carbon Footprint; Energy Efficiency (CED); Workplace Exposure; User Benefits; Life Cycle Costs; Risk Estimation for Men and Environment; Incident Aspects; Symbolic Benefits; Employment Effects; Societal Benefits; Legal Framework and Research Funding; Recyclability; Resource Availability; and Risk Perception.

10. This case study examined impacts of adding suspended Crystal Speed Hardening seeds ("X-SEED") as crystallization nuclei to concrete. This presentation concluded, amongst others, from this case study that:

- the case study X-SEED shows that nano innovations lead to several million tons of annual CO_2 savings and a small amount of nano scale additive improves the quality of the product at the molecular level; and

- Environmental optimum is not always the economical optimum (e.g. Life Cycle Costs of the Material scenario are identified as a weakness).

Nano zero-valent iron for environmental remediation

11. Ben Walsh (Oakdene Hollins Ltd, Aylesbury,UK) presented "Assessing the environmental benefits and risks of using nano zero-valent iron for environmental remediation".

12. Conclusions drawn from this case study included:

- Stakeholder viewpoints could be important in the absence of data (*risk* tolerance). However, these were not part of this assessment.

- In some cases, each site typically has a high social and economic value (£1billion over 20 years) and may warrant conducting site-specific LCA to evaluate the best approach for remediating a site.

Conclusive evidence of the fate, benefit and risk associated with nZVI for site remediation generally (and indeed most NMs in other applications) is not available.

Session 3-5: Breakout Group Discussion Session

Introduction to the Breakout Sessions

13. Two breakout sessions were held, organised as three discussion groups around the following topics:

i) specific issues of LCA;

ii) assessing the availability of LCA considerations based on tools and frameworks including their potential application at the research, up-scaling, regulatory and market level;

iii) discussing harmonisation, streamlining and user-friendliness, validation of suitable frameworks and suggested suitable refinement of such frameworks, if necessary.

Before the participants broke into each discussion group, a couple of case studies on general-LCA overviews were presented, which included detailed information on the general framework for LCA: i)

Selected National Activities related to LCA and Nanotechnologies in Germany; and ii) Sustainability indicators for nanotechnology (EU Prosuite Project).

Finally, an additional case study on "Prospective Environmental Life Cycle Assessment of Nanosilver in T-Shirts" by T. Walser et al. 2011 was also distributed as a background document.

During the second breakout session, participants deepened their knowledge of the specifics of the case studies and applied some of the lessons from the 1st breakout session to evaluating those studies.

Presentation on "Selected National Activities related to LCA and Nanotechnologies in Germany"

14. Wolfgang Dubbert (Federal Environment Agency (Umweltbundesamt), Dessau, Germany) introduced several activities from Germany which are relevant to LCA in the context of nanotechnology that served also as input for the breakout groups discussions.

15. Among five activities or studies presented, four studies were completed including: i) Environmental relief effects through nanotechnological processes and products; ii) Investigations into the application of nanomaterials in environmental protection; iii) Study of nanoparticle emission of selected products during their life cycle; and iv) NanoCommission: Guidelines for collecting data and comparing benefit and risk aspects of nanoproducts. One study on "developing a general assessment system for evaluation of sustainability aspects of nanotechnological products" was still underway.

Presentation on "Sustainability indicators for nanotechnology"

16. Lex Roes (Netherlands) presented "Sustainability indicators for nanotechnology", explaining the developed and selected indicators for each of the three pillars of sustainability (economic, social and environmental) by focussing on the environment and health pillar within the EU's PROSUITE Project (**PRO**spective **SU**sta**I**nability assessment of **Te**chnologies) that served also as input for the breakout groups discussions. It introduced three dimensions of sustainability: i) environmental and health aspects (16 elements such as global warming and ecotoxicity); ii) economic aspects (5 elements such as energy security, Life cycle costs; and iii) social aspects (9 elements such as equity concerns, trust in regulatory oversight).

17. His presentation concluded that it is essential to first close data gaps on the following aspects: toxicity, eco-toxicity and different type of exposure of and to nano-objects; and whether municipal solid waste incinerators remove nano-objects from off-gases sufficiently. Such data gaps can be closed by an effective cooperation between LCA-practitioners and risk assessors.

In addition to the environmental indicators/metrics from the PROSUITE Project, participants were also provided with the indicators from OECD's Green Growth Strategy[3], the Woodrow Wilson Project on Emerging Technologies Project Report on Nanotechnolgoy and Life Cycle Assessment[4], and the UK Land Remediation Report[5].

[3] OECD, 2011. "Towards Green Growth." OECD. Accessed 12 December, 2012 at: http://www.oecd.org/greengrowth/48224539.pdf.

[4] W Klöpffer, MA Curran, P Frankl, RHeijungs, A Köhler, SI Olsen, 2007. "Nanotechnology and Life Cycle Assessment: Synthesis of Results Obtained at a Workshop Washington, DC 2–3 October 2006." Woodrow Wilson Center for International Scholars, March 2007. Accessed 12 December, 2012 at: http://www.nanotechproject.org/file_download/files/NanoLCA_3.07.pdf

[5] CL:AIRE, 2010. "Contaminated Land Remediation." Accessed on 12 December, 2012 at: http://randd.defra.gov.uk/Document.aspx?Document=SP1001_9957_FRP.pdf

Breakout Group Discussions

18. The issues covered in these discussions were as follows: i) Basic structure and characteristic of LCA including in particular the selection of different environmental metrics/indicators suitable for different cases; ii) Application of LCA, i.e. at research, scale-up, regulation and market level; iii) Data availability, reliability, comparability and its generation; iv) Use of qualitative information if no quantitative data available, aspects related to the generation and use of default values as well as selection of suitable references allowing a comparative analysis of LCAs. Themes iii and iv were combined into a single breakout group.

Session 6: Plenary discussion

19. The last session of the workshop was a plenary discussion which summarized the outcomes and findings from each breakout group and invited further discussion from participants on the breakout topics and the case studies.

Conclusions and Findings

(1) Breakout group 1: Overarching Themes of the LCA- Basic structure & characteristic of LCA including especially the selection of different environmental metrics/indicators suitable for different cases

20. The group concluded, consistent with other workshops and expert groups (e.g., Sheetal Gavankar & Sangwon Suh & Arturo F. Keller (2012), Life cycle assessment at nanoscale: review and recommendations, Int. J. Life Cycle Assess, **17**, pp. 295–303), that life cycle analysis is also an important tool and framework in evaluating the negative and positive environmental implications of nano-enabled products, processes, or nanotechnology, but that it must be applied thoughtfully in order to provide answers that will be useful to decision-makers taking actively into account the specific nano-application including its functionalities (see case study examples presented).

21. It is important to consider the full lifecycle of a substance and product, even if only qualitative information is available. Users must begin by considering a full LCA; however, making limited considerations may be an appropriate approach during early decision-making, such as in the research phase.

22. The key is to establish linkages between LCA and risk assessment in order to provide decision-makers with full picture of the positive and negative environmental impacts. Ultimately, any LCA working group will need risk assessment information to complete an LCA. Since there is no concept of functional unit in risk assessment, the linkages can only be established if both LCA practitioners and risk assessors have the full picture. In this regard, they need to share the problem formulation and iterative results with each other.

23. The product and technology form an integral part of the system boundaries in an LCA.

24. Comparative LCA is acceptable when analysing relevant alternative products (either nano-enabled or not). A reference case involving non-nano-enabled products is not always available; in some cases nanotechnology has created a new product class that is a complete redesign of an old technology. In order to compare, the function of a nano-enabled product needs to be comparable to a non-nano-enabled product, if it is to be used as a reference. In developing the approach, it may be necessary to identify more than one or more product and groups of products covering both nano-enabled and non-nano-enabling

technologies. Participants identified the World Business Council of Sustainable Development as one source of guidance in terms of terminology when comparing products.

25. Participants agreed that it was critical to include the production phase in an LCA without exception. The use phase may be important for particular products or groups of products because of its impacts on the specific functionality of the nano-enabled product.

(2) Breakout Group 2: Application of LCA, i.e. at research, scale-up, regulation & market level

26. It is important to distinguish between those who will likely provide data that will be useful to the generation of an LCA, such as researchers in industry and government; regulators; and general business units, and those who may consume the information to aid in decision-making, such as research funders, regulators, general business units, general public (as an end consumer), policymakers, and other stakeholders.

27. For certain nano-enabled applications it is a significant challenge to conduct an LCA due to the lack of data for, e.g., nano-enabled product functionality, human health toxicity, eco-toxicity and different types of exposure of and to nano-objects; and the environmental fate and transport of nano-objects under various conditions. (For example, it is unclear whether municipal solid waste incinerators remove nano-objects from off-gases sufficiently). For early decision-making, one might be able to identify similar materials or processes that have a more complete dataset, but it is often unclear whether this data (on non-nano objects) can be applied to the nano-enabled case at hand with a great deal of confidence in the results that are obtained. For many nano-enabled applications, so little information is available on their functionality, identifying an appropriate proxy may be difficult, if not impossible.

37. However, there are a number of tools that might make LCA more useful for applications by different target groups. Furthermore, special decision-trees fine-tuned to the specific functionality of the nano-enabled product may be able to aid in early decision-making.

38. Developing product categories might be another tool to help deal with data gaps. This approach would use generically embedded data, except where specific data is available or can be made available. It would help focussing on the generation of data specifically to a particular application that was most relevant in ascertaining the environmental impacts of a particular technology, while also allowing the case to maintain ISO 14040 certification.

(3) Breakout Group 3: Data availability, reliability, comparability & its generation, along with the use of qualitative information if no quantitative data available, aspects related to generation, use of default values & selection of reference selection to allow for comparative LCAs

28. In line with other nano-LCA workgroups and reports, the ISO 14040/44 framework is a suitable harmonised, user-friendly and validated framework applicable to nanomaterials and nanotechnology that can be employed to analyse the potential positive and negative impacts on the environment and health of nano-enabled products. (e.g. Klöpffer W.; Int. J. Life Cycle Assess, Frankfurt, Germany, U. E.Mary Ann Curran, Cincinnati, USA, A. I. Paolo Frankl, Roma, Italy, C. Reinout Heijungs, Leiden University, Netherlands, E. Z. Annette Köhler, Switzerland and T. U. o. D. Stig Irving Olsen, Lyngby, Denmark (2007) Nanotechnology and life cycle assessment. Project on Emerging Technologies, Woodrow Wilson International Center for Scholars, The Pew Charitable Trusts, The European Commission)

29. All impact categories may be relevant for a particular LCA; the key first step is to prepare or obtain an inventory of data on impacts that are known, next to those that are unknown and reporting both.

30. For human health, eco-toxicity and various exposure type related indicators, it is relatively straightforward to identify releases during the manufacturing and processing cycles, but it is more challenging to quantify these elsewhere throughout the lifecycle including the consumer use and disposal phases. With respect to the specific Pro-suite approach of considering PM10 as the indicators for health effects the group wondered if this was not double counting impacts relevant to human health.

31. New impact categories to deal with nanotechnology are not needed; instead additional characterisation factors to deal with variables associated with nanotechnology are necessary. Top among these for nanomaterials would be material characterization, but human health, toxicity eco-toxicity and various exposure types are also important. Other impact categories have generally the same level of uncertainty as non-nano applications, though this depends on the application area (as some applications are novel).

Workshops Conclusions

The conclusions relevant for the subsequent work of the OECD Programme on the Safety of manufactured Nanomaterials were that:

(a) Life cycle analysis (LCA) per se is an important tool and framework in evaluating the negative and positive environmental implications of a product, process, or technology that can also be employed to nanomaterials. However, it must be applied thoughtfully keeping in mind the applications of nanomaterials in order to provide answers that will be useful to decision-makers.

(b) It is key in establishing linkages between LCA and risk assessment, since any LCA working group will need risk assessment information to complete an LCA. Given the fact that there is no concept of functional unit in risk assessment, such linkages can only be established if both LCA practitioners and risk assessors share the LCA objectives or problem formulation and exchange results with each other.

(c) In line with other nano-LCA workgroups, participants agreed that the ISO 14040/44 framework is a suitable harmonised, user-friendly and validated framework applicable to nanomaterials and nanotechnology.

ANNEXES I, II AND III

All annexes can be found in ENV/CHEM/NANO(2011)17/ADD.