出席經濟合作暨發展組織（**OECD**）奈米科技潛在環境效益研討會（**Potential Environmental Benefits of Nanotechnology：Fostering Safe Innovation－Led Growth**）

出國報告書

法國巴黎

2009 年 **7** 月 **12** 日至 **2009** 年 **7** 月 **19** 日

摘要

全球投入鉅額經費在奈米科技研發工作，期望對人類社會生活品質能有貢獻，同時特別注意到奈米材料可能帶來的健康環境安全（EHS）方面的衝擊。OECD 針對此一主題，在巴黎總部舉行爲期三天的研討會，分成 10 大主題深入研討，我國環保署亦就過去 6 年（2003-2008）的研究成果及未來 6 年（2009-2014）的規劃方向提供與會專家參考，會議內容對我國未來工作有很大的參考價值。

目　　　錄

壹、 會議目的

參與 OECD 國際會議，與世界主要國家進行技術交流與資訊交換，掌握奈米環境科技相關議題最新發展趨勢。

【環保署執行國科會國家型奈米科技計畫，從 2003 年起全程參與，第一期（2003-2008）主要成果及第二期（2009-2014）規劃報告二份英文論文，詳附件四及附件五，電子檔已在會前提供主辦單位大會召集人 Dr.Peter Kearns 參考】

貳、 會議行程

出國期間為 98 年 7 月 13 日至 98 年 7 月 19 日，共 7 日。行程如下：

98 年 7 月 12 日（日）	啓程	台北至巴黎
98 年 7 月 13 日（一）	抵達巴黎	由駐法代表處吳秘書嘯吟邀請大會召集人 Dr.Peter Kearns 共進午餐，交換環保及奈米議題
98 年 7 月 14 日（三）—17 日（五）	巴黎	全程三天出席 OECD 奈米環境會議
98 年 7 月 18 日（六）	回程	
98 年 7 月 19 日（日）	返抵台北	

參、 會議內容

一、會議背景

經濟合作發展組織(Organization for Economic Co-operation and Development，以下簡稱 OECD)為全球 30 個國家組成的政府間國際經濟合作組織，該組織創於 1961 年，總部設於法國巴黎。

由於奈米科技可以廣泛地運用於日常生活及經濟活動的各項層面上，例如:再生能源、水質淨化、改善環境品質等議題，但是在發展這些新科技的同時，也應著手發展與其相對應的責任管理規範，因此 OECD 下屬的化學品委員會(Chemicals Committee, 以

下簡稱 CC)，於 2006 年 9 月成立人造奈米材料工作小組(Working Party on Manufactured Nanomaterials，以下簡稱 WPMN)，專門探討與人造奈米材料相關安全性的議題。此外科學與科技政策委員會(Committee on Scientific and Technological Policy，以下簡稱 CSTP)，於 2007 年 5 月成立奈米科技工作小組(Working Party on Nanotechnology，以下簡稱 WPN)，WPN 的工作報告及重要會議決議均開放查詢，在「Reports」的子目錄下。WPN 在 2007-2008 年共推動 6 項計畫，包括：

（1）指標與統計 (Indicators and statistics)
（2）對公司與商業環境的衝擊 (Companies and the business environment)
（3）國際調查合作 (International scientific co-operation)
（4）拓展與公眾承諾 (Outreach and public engagement)
（5）政策對話 (Policy dialogue)
（6）全球性挑戰-水 (Global challenges)

從 2009 年起至 2010 年，WPN 依據上述 6 項專案計畫，提出 2 年期的延續計畫，分別是：

（1） 奈米科技的統計架構 (Statistical framework for nanotechnology)
（2） 奈米科技持續發展的監管與標竿 (Monitoring and benchmarking nanotechnology developments)
（3）提出奈米科技商業化環境之相關挑戰 (Addressing challenges in the business environment specific to nanotechnology)
（4）強化奈米科技發展應對全球性挑戰(Fostering nanotechnology to address global challenges)
（5）強化奈米科技之國際科學合作 (Fostering international scientific co-operation in nanotechnology)
（6）有關奈米科技重要議題之政策圓桌會議 (Policy roundtables on key policy issues related to nanotechnology)

綜觀而言，透過 OECD-WPN 的網站，產、官、學界得以了解當前跨國政府組織對奈米科技 EHS 相關議題，採取何種政策趨勢，並掌握關鍵重點，與國際政策及研究潮流接軌。

本次會議即在上述架構下，分別由環境健康安全部門（Dr.Peter Kearns）、科學及技術部門（Dr.Jacqueline Allan）分別具名召集及邀請（詳附件－邀請函）。

二、會議進行

分 10 個主題討論，但每一個主題均有共同的檢視面向，例如有無可用技術、潛在效益爲何、環境健康方面有無重大隱憂、社會觀感、限制條件等。由於 OECD 係以經濟發展爲前提，所以本次會議重點在奈米科技發展的環境潛在效益，而可能的潛在風險，雖有著墨，但並不多。OECD 的報告品質很好，他們的作法有二種，一種是先做研究，在形成委辦研究初稿後，再舉行研討會，讓研究報告更完整。一種是先舉行研討會，希望歸納出未來趨勢，再決定研究計畫的方向及內容。此一程序，固可借鏡，但重點亦在人爲，如果能請到真正的專家，則效能可立刻彰顯。本次會議基於上述原則，係採推薦邀請而非公開報名參加方式進行，總計出席各國專家約有 100 人。（詳附件二會議內容之主持人及主講人，以及附件三會議出席名單）

三、議題討論

十大主題分別爲：

（一）綜論
1. 達到永續解答之機會及障礙（現場經驗）
2. 奈米技術安全及效益（從碳奈米管觀點）
3. 我們願意記住過去的教訓嗎（預警原則）
4. 收斂的技術，放散的立法

（二）生命週期觀點
1. 奈米技術發展必須有平衡的作法
2. 奈米材料實現環境效益的量度方法
3. 生命週期及綠色化學
4. 應用奈米技術時，生命週期的想法是否真正能將預警原則在決策中實現
5. CNT 永續技術之發展：透過公私部門合夥（3P）的創新作法
6. 整合性政策架構推動所必須有的政策考量
7. 環境中的奈米技術—設計及暴露

（三）水處理及淨化
1. 利用奈米技術得到負擔得起的淨水
2. 光觸媒廢水處理技術
3. 太陽光觸媒程序做爲水之消毒單元
4. 修飾二氧化鈦強化光觸媒分解

5. 光觸媒用於飲用水淨化
6. 新穎奈米多孔材料容積型去離子（Capacitive Deionization）技術與海水脫鹽技術有競爭力
7. 奈米過濾及吸附的水處理方法，必須奈米技術

（四）環境感測
1. 微流量設備最新應用於環境監測及毒性評估
2. 即時環境暴露量測之新方法
3. 矽奈米結構用於化學及生化感測
4. 工程奈米材料定量及細胞毒性研究之感測工具
5. 以奈米材料爲主的環境感測技術
6. 半導體金屬氧化物的結晶奈米線做爲新一代的氣體感測器

（五）潔淨汽車技術
1. 減低汽車排放的新穎觸媒技術
2. NO 分解之奈米結構電化學反應器
3. NOx/PM 分解及微型 SOFCs 的奈米結構電化學反應器
4. 綠色運輸的陶瓷奈米技術
5. 車用 PEM 燃料電池的改進：從整件性能到特別定型電極之奈米結構材料

（六）纖維素奈米纖維
1. 細菌分解纖維素做爲新穎材料之構成元件（building block）
2. 纖維素奈米結晶及奈米纖維（歐洲觀點）
3. 生物奈米複合材料技術（全球觀點）
4. 確保人造奈米結晶纖維素之安全（加拿大新物質通告法規的風險評估例）
5. 奈米纖維素：材料、功能及環境觀點

（七）場址復育
1. 奈米技術用於場址復育
2. 表面修飾之鐵奈米粒子應用於整治：合成、特性及傳輸
3. 反應性奈米粒子現場地下水整治：表面修飾使效益最大並降低風險
4. 零價鐵奈米技術之現況：北美及國際現場實施之經驗
5. PCB 場址整治使用零價鐵奈米粒子對土壤微生物族群衝擊研究
6. 以奈米爲基礎的水處理技術的研究趨勢（韓國經驗）

（八）奈米創新製造更好的電池
1. 奈米材料促進高性能鋰離子電池
2. 車用鋰離子電池生命週期環境意涵

3. 混合或電動車鋰離子電池的生命週期評估
4. CNT 做爲鋰離子電池添加物的影響
5. 奈米結構及零排放提升電池之製造
6. 工業及使用者如何回收再用電池

（九）農業奈米技術

1. 奈米結構強化電子傳送設備在農業之應用
2. 奈米技術及印度農業：二次綠色革命
3. 即時農業污染物監測用之奈米感測陣列
4. 奈米技術之農業政策意涵
5. 巴西水淨化與奈米技術

（十）更綠色的奈米產品

1. 照明用的電子光纖
2. 自淨及延長使用年限的塗料
3. 省能的奈米塗料
4. 碳奈米管在塗料應用上的安全性
5. NanoGuard®在建物及內部之性能
6. 奈米技術與永續發展
7. 奈米材料回收與永續性

（上述 10 大主題發表文章之摘要，詳附件二會議內容之英文文件）

肆、 心得與建議

一、OECD 出版報告，品質及參考價值均佳，且長期維持一定之水準。除本次會議之資料外，本署過去執行至今（2003-2009）的奈米環境計畫，均追蹤並即時整理到相關年度計畫報告中。並以 OECD 爲重要的知識源，建置在本署環境奈米知識庫網站中，供各界使用，未來亦將隨時更新。

二、發展奈米產業之前提（經濟效益），必須建置在環境健康安全（EHS）的基礎上，所以全世界各國都在投注 EHS 的研究，我國雖然同步進行（衛生署、勞委會、環保署共同核心計畫，外加經濟部、國科會、教育部等均有關連計畫），但資源畢竟有限，國際上亦復如此，所以眾多的工程奈米材料必須透過國際分工來完成。OECD 最近完成一項了不起的分工，今後我國的研發工作，宜設法與他們的分工相連結：

富勒烯（C_{60}）	日本、美國（丹麥、中國）
SWCNTs	日本、美國（加拿大、法國、德國、EC、中國、BIAC）

MWCNTs	日本、美國（韓國、BIAC、加拿大、法國、德國、EC、中國）
銀奈米粒	韓國、美國（澳洲、加拿大、法國、德國、EC、中國）
鐵奈米粒	BIAC、中國（加拿大、美國）
碳黑	（加拿大、丹麥、德國、美國）
TiO_2	法國、德國（澳洲、加拿大、韓國、西班牙、美國、BIAC、中國、丹麥、日本）
Al_2O_3	（德國、美國、日本）
氧化鈽	美國、UK、BIAC（澳洲、荷蘭、西班牙、德國、瑞士、EC、日本）
ZnO	UK、BIAC（澳洲、西班牙、美國、加拿大、日本）
SiO_2	法、EC（比利時、韓國、BIAC、丹麥、日本）
Polystyrene	（奧地利、韓國）
Dendrimers	（西班牙、美國）
奈米黏土	（丹麥、美國）

上述分工出自 OECD 2009 年報告：Manufactured Nanoparticles at OECD：Human Health and Environmental Safety，括號內國家為協助國家。

附件

附件一：大會議程（及邀請函）

附件二：會議資料

附件三：與會人員

附件四：提供大會背景資料（論文一）

The Monitoring and Composition Analysis of Nanoparticles

附件五：提供大會背景資料（論文二）

Strategies toward Responsible Nanotechnology（2009-2014）

附 件 一

ORGANISATION DE COOPÉRATION ET DE DÉVELOPPEMENT ÉCONOMIQUES

OECD OCDE

ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

DIRECTION DE L'ENVIRONNEMENT
ENVIRONMENT DIRECTORATE

Division Environnement, santé et sécurité
Environment, Health and Safety Division

ENV/EHS/PK/dg/2009.77

Paris, 30 June 2009

Dr. Gwo-Dong ROAM
Executive Director
Office of Sustainable Development
Environmental Protection Administration
83, Jhonghua Road sec. 1
Taipei
Chinese Taipei

Subject: Invitation to participate in the OECD Conference on Potential Environmental Benefits of Nanotechnology: Fostering Safe Innovation-Led Growth

15-17 July 2009, OECD Conference Centre, Paris, France

Dear Dr.ROAM,

We are writing to you in order to invite you to participate in the OECD *Conference on Potential Environmental Benefits of Nanotechnology: Fostering Safe Innovation-Led Growth*, which will be held 15-17 July 2009 at the OECD Conference Centre in Paris, France.

This event is being organised by the OECD bodies working on Nanotechnology and Manufactured Nanomaterials. It will cover both the opportunities and challenges in the use of nanotechnologies for potential environmental benefits. The conference is composed of few plenary sessions together with several parallel workshops. These workshops will address specific themes related to nanotechnologies and will address the "state-of-the-art" with a view to identifying potential environmental benefits, while taking safety into account. We expect delegates from government, academia, industry and other stakeholders.

We would be grateful if you could confirm your participation at your earliest convenience.

Information on the Conference is available at: www.oecd.org/nanobenefits. For your convenience, information on OECD's Conference facilities, hotels and transportation in Paris is attached to this letter. You can also find more details at: www.oecd.org/conferencecentre. We have also attached a flyer describing this event.

Best regards,

Peter Kearns
Environment, Health and Safety Division
Environment Directorate

Jacqueline Allan
Science and Technology Policy Division
Directorate for Science, Technology and Industry

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Ligne directe/Direct line : +33 (0) 1 45 24 16 00 Fax : +33 (0) 1 45 24 16 75 E-mail : mar.gonzalez@oecd.org www.oecd.org

CONFERENCE BACKGROUND PAPER

BACKGROUND

The world is currently facing the most severe financial and economic crisis in decades. The OECD's latest Economic Outlook shows that the world economy is now in recession. Projections point to a protracted downturn in the economies of the OECD countries, with GDP likely to decline by at least a third of one percent in 2009.

In order to respond to these unprecedented events, many countries have launched economic stimulus packages with the aim of putting their economy back on a sustained growth trajectory. Most of them focus on pumping more "green" into their economies, on the premise that the use of solar panels and wind turbines, fuel-efficient cars and buildings, and low-carbon technologies will lead to more jobs, additional savings and a cleaner, safer planet.

Building on its expertise on structural issues and whole-of-government approaches to policy making, and on its longstanding work on open markets, the environment and innovation, the OECD is monitoring these developments and identifying policy options for addressing the crisis and seizing the opportunity to build a stronger world economy. One of key recommendations of the OECD is that any economic recovery measure should be based on low-carbon paths to growth, on innovation and on knowledge creation. In particular, innovation is considered as a key instrument for boosting productivity and sustainable growth. This will be further articulated in the OECD Innovation Strategy, currently under development, which will include recommendations to sustain and strengthen innovation under the current socio-economic conditions.

In one view of innovation, nanotechnology is described as a "platform technology". It is seen as having the potential to significantly contribute to raising living standards and improving quality of life. Nanotechnology is already being applied in many consumer products, particularly in the healthcare sector. Further applications are anticipated in areas ranging from energy to security, from environmental protection to information and communication technologies. Ways of maximising the benefits of nanotechnology are moving onto the agenda as a new source of growth and a possible "win-win" opportunity for both the environment and the economy. In this respect, the topic of this conference fits well with OECD's current efforts for fostering "green", "safe" and "innovation-led" growth.

OBJECTIVE AND SCOPE OF THE CONFERENCE

Informed by the recent OECD "Strategic Response to the Financial and Economic Crisis"[1], the OECD Working Party on Manufactured Nanomaterials (WPMN) and the OECD Working Party on Nanotechnology (WPN) are organising this conference to examine the contribution that nanoscale innovation may make in encouraging the development of technologies that can result in environmental gain without unintended consequences. These gains are both relative, such as reducing future environmental impacts of one technology when

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1 http://www.oecd.org/dataoecd/33/57/42061463.pdf

compared to other competing technologies, and direct, such as where a technology reduces the past environmental impacts of human activity.

The conference will cover both the opportunities and the challenges for the use of nanotechnologies as one societal approach in accessing potential benefits for the environment. The aim is to learn from international expertise and to identify ways in which to promptly improve policies, which could potentially enhance short-term, as well as long-term growth.

The conference will provide an opportunity for government, academia and industry to look into the state-of-art of nanotechnologies, their potential environmental benefits and potential human health and environmental safety concerns at the same time and to examine related policy considerations.

SPECIFIC OBJECTIVES

The objectives of the conference are to:

- Identify a range of environmental challenges, which could benefit from nanotechnology;
- Review key technologies with a nanotechnology component which are state of the art and which have the potential to bring environmental benefits;
- Identify the extent of the possible environmental benefits from the application of those nanotechnologies;
- Consider the environmental health and safety implications related to the use of nanotechnology for environmentally beneficial purposes;
- Identify challenges for the development, commercialisation and application of nanotechnology for environmental benefit; and
- Discuss policy measures to address challenges in the application of nanotechnology for environmental benefit and their relevance in the context of future OECD work programmes.

TOPICS OF THE CONFERENCE

The conference will address sustainability and life cycle aspects in a variety of sectors in which nanotechnology has the potential to give rise to environmental benefits. Thus, the conference will explore the environmental profiles of emerging nanoscale innovation with the goal of encouraging development of technologies that can result in environmental gain while avoiding unintended consequences.

The topics to be addressed will fall into four key areas:

- Societal drivers such as policy innovations, and business/NGO leadership.
- Applications to reduce pollution (e.g.: energy storage and generation and energy conservation, catalysis);
- Cleaner production (e.g.: green chemistry; synthesis and processing of nanoscale materials, water treatment and purification); and
- Other environmental benefits (e.g.: environmental remediation and monitoring, filtration, enhanced environmental sustainability of agriculture).

STRUCTURE OF THE CONFERENCE

The conference will consist of:

- Keynote presentation(s) by authoritative speaker(s) on the topics;
- Plenary sessions that introduce the conference and various perspectives on nanotechnologies;
- Parallel sessions that focus on specific technological case studies through workshops; and
- Plenary session wrap up and review of findings and policy-related conclusions.

The initial plenary sessions will introduce the discussion points for each following parallel session and focus on participants' attention on the conference topics and expected outputs. The first session will introduce the key policy themes of the conference through presentations of various stakeholder perspectives and start to raise the main policy issues that are to be addressed in the parallel sessions which follow. The second session will define and discuss what a life cycle perspective is and how it relates to nanomaterials design, development, incorporation and use in products and ultimate disposal.

The parallel sessions will focus on case studies related to specific applications and environmental benefits, including:

- Applications to reduce pollution (e.g.: energy storage and generation and energy conservation, catalysis);
- Cleaner production (e.g.: green chemistry; synthesis and processing of nanoscale materials, water treatment and purification); and
- Other environmental benefits (e.g.: environmental remediation and monitoring, filtration, enhanced environmental sustainability of agriculture).

Each session will be structured to address all of the following aspects:

- State-of-art technology (the state of the art of one or more nanotechnologies applicable to the sector);
- Potential environmental benefits (of using the technology);
- Potential human health and environmental safety concerns and issues (i.e. challenges for implementation); and
- Policy considerations (i.e. policy measures to address any challenges in the application of nanotechnology for environmental benefit).

This background paper is accompanied by a *Guidance for Speakers, Moderators, and Session Organisers*. The outcomes of the discussion will be reported back to the conference for further discussion and the drawing of conclusions in the final plenary session.

OUTPUTS OF THE CONFERENCE

At the end of the conference, participants will review the findings and policy-related considerations collected by the rapporteurs during the plenary sessions and workshops. This review will feed directly into the outputs from the conference which will be a summary report including:

- Each of the background papers from the plenary sessions and the workshops.
- A short review of the benefits and risks from state-of-the-art technologies which have been discussed at the conference and, in particular, the potential role of nanotechnology in realising environmental benefits;
- A summary of the challenges and opportunities in the application of nanotechnology for environmental benefit in the areas discussed; and
- A number of policy areas for further examination by the OECD to be undertaken through its Committees and Working Parties as appropriate.

The summary report of the Conference will be widely distributed to OECD stakeholders and other policymakers and will be made available through OECD website: www.oecd.org/nanobenefits.

PARTICIPANTS

Participants are from:

- International and intergovernmental organisations active in nanotechnology and environmental policy and regulation;
- National OECD delegates (from member and non-member countries) with government and agencies responsibility for nanotechnology, manufactured nanomaterials and related sectors;
- Business organisations and companies in sectors where nanotechnology has the potential to bring environmental benefits; and
- Other stakeholders including NGO's and academia.

OECD Conference on Potential Environmental Benefits of Nanotechnology: Fostering Safe Innovation-Led Growth

15-17 July 2009, OECD Conference Centre, Paris, France

Wednesday 15 July 2009		Thursday 16 July 2009				Friday 17 July 2009			
8:30	**Registration**								
9:30	**Opening Session**	9:00	**Parallel Sessions**			9:00	**Parallel Sessions**		
9:45	**Plenary Session 1: Setting the Scene**		**1. Water treatment and purification**	**2.Environmental sensing**			**6. Better Batteries Enabled by Nanoscale Innovation**	**7.Agricultural nanotechnology**	**8. Greener nanoproducts**
13:00	Lunch Break	13:00	Lunch Break			13:00	Lunch Break		
14:30	**Plenary Session 2 Life cycle perspectives**	14:30 - 18:00	**Parallel Sessions**			14:30 - 18:00	**Final Plenary Session**		
			3. Clean car technology	**4.Cellulose nano fibres**	**5. Site remediation**		Reports from parallel sessions Conclusions Closing Remarks		
18:00	Reception								

CONFERENCE PROGRAMME

Wednesday 15 July 2009

9:30-10:00	**Opening Session** Welcome Introduction from the Steering Committee Opening remarks
10:00-13:00	**Plenary Session One: *Setting the Scene***
13:00-14:30	Lunch Break
14:30-18:00	**Plenary Session Two: *Life Cycle Perspectives***
18:00	Reception

Thursday 16 July 2009

09:00-13:00	**Parallel Sessions**		
	1. Water Treatment and Purification	*2. Environmental Sensing*	
13:00-14:30	Lunch Break		
14:30-18:00	**Parallel Sessions**		
	3. Clean Car Technology	*4. Cellulose Nano Fibres*	*5. Site Remediation*

Friday 17 July 2009

09:00-13:00	**Parallel Sessions**		
	6. Better Batteries Enabled by Nanoscale Innovation	*7. Agricultural Nanotechnology*	*8. Greener Nanoproducts*
13:00-14:30	Lunch Break		
14:30-18:00	**Final Plenary Session**		
	14:30 - 16:00 Reports from parallel sessions 17:00 - 17:50 Final discussion and conclusions 17:50 - 18:00 Closing remarks		

Wednesday 15 July 2009

Opening Session **9:30 - 10:00**
Welcome: Mario Amano (Deputy Secretary-General of the OECD) **Introduction from the Steering Committee** **Opening remarks:** Jean-Philippe Bourgoin (Director of Nanoscience Programme, Atomic Energy Commission -CEA, France)
Plenary Session One: *Setting the Scene* **10:00 - 13:00**
This plenary session will introduce the conference themes, objectives and expected outputs. The session will provide an overview of the technologies to be discussed, illustrations of their potential environmental benefits, examples of challenges which are impacting or may impact upon the development and application of these technologies and some indications of policy measures being used to address those challenges. **Introduction** *Moderator: Iain Gillespie (Science and Technology Policy Division, OECD)* **Keynote speech: Barriers and opportunities in the delivery of sustainable solutions – Lessons from the field** *Speaker: Edward W. Manning (Tourisk Inc. and Carleton University, Canada)* **Benefit and safety aspects of nanotechnologies – From the viewpoint of carbon nanotubes** *Speaker: Morinobu Endo (Shinshu University, Japan)* **Are we willing to heed the lessons of the past? – Using the precautionary principle to foster safe innovation-led growth** *Speaker: Steve Mullins (ACTU, Australia)* **Converging technologies, diverging regulation** *Speaker: Geert van Calster (Katholieke Universiteit Leuven, Belgium)* ***Questions and Answers***
Lunch Break **13:00 - 14:30**

Wednesday 15 July 2009

Plenary Session Two: *Life Cycle Perspectives*

14:30 - 18:00

To present and discuss key organising concepts as a framework for identifying and considering potential environmental impacts and how they may affect potential societal benefits from nanotechnology. To develop a full appreciation of societal benefits of nanotechnology, it is important to understand both the potential benefits and the potential impacts of nanomaterials.

The need for a balanced approach to nanotechnology development
Speaker: Caroline Baier-Anderson (EDF, United States)

Ways to measure and realise environmental benefits with nanomaterials
Speaker: Arnim von Gleich (University of Bremen, Germany)

Greener nanoscience – A proactive approach to advancing applications and reducing implications of nanotechnology throughout the life cycle
Speaker: James Hutchison (University of Oregon, United States)

Putting 'benefits' into context – Can life-cycle thinking really provide for inclusive and precautionary decision-making on the use of nanotechnology?
Speaker: David Santillo (Greenpeace, United Kingdom)

The innovation alliance CNT - A novel public-private partnership model for the responsible development of sustainable CNT related technologies and applications
Speaker: Péter Krüger (Bayer, Germany)

Policy considerations for an integrated policy framework
Speaker: Lynn Bergeson (Bergeson & Campbell, P.C., United States)

Nanotechnology in the environment – Design and exposure
Speaker: Vicki Colvin (Rice University, United States)

Panel discussion

Reception

18:00

Thursday 16 July 9:00 - Friday 17 July 13:00

Parallel Sessions

Each parallel session will have workshops covering the three technology themes (pollution reduction, cleaner production, and other environmental benefits) and addressing the following issues: i) State-of-art technology; ii) Potential environmental benefits; iii) Challenges for implementation; and iv) Policy considerations.

Each workshop will finish with Q&A and discussion. Key findings from the workshop will be presented during the final plenary session.

Session 1. Water Treatment and Purification

9:00 - 13:00

Conventional remediation techniques prove relatively ineffective in reducing the levels of pollutants in water but the use of nanostructured materials can significantly improve efficiency. The speakers will compare photocatalysis and nanofiltration as emerging technologies for the purification and treatment of water.

Affordable clean water using nanotechnology
Speaker: T. Pradeep (Indian Institute of Technology Madras, India)

Photocatalytic wastewater treatment
Speaker: Ralf Dillert (Leibniz Universität Hannover, Germany)

Solar photocatalytic processes for water disinfection
Speaker: Pilar Fernández Ibáñez (CIEMAT, Spain)

Enhancement of photocatalytic degradation by modification of titania
Speaker: Alexander Orlov (State University of New York, United States)

Photocatalysis for drinking water purification
Speaker: Patrick Dunlop (University of Ulster, United Kingdom)

Capacitive deionisation using novel nanoporous materials as a competitive process for the desalination of sea and brackish waters
Speaker: Marc Anderson (University of Wisconsin, United States)

Nanofiltration and adsorption for water treatment – the need of nanotechnologies
Speaker: Armand Masion (CNRS, France)

Panel discussion

Thursday 16 July 2009

Session 2. Environmental Sensing **09:00 - 13:00**
Nanotechnology can enable the development of environmental sensing devices and greatly enhance the deployment of their networks that will result in an holistic assessment of the environment and in improved environmental protection. **Recent advances in microfluidic device applications for environmental monitoring and ecotoxicological assessments** *Speaker: Tae-Hyun Yoon (Hanyang University, Korea)* **New methods to measure environmental exposure in real time** *Speaker: Hans Jürgen Grimm (Grimm Aerosol, Germany)* **Chemical and biochemical sensing with silicon nanostructures** *Speaker: Michael J. Sailor (University of California - San Diego, United States)* **Sensors as tools for quantitation and cytotoxicity studies of engineered nanomaterials** *Speaker: Omowunmi Sadik (State University of New York-Binghamton, United States)* **Nanomaterial based environmental sensing** *Speaker: Sung Ik Yang (Kyung Hee University, Korea)* **Crystalline nanowires of semiconducting metal oxides as a new generation of gas sensors** *Speaker: Alberto Vomiero (CNR, Italy)* **Exposure and dose relationships of particulate matter in the environment** *Speaker: Robert Muir (Naneum Ltd, United Kingdom)* **Micro- and nanotechnology enabled platforms for environmental monitoring** *Speaker: Ashwin Seshia (Cambridge University, United Kingdom)* **Panel discussion**
13:00 - 14:30 Lunch Break

Thursday 16 July 2009

Session 3. Clean Car Technology

14:30 - 18:00

Developing advanced catalysts, electro-chemical reactors and other technologies for successful car emission control and for new types of power modules is one of the most anticipated applications of nanotechnology. Each speaker will cover this application from a different methodological perspective and examine policy implications.

Novel catalytic technologies for car emission reduction
Speaker: Hideaki Hamada (National Institute of Advanced Industrial Science and Technology, Japan)

Nanostructured electrochemical reactors for NO decomposition
Speaker: Sergey Bredikhin (Institute of Solid State Physics Russian Academy of Science, Russia)

Nanostructured electrochemical reactors for NOx/PM decomposition and Micro SOFCs
Speaker: Masanobu Awano (National Institute of Advanced Industrial Science and Technology, Japan)

Ceramic nanotechnology for green transportation
Speaker: Michael Stelter (Fraunhofer Institute for Ceramic Technologies and Systems Dresden, Germany)

Improvement of PEM fuel cells for car application – From stack characterisation to tailored electrodes nanostructured materials
Speaker: Patrick Achard (MINES-ParisTech, France)

Panel discussion

Thursday 16 July 2009

Session 4. Cellulose Nano Fibres **14:30 - 18:00**
Design, manufacturing and environmental issues of manufactured nanocrystalline cellulose: A research, commercialisation and risk assessment overview. **Introduction** *Speaker: Mohini Sain (University of Toronto, Canada)* **Bacterial cellulose as a building block for novel materials** *Speaker: Alexander Bismarck (Imperial College London, United Kingdom)* **Overview of cellulose nanocrystals and nanofibres: The science and technology – A European perspective** *Speaker: Denilson Da Silva Perez (FCBA, France)* **Global overview of bio-nano composite technology** *Speaker: Mohini Sain (University of Toronto, Canada)* **Ensuring the safety of manufactured nanocrystalline cellulose – A risk assessment under Canada's new substances notification regulations** *Speaker: Brian O'Connor (FPInnovations-Paprican Division, Canada)* **Nanocellulose – Materials, functions and environmental aspects** *Speaker: Orlando J. Rojas (North Carolina State University, United States)* **Panel discussion**

Thursday 16 July 2009

Session 5. Site Remediation **14:30 - 18:00**
The use of nanotechnology applications for site remediation can result in faster, more cost-effective clean-ups of hazardous waste sites, including those with challenging site conditions.
Nanotechnology for site remediation *Speaker: Marti Otto (EPA, United States)*
Surface-modified iron nanoparticles for remediation – synthesis, characterisation and transport *Speaker: Subhasis Ghoshal (McGill University, Canada)*
Reactive nanoparticles for in situ groundwater remediation – Optimising the benefits and mitigating the risks with surface coatings *Speaker: Gregory V. Lowry (Carnegie Mellon University, United States)*
Status of nZVI technology – Lessons learned from North American and international field implementations *Speaker: Jean Pierre Davit (Golder Associates-Europe, Italy)*
Deployment of nZVI to soil for polychlorinated biphenyl remediation: impacts on soil microbial communities *Speaker: Liz Shaw (University of Reading, United Kingdom)*
Overall research trends in nano-based water treatment technologies which have been recently applied in South Korea *Speaker: Young Haeng Lee (KIST, Korea)*
Panel discussion

Friday 17 July 2009

Session 6. Better Batteries Enabled by Nanoscale Innovation

9:00 - 13:00

Improved nano-enabled batteries, especially lithium-ion types, offer the potential to enable plug-in electric vehicles and green power generation. Each speaker will cover this technology from a different perspective culminating with an examination of policies to ensure rapid and responsible development.

Nanomaterial approaches to enhance lithium ion batteries
Speaker: Brian Landi (Rochester Institute of Technology, United States)

Understanding the life-cycle environmental implications of nanotechnology in lithium-ion batteries for automobiles
Speaker: Thomas Seager (Rochester Institute of Technology, United States)

Life-cycle assessment of lithium-ion batteries for use in hybrid and electric vehicles – Understanding the policies of potential benefits and impacts
Speaker: Kathy Hart (EPA, United States)

Effects of CNTs for lithium-ion batteries as additives
Speaker: Chiaki Sotowa (Showa Denko, Japan)

Nanostructures & zero-emission advanced battery manufacturing for zero-emission electric vehicles
Speaker: Gitanjali DasGupta (Electrovaya, Canada)

End of life issues with batteries – Industrial and consumer recover and reuse/Materials management for batteries
Speaker: Shane Thompson (Kinbursky Brothers-Toxco, United States)

Panel discussion

Friday 17 July 2009

Session 7. Agricultural Nanotechnology

9:00 - 13:00

Nanotechnology has vast potential to revolutionise agriculture. This session will focus on nanotechnology applications involving nano-enabled electron transfer devices for agricultural application; nanotechnology applications in agriculture in India; nanotechnology water projects in Brazil; and more. Each speaker will address specific applications and consider the benefits, challenges, and life cycle implications posed by these enabling technologies.

Nanostructure-enhanced electron transfer devices for agricultural applications
Speaker: Guigen Zhang (Clemson University, United States)

Nanotechnology and agriculture in India – The second green revolution?
Speaker: R. Kalpana Sastry (National Academy of Agricultural Research Management, India)

Impact on nano-scale technologies on food and agriculture
Speaker: Pat Roy Mooney (ETC, Canada)

Nanosensor arrays for real-time monitoring of agricultural pollutants
Speaker: Ashok Mulchandani (University of California, United States)

Agricultural policy implications of nanotechnology
Speaker: Steve Froggett (Department of Agriculture, United States)

Nanotechnology and water purification in Brazil
Speaker: Victor Bertucci Neto (Agricultural Instrumentation Centre, Brazil)

Panel discussion

Friday 17 July 2009

Session 8. Greener Nanoproducts

9:00 - 13:00

There are several alternatives ways in which nanotechnology can reduce the use of chemicals, materials and energy. Each speaker will cover different products including an examination of policies to ensure rapid and responsible development.

Quantum light™ optics for lighting
Speaker: Seth Coe-Sullivan (QD vision Inc., United States)

Self-cleaning and longer-lasting coatings
Speaker: Wendel Wohlleben (BASF SE, Germany)

Nanocoatings for energy conservation and generation
Speaker: Joe Pimenoff (Beneq, Finland)

The safe use of carbon nanotubes in coating applications
Speaker: André J. Lecloux (Nanocyl, Belgium)

Preserved, pure and precious – NanoGuard® for building and interior
Speaker: Michael Overs (Nanogate AG, Germany)

Binding particles to patience – Nanotechnology in a true context of sustainability
Speaker: Ian Illuminato (FoE, United States)

Sustainability and recycling issues
Speaker: Amin Reller (University of Augsburg, Germany)

Panel discussion

13:00 - 14:30 Lunch Break

Friday 17 June 2009

Final Plenary Session
Reports from parallel sessions **14:30 - 16:30**
Rapporteurs from each sessions will present key findings focusing on: • State-of-art technology; • Potential environmental benefits; • Challenges for implementation; and • Policy considerations A short question and answer and discussion session will follow.
Final discussion and conclusions **17:00 - 17:50**
Panel discussion
Closing remarks **17:50 - 18:00**

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ABSTRACTS AND SESSION MATERIALS

TABLE OF CONTENTS

PLENARY SESSION ONE – SETTING THE SCENE

Context for the Session

This session is a scene setting plenary which aims to introduce the key policy themes of the conference, to highlight the discussion points for each parallel session and to focus participants' attention on the expected outputs.

The session will provide an overview of the technologies to be discussed, illustrations of their potential environmental benefits, examples of challenges which are impacting or may impact upon the development and application of these technologies and some indications of policy measures being used to address those challenges.

Questions to be addressed in the presentations at the session will be:

- What are the available nanotechnologies?
- What are the potential benefits of using nanotechnologies?
- What are the potential environmental and health challenges throughout the lifecycle, for the safe introduction of nanotechnology to sustainably aid the environment in this area? What are the limiting factors, if any, for its adoption?
- What are the social drivers and what are the policy actions which can be taken by governments and agencies to bring the benefits to the market and the consumer while the potential environmental impacts are minimized?

ABSTRACTS

Barriers and Opportunities for Delivery of Sustainable Solutions: Lessons from the Field

Edward W. Manning, President, Tourisk Inc., Ottawa, Canada (KEYNOTE)

The achievement of sustainable development is a multifaceted challenge, and technology is one of the key building blocks. While nanotechnology has immense promise, and is very likely to provide significant elements in solutions to a very broad range of problems, it is likely to be a challenge to make the most of the opportunities provided and to get acceptance and adoption at many levels. All new approaches engender opposition, and some of this derives directly from a lack of information.

Communication from the laboratory to the user is a very fragmentary chain. The policy makers, the specialists, the vendors and the implementers seldom speak the same language. Real risk and perceived risks are seldom the same. Decision makers often cannot effectively define their problems relative to the range of potential solutions. Our institutions themselves pose barriers. My work in more than 50 countries shows a real need for new technologies at all scales, but also major gaps in knowledge about potential. A key challenge is to close the information gap – and match the supply of technology to real demands, most importantly at the local and enterprise level.

For more than 30 years my work has focused on how to make a difference in the human footprint. As a geographer, researcher and policy maker I have had the opportunity to work with a very broad range of people who want to make a difference –from senior officials in the governments of Canada, China, Mexico, or Pakistan to village leaders in Cameroon, Sri Lanka or Russia to managers of relic chemical factories on the Yangtze or Riachuelo (Argentina), heads of international hotel chains and local ecolodges in remote locations. What I have learned is that there are many problems in delivery of more sustainable solutions, and that nanotechnology may hold the answer for some.

In nearly all small communities where we have done local studies, water purification and sewage treatment systems are among the most critical issues – but current techniques often fall short. Energy management, particularly in places like small islands where there are no accessible fossil fuels, drives an unrequited demand for improved solar and storage methods. And how can we make a solar collector look like a thatched roof? Communities and their industries in many nations are waiting for the techniques which will decontaminate their effluents and detoxify sites – particularly in areas where a toxic mix defeats current filtration or bioremediation processes. I f you can't see it, you can't manage it – so better monitoring and measurement tools are critical, and we lack key tools. Can you drop it from a plane and will it continue to provide information?

With regard to industry decision-makers the economics will always be the core focus, and cost effective technologies will be the most attractive. This is also consistent with the increasing public commitment of many firms to environmental and social objectives. At the same time, growing concern with broad risk reduction may be a barrier to adoption or new processes or materials, as can the existing regulatory frameworks may not be flexible enough to permit new products or processes without amendment. The overall challenge of future sustainability lies in reducing the human footprint in many ways - and nanotechnology can be a significant part of the solution.

Benefit and Safety Aspects of Nanotechnology: From the Viewpoint of Carbon Nanotubes

Morinobu Endo, Faculty of Engineering, Shinshu University, Japan

Nanotechnology as innovation for tomorrow's world will change our way of life. The most distinguished nanotechnology related nonmaterial is "one-dimensional carbon nanotubes" which have attracted a particular interest from academy and industry, and thereby their related science and technology have developed rapidly, since their unique structure impart them to have novel physico-chemical properties: mechanical strength that is 100 times higher than steel, electrical conductivity that is as high as copper, and thermal conductivity that is as high as diamond. Those excellent properties of any reported value for any type of material make them promising in numerous applications (e.g., nanocomposite, energy storage and energy-conversion systems, sensors, filed-emission displays and lighting tubes, radiation sources, nano-devices, actuator and probes).

Unfortunately, the current large obstacle for blocking widespread applications of carbon nanotubes and their related materials in numerous application fields is considered to be the safety issue, due to their limited studies on the biocompatibility of carbon nanotubes. Thus, it is now urgently needed to clarify their potential toxic nature on human health and environment with detailed and systematic studies of toxicological evidences of carbon nanotubes, because what we worry the most is the misunderstanding among the general public, which might lead to the reluctance to use these tiny materials. In my talk, I shortly describe the basic features of carbon nanotubes as well as their current status and prospect from the viewpoint of business by relating their systematic biocompatibility studies.

Are We Willing to Heed the Lessons of the Past?: Using the Precautionary Principle to Foster Safe Innovation-led Growth

Steve Mullins, Australian Council of Trade Unions, Australia

While this conference is focused on exploring the benefits of nanotechnology to foster safe innovation-led growth there are lessons to be learnt from past mistakes with new technologies that can only help establish a greater depth of understanding of what safe innovation-led growth means.

Despite growing evidence of potential health effects and invasive nature of nanoparticles, the nanotechnology industry is booming with the support and encouragement of many governments around the world. The global value of revenues related to nanotechnology is expected to increase from US$32 billion to US$3.1 trillion over the next decade (Lux Research 2008) and it is predicted to potentially extend into almost every industry sector (Victorian Nanotechnology Statement, 2008, p.6).

This paper draws from the asbestos legacy and in it I argue that it is imperative that a rigorous health and safety framework be applied to the use of nanomaterials. Without specific regulation and in the absence of conclusive research we will be exposing thousands of workers to an uncertain future.

So as to fully explore these issues, it is important that due consideration is given to the potential costs of nanotechnology so that the health and safety of workers can be prioritised and protected on the path towards innovative developments.

This paper will provide the following insights:

- Provide an overview of a precautionary approach to innovation
- Lessons learnt from mistakes of the past
- Nanotechnology for environmental benefits but at what cost?
- Provide an overview of gaps in knowledge and effectiveness of existing risk management and controls over the life cycle of nanomaterials
- Can we protect health and safety and promote innovation? The next steps.

Converging Technologies, Diverging Regulation

Geert van Calster, Collegium Falconis, Katholieke Universiteit Leuven - Member of the Brussels Bar, Belgium

The idea of a one-stop port for regulatory oversight of nanotechnologies, was never seriously mooted in any of the usual suspects (led by the EC and the US). This has led to an incremental approach to regulating the various applications of the technology, with the EC recently more eager to include nano-specific requirements in food and cosmetics legislation in particular. These two examples illustrate the existing focus, in regulatory circles, on Health & Safety considerations, more specifically consumer health and safety (as opposed to occupational H&S). While prioritising is certainly to be commended in the regulatory approach, one currently runs the risk of fragmenting the legal response to nanotechnologies. Moreover, the environmental impact in particular risks becoming an afterthought.

This presentation aims at combining the need for prioritisation, with the avoidance of fragmentation, and reviews in this respect the conceptual (un)suitability of the EU's regulatory set-up in particular, to ensuring an integrated approach to nanotechnology regulation.

PLENARY SESSION TWO - LIFE CYCLE PERSPECTIVES

Context for the Session

To present and discuss key organizing concepts as a framework for identifying and considering potential environmental impacts and how they may affect the societal benefits from nanotechnology. To develop a full appreciation of the societal benefits of nanotechnology, it is important to understand both the benefits and the impacts of nanomaterials. This framework, built around a life cycle perspective, and incorporating the principles of green chemistry, forms the basis for a charge to the presenters of each of this week's case studies.

Session Overview

Speakers will define and discuss what a life cycle perspective is and how it relates to nanomaterials design, development, incorporation, and use in products and their ultimate disposal. To understand better the net environmental benefits of nanomaterial applications, life cycle frameworks will be examined as a mechanism for organizing information and identifying potential data gaps and data needs at each stage of material flow. Speakers will discuss how a life cycle perspective can address material and energy inputs and outputs, and discuss data needs for hazard characterization and "source to dose" concept models for exposure assessment. Because this meeting focuses on beneficial uses of nanotechnology, the characterization of relevant exposure scenarios will be emphasized. In the larger context of maximizing benefits and minimizing impacts from a societal perspective, each of these factors will be weighed against each other.

Background – Life Cycle Perspectives

We have chosen to use the term "life cycle perspectives" to characterize the need to consider both the benefits and impacts throughout the life cycle of the nanomaterial/nanotechnology application. The life cycle of a material or product includes the assessment of raw material and energy use and emissions during extraction, manufacture, distribution, use, and disposal, including transportation between and within each stage. These assessments may also attempt to identify opportunities to "close the loop" by including reuse and recycling (Figure 1). Some critics of life cycle assessment (LCA) claim that the incorporation of so many factors, each with different metrics, does not allow for a sufficiently detailed assessment of risks and benefits. Others suggest that the broad overview accorded by LCA allows for prioritization of information needs.

We use the term "life cycle perspectives" to refer generally to thinking holistically about the benefits and impacts of nanotechnology. The term includes, but is not limited to, formal and informal approaches to LCA methodologies. A life cycle perspective allows product manufacturers to consider the environmental impacts (*e.g.*, use of renewable and non-renewable resources, air impacts, energy use, land use, and related factors) associated with the material and energy inputs and outputs for each process in each life cycle stage of a material or product, but without the strictures of adding together different metrics. By comparing life cycle impacts of a nano-based product to traditional materials and products, potential environmental benefits (*e.g.,* reduced impacts) can be identified. In addition, areas for improvement in product design may be identified that further reduce impacts (*e.g.*, using materials that pose fewer impacts as a result of upstream extraction, finding processes and life cycle stages with highest energy use), and the results may be used to support green marketing claims, where appropriate. The incorporation of life cycle perspectives can be a valuable tool to inform decision-makers in governmental or non-governmental organizations, for strategic planning, priority setting, and to select relevant indicators of environmental performance, including measurement techniques.[1]

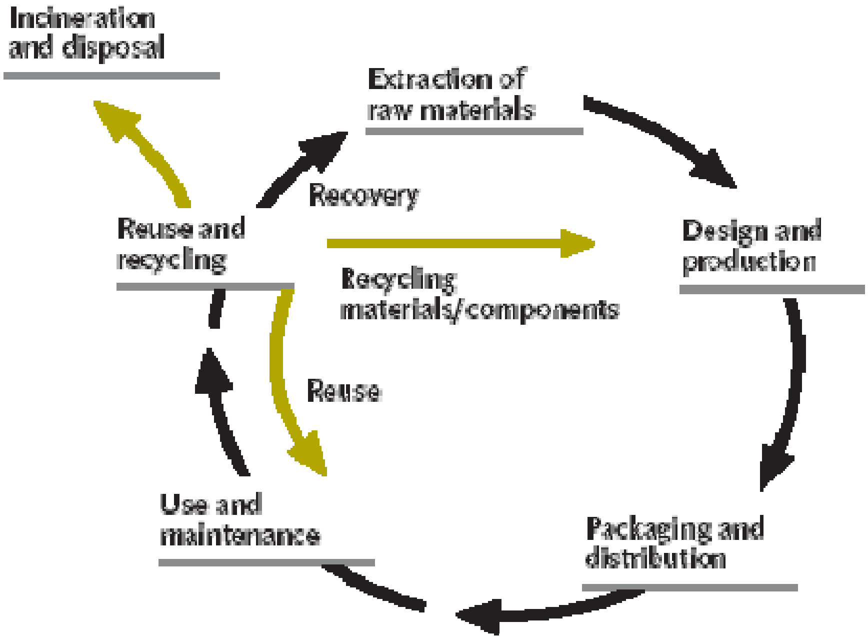

Figure 1: http://www2.mst.dk/common/Udgivramme/Frame.asp?http://www2.mst.dk/udgiv/ Publications/2003/87-7972-458-2/html/kap01_eng.htm

A variety of guidance documents and tools are available to facilitate life cycle analysis,[2] including the ISO 14040.[3] The Woodrow Wilson Center for Scholars, Project on Emerging Nanotechnologies hosted a workshop on Nanotechnology and Life Cycle Assessment, and published a synthesis of the results.[4] It concluded that the ISO framework for LCA is applicable to nanomaterials, although a lack of data and understanding in certain areas are major obstacles to its application.

The process of LCA involves the following steps[5] (Figure 2): [6]

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[1] International Organization for Standardization. 2006. ISO 14040:2006, Environmental management -- Life cycle assessment -- Principles and framework. Available at: http://www.iso.org/iso/iso_catalogue/catalogue_tc/catalogue_detail.htm?csnumber=37456

[2] http://lca.jrc.ec.europa.eu/lcainfohub/directory.vm

[3] International Organization for Standardization. 2006. ISO 14040:2006, Environmental management -- Life cycle assessment -- Principles and framework. Available at: http://www.iso.org/iso/iso_catalogue/catalogue_tc/catalogue_detail.htm?csnumber=37456

[4] Project on Emerging Nanotechnologies. 2007. Nanotechnology and Life Cycle Assessment. Available at: http://www.nanotechproject.org/publications/archive/nanotechnology_life_cycle_assessment/

[5] Ibid.

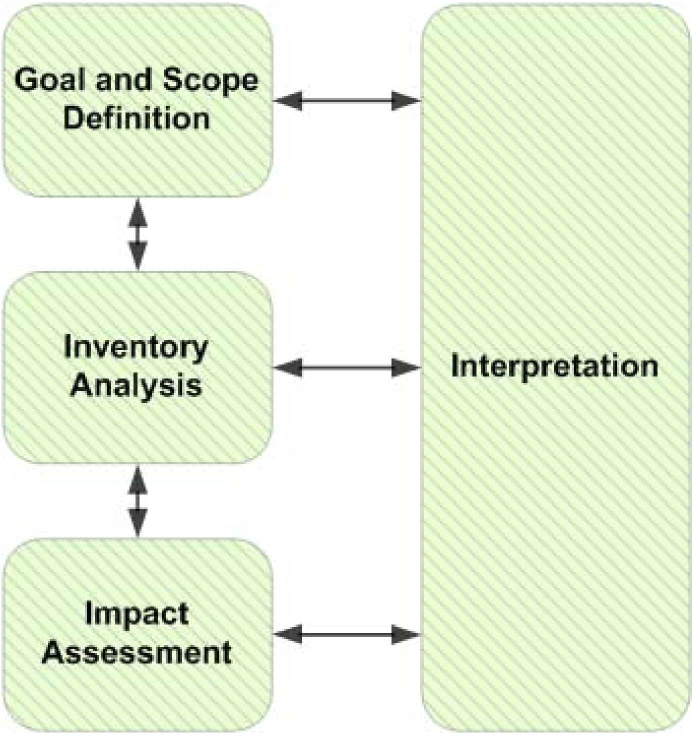

Figure 2: Life cycle assessment phases (http://en.wikipedia.org/wiki/Life_cycle_assessment)

Goal and Scope Definition

The goal and scope of the study is identified in relation to the intended application, and should address the overall approach that is to be used to establish the analytical and product system boundaries.

Life Cycle Inventory

The life cycle inventory involves modeling the product system, and collecting data for all material and energy inputs and outputs (in the form of air emissions, water emissions, or solid waste). For conventional processes, dedicated software packages have been developed for the purpose of compiling life cycle inventories. One particular challenge with nanotechnology is that it is unclear in many cases how processes related to use, maintenance, and end-of-life services (*e.g.,* disposal, recycling) will proceed. Some materials will be released during use, either intentionally (*e.g.*, nano-additives in gasoline) or unintentionally (*e.g.,* nano-additives in tires).

Life Cycle Impact Assessment

In the assessment phase, the contributions of the inventory data to each of the impact categories (*e. g.,* use of renewable and non-renewable resources, air impacts, energy use, land use, and related categories) are calculated. This phase may also include sensitivity and uncertainty analysis. The results may then be presented in a variety of ways: by impact category, by life cycle stage, or by processes or materials that are the largest contributor to each impact category, to indicate where improvements may be made.

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[6] Ibid.

Toxicity impacts can be incorporated into LCA methodologies. For example, in the methodology used in several LCAs conducted by U.S. Environmental Protection Agency's (EPA) Design for the Environment (DfE) Program (*see* www.epa.gov/dfe), toxicity data for each chemical on the life-cycle inventory--and their inventory amount--are used to calculate hazard scores, as an indication of the relative toxicity impacts in occupational settings (using inventory input amounts) and to the public (using output amounts). Tools such as TRACI, the Tool for the Reduction and Assessment of Chemical and other environmental Impacts, developed by EPA's Office of Research and Development (see http://www.epa.gov/nrmrl/std/sab/traci/), also assess cancer, non-cancer, and ecotoxicity impacts in an LCA framework.

LC Interpretation

The interpretation phase may include data integration and weighting of the different impact categories. Integration involves normalization of individual impacts, which are usually measured in different units. This provides a basis for comparing different types of environmental impact categories (all impacts get the same unit), and weighting, which involves assigning a weighting factor to each impact category depending on its relative importance to the user of the results. The results of this phase are usually some type of conclusion regarding the stated goals of the assessment.

Applying a life cycle perspective in the development of nanotechnologies entails the same types of considerations that are employed in a traditional LCA: goals are developed, the scope is defined, and inventories are compiled.

Green Chemistry and Nanotechnology

The overarching goal of green chemistry is to develop chemicals and chemical processes designed to reduce or eliminate potentially negative environmental and human health impacts.[7] EPA defines chemicals that are less hazardous to human health and the environment as:

- Less toxic to organisms and ecosystems
- Not persistent or bioaccumulative in organisms or the environment
- Inherently safer with respect to handling and use [8]

Twelve principles of green chemistry have been defined[9] and these can be applied to nanotechnology design. This would require that nanomaterials be designed to be less hazardous to human health and the environment, manufactured without the use of hazardous substances, and designed for materials efficiency and waste reduction. These principles are compatible with life cycle thinking as their implementation will help to reduce the likelihood of adverse impacts from nanotechnology development throughout the material or product lifecycle.

In this session and throughout the conference, specific examples will be provided to illustrate the types of data that are needed for occupational, environmental, and consumer use scenarios. These examples can be used to illustrate how Environment, Health and Safety (EHS) considerations change throughout the product life cycle, and how green chemistry can reduce EHS concerns. The Life Cycle Perspectives panel will also introduce the charge to

[7] http://www.epa.gov/greenchemistry/pubs/about_gc.html

[8] Ibid.

[9] Anastas, P. and Warner, J. 1998. **Green Chemistry: Theory and Practice**. Oxford University Press: New York.

presenters: Please address the following questions in the presentation of your case study:

- What is the environmental benefit and who are the beneficiaries? Is it measurable? What opportunities exist to further enhance environmental benefits (*e.g.*, finding ways to more cleanly or efficiently produce the nanomaterials)?
- Given life cycle considerations for the nanomaterial application, what is (or are) the most important, compelling, or relevant exposure scenarios that must be addressed? What data are needed to conduct a comprehensive exposure assessment for this scenario? What data are currently available, what are the data gaps, and what are the obstacles to collecting additional data?
- What are the barriers and suggestions for a path forward to enhancing benefits and minimizing risks?

Session Schedule

Topic	Speaker	Stakeholder type	Time
The need for a balanced approach to nanotechnology development	Caroline Baier-Anderson (Environmental Defense Fund, US)	NGO	15 min
Ways to measure and realize environmental benefits with nanomaterials	Arnim von Gleich (University of Bremen, Germany)	Academic	30 min
Green chemistry and life cycle perspectives	James Hutchison (University of Oregon, US)	Academic	30 min
Coffee Break			15 min
Putting 'benefits' into context: can life-cycle thinking really provide for inclusive and precautionary decision-making on the use of nanotechnology?	David Santillo (Greenpeace, UK)	NGO	20 min
The innovation alliance CNT: A novel public-private partnership model for the responsible development of sustainable CNT related technologies and applications	Peter Krueger (Bayer MaterialScience AG, Germay)	Industry	20 min
Policy consideration for what is needed to facilitate integration into a policy framework.	Lynn L. Bergeson (Bergeson & Campbell, P.C., US)	Legal/Policy	20 min
Nanotechnology in the environment – Design and exposure	Vicki Colvin (Rice University, US)	Academic	30 min
Panel Discussion			30 min

ABSTRACTS

The Need for a Balanced Approach to Nanotechnology Development

Caroline Baier-Anderson, Senior Health Scientist, Environmental Defense Fund, United States

Nanotechnology has potential applications in nearly every business sector, including consumer products, health care, transportation, energy and agriculture, and the responsible development of these applications requires attention to the potential implications of nanotechnology. The purpose of this plenary session, Life Cycle Perspectives on the Environmental Benefits of Nanotechnology, is to present and discuss key organizing concepts as a framework for identifying and considering potential health and environmental impacts and how they may affect the societal benefits from nanotechnology. This framework, built around a life cycle perspective, and incorporating the principles of green chemistry, forms the basis for a charge to the presenters of each of this week's case studies.

The speakers in this plenary have been asked to define and discuss what a life cycle perspective is and how it relates to nanomaterials design, development, incorporation, and use in products and their ultimate disposal. To understand better the net environmental benefits of nanomaterial applications, life cycle frameworks will be examined as a mechanism for organizing information and identifying potential data gaps and data needs at each stage of material flow. The introduction of green chemistry concepts will describe the benefits of designing safer materials at the outset of technology development. Because this meeting focuses on beneficial uses of nanotechnology, the need for the characterization of relevant exposure scenarios will be emphasized.

Ways to Measure and Realize Environmental Benefits with Nanomaterials

Arnim von Gleich, Technology Shaping and Technology Development, University of Bremen, Germany

In the early phases of the innovation process, potential impacts of nanomaterials and nanomaterials based products are difficult to assess. This also holds true for the respective opportunities and threats. Furthermore, impacts, opportunities and threats are usually only discussed in terms of their potentials. But opportunities must actively be realized and threats should actively be minimized, which poses real challenges for the development process. Our group developed a three tiered approach to deal with these challenges[10]. It combines a life cycle approach (ecoprofiles), an approach for preliminary risk assessment (hazard characterization) and an approach for designing materials and products oriented by guiding principles (‘green nanotechnologies’).

We will present this approach along with selected results from eight case studies: Nano

[10] Gleich, Arnim von, Michael Steinfeldt, Ulrich Petschow: A Suggested Three-Tiered Approach to Assessing the Implications of Nanotechnology and Influencing its Development, in: Journal of Cleaner Production, Volume 16, Issues 8-9, May-June 2008, Pages 899-909

coatings in car industry, nano catalysts in styrene production, nano innovations in displays, nano applications in the lighting industry, organic metal nano finish in circuit boards, production process of MWCNT, lithium ion batteries in public transport buses and a high speed injection mould polymer[11].

Greener Nanoscience: A Proactive Approach to Advancing Applications and Reducing Implications of Nanotechnology throughout the Life Cycle

James Hutchison, University of Oregon, Oregon Nanoscience and Microtechnologies Institute, Safer Nanomaterials and Nanomanufacturing Initiative

Nanotechnology offers new materials and applications that promise numerous benefits to society and the environment, yet there is growing concern about the potential health and environmental impacts of production and use of nanoscale products. Because nanotechnology is still in the "discovery" phase, the design and production of materials have yet to be optimized. For example, although hundreds of studies of nanomaterial hazards have been reported, there is no consensus about the impacts of these materials or design rules that guide the future development of the materials. Additionally, the synthetic methods used to produce nanomaterials are often inefficient or require the use of hazardous reactants. Green chemistry is an approach to the design of materials, processes and applications that has the potential to reduce hazards at each stage of the life cycle. In this presentation, I will describe how green chemistry applied to nanoscience - greener nanoscience - offers an approach to developing safer, more efficient nanosyntheses and to developing and implementing the design rules for safer nanomaterials. To advance beneficial applications of nanomaterials and minimize harm, we need to develop an understanding of how nanomaterials interact with and in the environment and their biological impacts and develop new methods of production that address the limitations of discovery scale approaches. Examples will be provided that illustrate a research approach to determining the design rules for effective and safe nanomaterials. The results of these types of studies can guide design of new materials for which product safety is a design metric. Examples will also be provided that address challenges faced in greening the nanomanufacturing process, including approaches to greener syntheses, purification and continuous flow production. The results of these studies suggest that green chemistry approaches to nanomaterial production can significantly reduce waste and hazard, while enhancing material quality, increasing process throughput and decreasing costs.

Putting 'Benefits' into Context: Can Life-Cycle Thinking Really Provide for Inclusive And Precautionary Decision-Making on The Use of Nanotechnology?

David Santillo & Paul Johnston, Greenpeace Research Laboratories, School of Biosciences, Innovation Centre Phase 2, Rennes Drive, University of Exeter, UK

[11] Steinfeldt, M.; von Gleich, A., Petschow,U.; Haum, R.: Nanotechnologies, Hazards and Resource Efficiency – A three-tiered approach to assessing the implications of nanotechnology and influencing its development, Springer Verlag Berlin, Heidelberg New York 2007;
Steinfeldt, Michael; von Gleich, Arnim; Petschow, Ulrich; Pade, Christian; Sprenger, Rolf: Entlastungseffekte für die Umwelt durch nanotechnische Verfahren und Produkte, Studie im Auftrag des Umweltbundesamts UBA-FB III 2.3, UFOPLAN-Nr. 206 61 203/02 Bremen, Juli 2008

Nanotechnology is a reality: we are already living with numerous applications and, however unwittingly, with the consequent risks, even if they are so far poorly described and understood. As uses continue to expand, the societal and environmental exposure to nanomaterials, both deliberate and unintentional, will inevitably also grow. So how should we decide whether the benefits claimed for nanotechnologies are likely to be realised and to outweigh the associated risks? Just as importantly, who is equipped to decide and who should be mandated to take such decisions on our behalf? And in coming to decisions, how should we deal with the unavoidable and currently substantial limits to knowledge and the power of predictions?

Against this background, proposals to incorporate life-cycle thinking into the evaluation of nanotechnologies are welcome in principle. However, such apparently 'holistic' approaches will only begin to support a high level of protection for human health and the environment if they are truly holistic in practice and are set within the right context. One critical aspect is that for LCA to generate meaningful output for decision-makers, it will need to be application-focused, not material or technology-focused, and capable of providing for comparison of different options. Rather than starting from an assumption that environmental benefits are specific to nanotechnologies, any assessment should start from a clear definition of scope and of the purpose or function of the application under consideration, should include an evaluation of the true value or need for that function and should then proceed through a full and proper assessment of all practicable alternatives to provide that function.

Another critical element will be to ensure that data gaps and the ensuing uncertainties and unknowns are given thorough and consistent consideration and are explicitly documented in the final decision, rather than becoming hidden as default values and implicit assumptions. This second point will be of particular relevance to nanomaterials given that understanding and assessment tools for toxicity and ecotoxicity are at such an early stage of development. Preparation of reliable inventories covering manufacturing, use and end-of-life processes will be vital to inform descriptions of inputs of nanomaterials to the environment, but must be complemented by far better understanding of their fates and effects in different environmental compartments, as well as of our abilities to monitor their presence and the feasibility of taking remedial action if necessary.

Any tools for assessment of nanotechnologies cannot be considered in isolation from the systems of governance under which they will operate, nor from the motivations behind the ongoing development of the industry. We have come to realise all too late that effective regulation of conventional chemicals, including transparency of registration and reporting and a presumption against continued use of the most hazardous substances, is not an ideal but a necessity. And yet we continue not merely to allow, but to facilitate, increasingly widespread deployment of nanomaterials in a manner which is far from transparent, cannot be properly assessed and for which governance mechanisms remain ill-defined. Many in the nanotechnology industry favour voluntary codes of conduct over regulation. However, recent reviews indicate that while such codes may go some way to addressing issues of transparency, monitoring and reporting, they are generally powerless when it comes to enforcement and sanctions. Just as experience shows with conventional chemicals, voluntary commitments generally only take full effect when underpinned by effective regulation.

In providing a theoretical framework for comparative evaluation of all phases in material lifetimes, LCA undoubtedly offers something useful. However, if our objective is truly the provision of environmental benefits, then the primary goal of LCA or any other system must be the identification of the most suitable and sustainable solutions to reach that objective, not fostering the growth of any one technology, however innovative it may be. If a nanotechnology proves itself to be more sustainable than other solutions, then it will survive. If not, then neither assessment nor governance mechanisms should aim at its continued promotion in the name of innovation and growth.

Innovations Alliance CNT: A Novel Public-Private Partnership Model for The Responsible Development of Sustainable CNT Related Technologies And Applications

Péter Krüger, Bayer MaterialScience AG, Germany

Carbon Nanotubes (CNT) have achieved enormous attention in the scientific-technical community during the past two decades. Despite of diverse highly promising technical opportunities, offered by CNT, the commercial applications of CNT based materials are currently not in that development stage as expected before.

To overcome the challenge of a broad commercialization along the value chain, a cluster of 18 internally interlinked projects with a total budget of 80 million € using a partial financial support of the government has been initiated in Germany. 80 partners from academia and industry are participating in that four year runtime alliance.

Three of the projects are cross-sectional platforms considering key technical steps of production, functionalization and dispersion of CNT. 14 Projects are dedicated to develop sustainable applications of CNT based materials on the field of Energy/Environment, Mobility and Light Weight Construction. Finally, one cross sectional project is taking care of Health, Safety and Environmental issues of CNT.

The presentation will deliver information on structure and goals of the Innovation Alliance CNT in detail.

Policy Considerations for an Integrated Policy Framework

Lynn L. Bergeson, Bergeson & Campbell, P.C., United States

The emergence of nanotechnologies offers extraordinary opportunities for advancements in cleaner production, energy generation, environmental remediation, and reducing pollution to name a few promising and beneficial applications. Governments, business interests (large and small), non-governmental organizations (NGO), public health professionals, and others (collectively nanotechnology stakeholders), however, are challenged to identify and address effectively the many legal, regulatory, legislative, and policy issues that have also emerged in connection with nanotechnologies and demand resolution to ensure that commercialization of nanotechnologies proceeds responsibly. Mindful of these challenges, nanotechnology stakeholders are pursuing a wide variety of innovative regulatory, voluntary, and policy initiatives designed to facilitate the responsible development of nanotechnologies. Indeed, the unprecedented number of global initiatives focusing on ways to ensure the responsible development of nanotechnologies demonstrates a significant and enduring commitment to achieve this goal.

This presentation will focus on identifying key considerations, including the need to ensure that life cycle perspectives and the means to identify and integrate nanotechnology benefits and implications are appropriately expressed, in developing an integrated and effective policy framework. This presentation will also explore the use of existing regulatory, legislative, and private-party governance tools to address the potential impacts of nanomaterials, and assess the need for additional measures to foster cooperation and efficiencies among international governance systems.

Nanotechnology in the Environment: Design and Exposure

Vicki Colvin, Department of Chemistry, Rice University, United States

Nanotechnology-enabled systems offer much promise for solving difficult environmental problems ranging from water purification to waste remediation. These solutions must not only be cost-effective and sustainable, but they must also be safe for people and the environment. Our emerging understanding of the interface between nanomaterials and biological systems gives us the critical ability to approach the latter issue early in the development of nanotechnology. This talk will discuss in some detail how the chemical and physical properties of engineered nanomaterials impact their biological effects in model systems. Three case studies, ranging from fullerenes to metal oxides, illustrate the vast diversity of nanomaterial features and biological response. The composition of a nanomaterial is the primary factor in describing acute biological effects, and among the different examples nanoparticle charge and surface coating can be of equal importance. Interestingly, the size of the inorganic material itself – such an important feature for applications development – in these three examples is secondary in defining the materials' acute biological effect. In all cases, the biological and environmental compartments experienced by nanomaterials lead to substantial modification of their hydrodynamic size and charge. The bio-modified material that results is the central element to understand and characterize in order to detect the underlying correlations between the inorganic nanomaterial phase, composition and size with biological outcomes. These correlations form the basis for guidelines that permit researchers creating new nanoparticles to focus their energy on materials that are 'safe by design'.

Equally important to strategies for eco-responsible design are principles for characterizing the concentration, form and ultimately fate of nanoparticles in the environment. This is an issue for analytical chemistry and it an enormous challenge given the dearth of labeling for these products. This talk will also cover what is currently understood about the actual use of nanoparticles in consumer products; such analysis begins with estimates of quantities and forms of materials. In particular, nanoscale silver and nanoscale titania are two interesting case studies. However, as will be discussed once formulated into a product these nanoparticles can behave in ways quite distinct from their bulk suspensions. Upon disposal, their ultimate environmental fate is unknown but we can speculate as to the most likely environmental compartments they may occupy. Finally, throughout this entire cycle the materials are modified substantially – either through dissolution, aggregation, or modification with natural organic and inorganic substances. While the complexity of this various exposure factors can be daunting, the unique features and tunability of the nanoparticles themselves offer great flexibility for designing detection schemes even in complex environmental matrices.

PARALLEL SESSION ONE - WATER TREATMENT AND PURIFICATION

Context for the Session

Conventional remediation techniques have proved relatively ineffective in reducing the levels of pollutants in water. Filtration and purification systems for drinking water, for instance, tend to have only limited success because of the relatively low efficiency of the active materials. As a result of their greater specific surface area, nanostructured materials are significantly more reactive than micron-sized or bulk materials with the same chemical composition.

Photocatalysis is emerging as an alternative to conventional water treatment technologies. Titanium dioxide is the most widely employed photocatalytic material for these applications. The power required for the UV light source is the most significant operating cost for photocatalytic water treatment. Solar photocatalysis has hence become the subject of significant research and development activity. Photocatalytic treatment of water is an effective method for the degradation of pollutants and the destruction of micro-organisms. Research activities in this area include water treatment and purification, electrolysis using solar energy and self-sterilising surfaces.

Nanofiltration is another viable method for the treatment of process and waste water. The pore size is similar to that of pesticide molecules and other chemicals found in water and the technique bridges the gap between reverse osmosis and ultrafiltration techniques in relation to the size of the molecules removed. It is suitable for use in water softening, removal of natural organic matter (NOM), micropollutants and heavy metals, disinfection, desalination, and ion separation. Applications include safe discharge and reuse of wastewater, high quality drinking water, groundwater treatment, removal of organic and inorganic pollutants from surface water, and the recycling of process water.

Session Overview

This session focuses on photocatalysis and nanofiltration as emerging methods for the purification and treatment of water. The aims will be to discuss:

- The state of technical advancement and the market potential of different photocatalytic and nanofiltration applications;
- Challenges and needs for further research;
- The potential environmental and health benefits that could result;
- Potential environmental and health risks associated with these technologies;
- Strategies to promote safe and responsible development.

The session will provide time for perspectives from the stakeholders, including researchers developing new photocatalytic and nanofiltration water treatment technologies, industrial and other end users and NGOs concerned with the potential risks and benefits.

Background on Water Treatment Technologies

Titanium dioxide has proved to be the most promising material employed in both fundamental research and practical applications because it is highly photoreactive, inexpensive, of low toxicity, chemically and biologically inert, and photostable. When it is illuminated with ultraviolet (UV) light, an electron-hole pair is formed. The valence band potential is positive enough to generate hydroxyl radicals at the surface and the conduction band potential is negative enough to reduce molecular oxygen. The hydroxyl radical is a powerful oxidising agent and destroys organic pollutants on or close to the surface of the photocatalyst, by converting them to carbon dioxide and water.

The numerous studies conducted to date have reported excellent efficiencies in the degradation of contaminants. The main advantages using titanium dioxide are that it is abundant and thus inexpensive; it is chemically stable, has a high oxidative ability and can be immobilized on a substrate.

Photocatalytic products containing titanium dioxide nanoparticles are already on the market; examples include paints, surface coatings and cement. The application of such materials is mainly due not to the de-polluting effect but rather to the self-cleaning properties of the material. However, increasing photocatalytic efficiency remains a challenge. So far the photocatalytic efficiency (percentage of incident photons used) is only around 0.01%. Attempts are being made to increase this by doping the material with nitrogen, boron or noble metals such as gold to improve the photocatalytic efficiency.

An important potential application of photocatalysis with titanium dioxide is the treatment of drinking water to destroy microbes without the use of disinfectants. Titanium dioxide can also degrade a variety of common pollutants (e.g. atrazine, endocrine distrupting chemicals, dyes, organic pollutants, MTBE) in water. In order to avoid the risk of free nanoparticles in the water, the nanoparticles can be immobilised on the substrate.

It has been shown that the photocatalytic inactivation of bacterial spores in river water samples is effective within a period of a few hours. Photocatalytic disinfection to destroy pathogenic micro-organisms is an effective method for providing clean drinking water and works also for chlorine-resistant organisms. Tests have shown significantly increased disinfection efficiencies using photocatalysis as compared to UVA irradiation alone.

Nanofiltration membranes typically have a multilayer structure and transport one component more readily than another due to differential transport, separating them into a retentate, enriched in less mobile components, and a permeate, enriched in faster components. Separation takes place in the top layer, which is mechanically supported by a series of asymmetric layers. The pores are of the order of 1 nm diameter.

While nanofiltration is an effective method for production of high-quality water, it has inherent problems due to the treatment of concentrates, fouling, difficulties in obtaining complete separation, construction of suitable membrane structures, and improvement of process design. The concentrate or retentate can also contain high levels of heavy metals and toxins. However, it is cheaper than reverse osmosis because lower pressures are required and membrane life-time may be up to 5 years.

Membrane fouling is the most serious problem limiting performance and depends on the interaction between the solute parameters and the membrane material. One solution is modification of the structure to obtain a hydrophilic surface to reduce fouling and to allow stable operation Solute rejection can be modelled by means of transport equations and approximate expressions have been derived describing the filtration process. Additional theoretical studies are required to understand how the quality of the permeate can be better controlled.

Other membrane types, such as membranes consisting of a colloidal interlayer with an oxide top layer on a ceramic support, are also being investigated. Novel process methods are currently being developed using membrane cascades and recycling of permeate or concentrate for better separation between ions and organic solutes or between different organic solutes. Nanoporous structures have also been developed that use charged surfaces to provide more efficient deionisation.

Current technical challenges include:

- modelling of membrane structures and development of simulation tools to provide a better understanding of transport mechanisms
- membrane-solvent interactions for prevention of fouling, increased flux, and high rejections
- better process design for lower energy consumption and improvement of separation

Environmental and Health Considerations

The use of nanotechnologies in water purification applications has been successfully demonstrated both on a laboratory scale and in pilot plants but, in the majority of cases, still require further verification of their efficacy and safety in the field. One of the potential dangers of environmental remediation is that the products might be more toxic than the original pollutants. Additional risks are constituted by entry of toxic by-products into the environment and the food chain. There are significant concerns that need to be addressed regarding the effect of nanoparticle release on soil ecosystems. This is a major unknown because there are relatively few data available.

Solar photocatalysis can be expected to be a main technology breakthrough for water treatment and purification. This could have implications for clean drinking water, particularly in developing countries or in emergency situations, where waterborne diseases constitute a severe threat. Photocatalysis uses sunlight, which is readily available and free of charge, so that operational costs are low and the environmental impact, in terms of energy demands and the use of chemicals, is reduced.

Commercial systems are already available that employ photocatalytic methods for water purification and nanosized titanium dioxide is being produced by several companies on a commercial scale. One of the main barriers to commercialisation is the need for education of potential users on the limitations of conventional water treatment systems. Further research is needed in order to control the treatment effectively in order to eliminate any toxic by-products. Investigation is also needed of the long term health and environmental risks of using nanoparticles for water purification and sustainability and recycling problems.

Nanofiltration systems are on or nearly on the market, but additional modifications might significantly improve the efficiency of the process in order to achieve successful commercialisation. The health and environmental risks related to nanofiltration lie not in the application of the nanoporous materials but in the disposal of the toxic products remaining in the concentrate and retentate and the contaminated filters after use.

Exposures to both types of nanotechnologies may occur in occupational settings. As is generally the case with nanoscale materials, the actual exposures, as well as the toxicity associated with the materials requires further exploration.

Session Schedule

Topic	Speaker	Stakeholder type	Time
Affordable clean water using nanotechnology	T. Pradeep, (Indian Institute of Technology Madras, India)	Academia	25 min
Photocatalytic wastewater treatment	Ralf Dillert (*Leibniz Universität Han-nover*, Germay)	Academia,	25 min
Solar photocatalytic processes for water disinfection	Pilar Fernández Ibáñez (CIEMAT, Spain)	Government/ Industry	25 min
Enhancement of photocatalytic degradation by modification of titania	Alexander Orlov (State University of New York, US)	Academia	25 min
Coffee Break			25 min
Photocatalysis for drinking water purification	Patrick Dunlop (University of Ulster, UK)	Academia	25 min
Capacitive deionization using novel nanoporous materials as a competitive process for the desalination of sea and brackish waters	Marc Anderson (University of Wisconsin, US)	Academia	25 min
Nanofiltration and adsorption for water treatment – the need of nanotechnologies	Armand Masion (CNRS, France)	Academia	25 min
Panel Discussion			40 min

ABSTRACTS

Affordable Clean Water Using Nanotechnology

T. Pradeep, Department of Chemistry and Sophisticated Analytical Instrument Facility, Indian Institute of Technology Madras, India

Water is one of the essential enablers of life on earth. But pure water is not available to a large fraction of the population of the planet. While availability is an issue, contamination is another major concern which threatens the survival of many. Intensive farming, rapid industrialization and increasingly sophisticated lifestyles have added artificial chemicals into the water bodies. While pesticide residues in ground waters were unexpected years ago as soil was thought to act as a filter, it is an established fact that even drinking water is contaminated with them in many parts of the world. Pesticide residues measured in drinking water and soft drinks in India far exceed the acceptable limits. Although these levels are significant vis-à-vis the permissible limits, the concentrations are low in comparison to those of commonly encountered chemicals and the purification technologies have to be efficient for them to be removed at affordable cost. In addition, the kinetics of the processes has to be such that a single encounter event with the filter medium must remove them effectively. As the affected populations may be at remote locations, inaccessible to piped supply, such methodologies have to be used also for point-of-use water purification applications. Significant progress has been made to utilize the chemistry of nanomaterials for water purification.

This talk outlines the recent efforts in the use of nanotechnology for providing clean water at affordable cost. This author has used noble metal nanoparticle based chemistry extensively for drinking water purification for three major types of contaminants: halogenated organics including pesticides, heavy metals and microorganisms. Recent efforts for the removal, as well as ultralow concentration detection of such species, using noble metal nanoparticles are summarized.

Important challenges during the commercialization of nano-based products are highlighted through a case study of pesticide removal using noble metal nanoparticles. Recent efforts in drinking water purification using other forms of nanomaterials are also summarized. The talk will touch upon recent investigations on the issue of nanotoxicity and its implications for the future. Our efforts to commercialize such technologies and the need to develop partnerships will be mentioned.

References

1. T. Pradeep and Anshup, Noble metal nanoparticles for water purification: A critical review, Thin Solid Films (2009) ASAP.

2. T. Pradeep and Anshup, Detection and extraction of pesticides from drinking water using nanotechnologies, in Nanotechnology Applications for Clean Water, N. Savage, M. Diallo, J. Duncan, A. Street and R. Sustich (Ed.) William Adrew, Norwich, New York, 2009.

Photocatalytic Wastewater Treatment

Ralf Dillert, Institut für Technische Chemie, Leibniz Universität Hannover, Germany

Photocatalysis using semiconductor particles has found increasing interest to solve global pollution problems. Compared to other semiconductor photocatalysts, TiO_2 has so far been shown to be the most promising material used for both fundamental research and practical applications because it is highly photoreactive, cheap, non-toxic, chemically and biologically inert, and photostable. The artificial generation of photons required for the detoxification of polluted water is the most important source of costs during the operation of photocatalytic water or air treatment plants. This suggests using the sun as an economically and ecologically sensible light source. Thus Solar Photocatalysis has become an important issue of research and development during the past 20 years. With a typical UV-flux near the surface of the earth of 20 to 30 Wm^{-2} the sun puts 0.2 to 0.3 mol photons $m^{-2}h^{-1}$ in the 300 to 400 nm range at the process disposal. Principally, these photons are suitable for destroying pollutants present in water, air, or on photocatalytically coated surfaces. The present lecture will present an overview of the authors' laboratory activities in Solar Photocatalytic Wastewater Treatment.

The properties and requirements for efficient photocatalyst materials will be discussed. A few representative model compounds have been selected to illustrate the major reaction pathways in photocatalytic degradation processes. Crucial reaction parameters such as pH, temperature, solute concentration and light intensity, are given together with current theoretical models to explain their effects on the overall process efficiency.

In recent years several reactors for the solar photocatalytic water treatment have been developed and tested. The four most frequently used reactor concepts are presented and several examples for the treatment of real wastewater are shown together with some initial economic considerations. In particular, the Thin Film Fixed Bed Reactor (TFFBR), the Double Skin Sheet Reactor (DSSR), the Compound Parabolic Concentrating Reactor (CPCR), and the Aerated Cascade Photoreactor (ACP) will be described in detail. Pilot Plants employing these reactor concepts have meanwhile been built and tested by various research teams, hence, a brief overview concerning the first experiences with these installations will be given.

References

1. R. Dillert, A. E. Cassano, R. Goslich, D. Bahnemann, "Large Scale Studies in Solar Catalytic Wastewater Treatment", Catalysis Today 54 (1999) 267-282

2. D. Bahnemann, "Photocatalytic Water Treatment: Solar Energy Applications", Solar Energy 77 (2004) 445-459

Solar Photocatalytic Processes for Water Disinfection

Pilar Fernández Ibáñez, Plataforma Solar de Almería, CIEMAT, Spain

During the past years there has been tremendous research and development in the area of photocatalysis. One of the major applications of this technology is the degradation of organic pollutants in water by what are then called Advanced Oxidation Processes (AOP). This conference reviews the use of sunlight to produce the •OH radicals. The systems necessary for performing solar photocatalysis will be described. Most of the research related to solar photocatalytic degradation of water contaminants carried out during recent years in Plataforma Solar de Almería facilities, and how it could significantly contribute to the treatment of very persistent toxic compounds will be summarised. Various solar reactors for photocatalytic water treatment based mainly on non-concentrating collectors erected during the last few years will be also described in detail. The use of the solar photocatalytic processes (TiO2) to inactivate microorganisms present in water will be reviewed, placing special emphasis on some experimental systems erected to optimize this disinfecting technique. Recent experiences on solar photocatalytic and solar-only disinfection of water done in Plataforma Solar de Almería will be shown in this speech.

Enhancement of photocatalytic degradation by modification of titania

Alexander Orlov, Materials Science and Engineering, State University of New York at Stony Brook, United States

Combining solar light with photocatalysts can destroy a variety of dangerous pollutants in air and water. Depositing the known photocatalytic materials on nanostructured support, using nanoparticles to modify the activity of semiconductors, doping and changing the particle size of the catalysts are the strategies we have employed to enhance the activity of photocatalysts. Modifying the traditional catalysts with metal nanoparticles can lead to unprecedented increase in activity. We have deposited the noble metal nanoparticles on conventional TiO_2 based photocatalyts. The optimum metal loading corresponded to a mean particle size of $\leq$ 3 nm at which point it may no longer be metallic. Such catalysts have exhibited a threefold rate enhancement of MTBE degradation compared to unmodified TiO_2. These materials have also been very active towards a degradation of 4-chlorophenol, exhibiting twofold rate enhancement.

We have also explored the unusual properties of high surface area materials, such as mesoporous molecular sieves, for environmental degradation of 4-chlorophenol. We have used several methods of post-synthesis modification of the mesoporous molecular sieve with titanium: impregnation, grafting and modification with colloidal titania. The resulting materials were characterized various spectroscopic techniques. All modified materials have showed a significant activity towards the degradation of 4-chlorophenol.

Finally, we have explored the strategies of shifting the activity of catalysts into visible region. The advantage of visible light active as compared to UV light active materials is much more efficient energy utilization, as the solar spectrum contains only a small UV component. We have developed various photocatalytic materials, more active than the conventional materials under both UV and visible light. Based on theoretical calculations and model system studies we have addressed the issues of reproducibility and activity of N-doped, B-doped and B,N-codoped catalysts.

Photocatalysis for Drinking Water Purification

Patrick SM Dunlop, Nanotechnology and Integrated Bioengineering Centre (NIBEC), University of Ulster, Northern Ireland

The use of titanium dioxide photocatalysis for environmental remediation of air and water is well documented and explored. Photocatalysis research at the University of Ulster has been ongoing for several years with particular emphasis on water treatment applications utilising immobilised nanoparticle films. Significant research has been carried out with regards the degradation of organic pollutants in water using a range of titanium dioxide powder films, including the research standard Degussa P25. Recent attention has been focused on the development of novel photocatalytic nanoparticles which offer beneficial properties based upon the increased surface area available redox chemistry.

This presentation will focus on the photocatalytic research undertaken at the University of Ulster to remove persistent organic pollutants (POP's) and microorganisms from drinking water sources. POP's present a significant threat to human health and the environment due to their tendency to bio-accumulate in the tissues of living organisms and progress through the food chain. Many of these pollutants have also been reported to have endocrine disrupting capabilities. Photocatalysis using immobilised titania nanoparticles has been shown to be effective for the degradation of pesticides and endocrine disrupting chemicals. Chlorine resistant organisms also represent a significant problem to the drinking water industry. Photocatalysis has again shown promise towards disinfection of microorganisms including Clostridium spores and Cryptosporidium oocysts. Photocatalytic disinfection using solar radiation shows particular promise in relation to water purification in developing regions. Materials research into the production, characterisation and application of novel photocatalytic nanorods and nanotubes will also be discussed.

Capacitive Deionization Using Novel Nanoporous Materials as a Competitive Process for the Desalination of Sea and Brackish Waters

Marc A. Anderson, Environmental Chemistry and Technology Program, University of Wisconsin – Madison, United States

Capacitive Deionization (CD) or sometimes referred to as electro-sorption is a low pressure process of deionization that can directly compete with membrane or distillation as a means to deliver waters free of ions at reduced cost and operating expense. This process operates by sequestering ions near charged surfaces in the electrical double layer. A schematic pictorial of how this process works is shown in Figure 1. A solution of ions flows through a highly porous conducting pair of electrodes and the anions or other negatively charged species are removed at anode while the cations or positively charged species are removed at the anode.

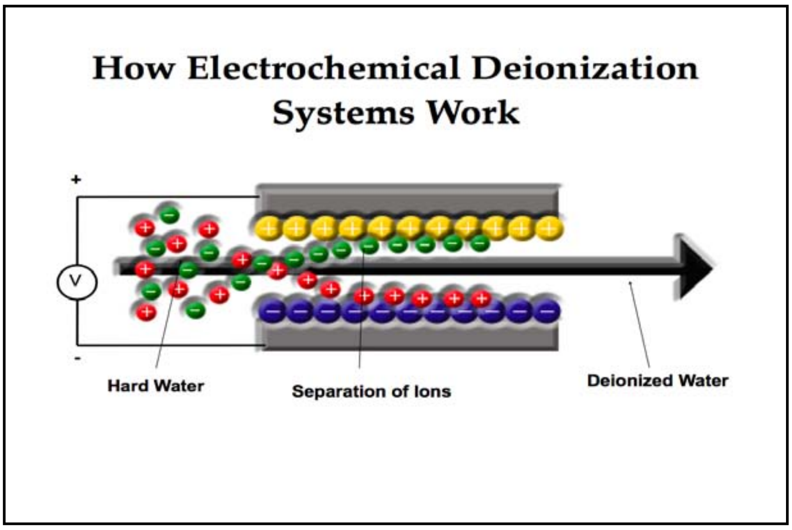

Figure 1. Schematic diagram showing the removal of charged ions or species by two charged electrodes.

This process is more efficient and uses less energy than either Reverse Osmosis (RO) or

Multi Stage Flash Distillation (MFD), the two most used methods of desalination in the world today. Furthermore, because ions are stored at the interface of a charged surface this device is actually capable of storing its own energy. It thus is energy efficient. This process is 10 years old and in its early stages of adoption. Using new nanoporous materials that are 30-60% more efficient, and a novel method of regeneration, we have shown we can greatly improve this capacitive deionization making it even more competitive with RO and CFD.

In comparison to present desalination techniques these systems use low voltage and low pressure. In addition, they are not subject to as much fouling as RO is, thereby reducing the cost of cleaning. In summary, capital and operating cost are expected to be significantly lower than RO and MFD technologies.

We hope that in the not too distant future our novel method of capacitive deionization using nanoporous oxide materials will become cost competitive with conventional desalination systems and present some interesting alternatives for water treatment.

Nanofiltration and Adsorption for Water Treatment – The Need of Nanotechnologies

Jean-Yves BOTTERO; Jérôme ROSE*; Mélanie AUFFAN& ; Matthew HOTZE* ; Armand MASION*; Jérôme LABILLE* ; Mark-Robert WIESNER&*

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In the environmental technology industry alone, nanomatériaux will enable new means of reducing the production of industrial wastes, using resources more sparingly, remediating industrial contamination, providing potable water, and improving the efficiency of energy production. Three new kinds of nanotechnology materials that should be developped in the future : Membranes, Oxidants, Adsorbents . Nanoscale control of membrane architecture may yield membranes of greater selectivity and lower cost in water treatment. Fullerene-basded oxidant nanomatériaux such as C60 have a high electron affinity and reactivity, and are capable of producing reactive oxygen species such as single oxygen and superoxides. Fullerene might be used in engineered systems to photocatalytically oxidize organic contaminant, or inhibit or inactivate microbes or viruses. In the same way the use of nano zero valence iron (ZVI) to treat in-situ polluted ground water is based on the oxidation of ZVI and réduction of organic pollutants. The high capacity of nanomaghemite or nanomagnetite to (ad)(ab)sorb metals as As, Co….is due to the existence of new adsorbing sites when size is lower than ~20 nm could open a new route for developping new adsorbents.

PARALLEL SESSION TWO - ENVIRONMENTAL SENSING

Context for the Session

One potential application of nanotechnology for the environment is the development of rapid, accurate, miniature environmental sensing and monitoring instruments and tools. The incorporation of "smart" technology, i.e. the ability to perform specified action depending upon the nature, concentration, and location of the detected substance(s) and to self-repair in the event of failure or trauma, will enhance this detection and monitoring capability. Alerts can subsequently be issued immediately both to the general public and personnel within appropriate regulatory agencies concerning toxic or hazardous substances in the air, water, or soil media. Timely alerts could avert or at least minimize the public's potential for exposure and hasten agency response actions. Anticipated future capabilities would include the ability to: detect minute concentrations of a variety of compounds simultaneously, record the collected data, transmit the data to a central facility in a user-friendly format, provide warnings for potential exposures to dangerous concentrations of toxic compounds, isolate these compounds to minimize human and environmental impacts, and facilitate remediation and/or treatment.

Significant societal benefits would derive from field advancement of nanotechnology-enabled sensing and monitoring devices. Not only would such research enable protection of the public from toxic compounds, but it would also prevent the deterioration of the ecosystem. The development of sensing devices would also provide a more holistic understanding of the state of the environment – from biodiversity (species extinction) to soil erosion. The complex interwoven fabric of personal health and the health of the environment requires a multi-faceted, multi-media understanding, which in turn requires multi-disciplinary, integrated data sets. Nanotechnology-enabled sensing and monitoring would allow these devices to yield such data.

Potential adverse impacts resulting from such devices should be considered prior to widespread adoption of the technology. Specifically, whether the miniaturization of devices may result in these devices being easier to dispose of rather than recycled, resulting in environmental litter. Potential societal and cultural issues should be considered as well. The adoption of novel technologies that appear contrary to cultural, moral, or religious tenets are unlikely to be embraced.

Other significant potential environmental benefits of nanotechnologies through 'environmental sensing' include innovative detection technologies of nanoparticles in the environment (i.e. developments of detectors and detection technologies that can trace and/or identify manufactured nanoparticles against the background of naturally occurring nanoparticles).

Research needs in the area of sensing are for more accurate, precise, and inexpensive devices that are capable of rapid detection of minute concentrations of analytes in complex matrices. In addition, the development of improved computational techniques that can efficiently assimilate massive data sets of varying formats and provide a comprehensive account of the environment are a vital aspect to developing a holistic understanding of the state of the environment.

Session Overview

The researchers and technologists participating in this workshop will present an overview of state-of-the-art research in sensing devices, outline potential opportunities in this area, and provide an assessment of potential challenges. The workshop will also provide information concerning the possible adverse societal effects posed by the introduction of these novel devices. The potential implications of these devices and materials will be explored from the complete material life cycle.

Information provided by this workshop will include:

- the future of nano-enabled sensing devices and nanomaterials sensors and detector with high sensitivity and specificity,
- the opportunities to advance the field and positively impact development of nanotechnology-enabled sensing devices, and of nanomaterials detection in the environment;
- the challenges to advancing the field of sensing through the use of nanotechnology-enabled sensors, as well as through improvement of nanomaterials sensors and detectors; and
- the consideration of societal impacts resulting from the introduction of novel technologies.

The workshop will provide time for perspectives from researchers in academia and industry and will represent international perspectives.

The workshop on Nanotechnology-Enabled Sensing Devices / Environmental Sensing will last approximately 4 hours including a coffee break and could run in parallel with another workshop. Presentations are between 20 and 30 minutes in duration. Two moderators will introduce speakers, monitor time, and manage questions. A rapporteur will capture the major findings of the presentations and discussion for the Conference document.

Background on Sensing Technology

The next generation of sensing devices, designed to utilize nanotechnology or to detect nanomaterials, will enable revolutionary data gathering approaches for understanding the environment by providing observations at novel temporal and spatial scales. Improvements in data collection and assimilation will generate a holistic understanding of the status of our environment and will enable the development of more proactive approaches for environmental protection.

The first sensors enabled scientists to determine the levels and types of compounds found in certain media. Sensor development has lead to the ability to predict transport and transformations of some compounds in various environmental media. The collection of air pollutant concentrations, for example carbon dioxide, particulate matter, sulfur dioxide, nitrogen oxides, and ozone, has enabled scientists to link contaminants with human health effects. Subsequent actions taken by regulators, policy makers, and industries have resulted in reductions in cleaner air and healthier populations.

There is, however, a need to develop more integrated assessments of the effects of complex mixtures and multi-media models that will enhance our ability to protect public health and the environment. There is also a need to understand the interconnectivity between identified human activities and ecosystem impacts. Advancements in sensing devices using nanotechnology is a way toward meeting that need.

Advances in Sensing Technology

Advances in wireless network technology and miniaturization will enable the attainment of realistic and accurate data on the environment. Reaching this goal will require understanding the field or domain under observation, defining limits and incorporating appropriate data sets. Sensing networks that provide an understanding of the physical, chemical, and biological state of the environment will advance scientific understanding of the ecosystem and the interwoven impacts of human activity and ecosystem response, and enable enhanced protection of human health and the environment. The ability to understand how one compound interacts with the ecosystem, impacts human and ecological health, which in turn impacts the ecosystem further, will enable the development of preventative approaches to exposure and novel treatment techniques.

Human Health, Environmental, and Societal Impacts

The impact of novel technologies, including nanotechnology, upon human health, the environment, and society will also be discussed at this workshop in terms of nano-enabled sensing devices and networks. The possible development of devices and networks that are left in the ecosystem at the end of their usefulness could result in deleterious effects on the ecosystem. In addition, the release of harmful, albeit minute, concentrations of compounds may reach a critical mass if hundreds of thousands are deployed in the environment.

Careful scrutiny of the manufacturing and chemical processing of nano-enabled sensing devices should be undertaken to ensure use of benign materials. In addition, the replacement of toxic compounds in current sensing devices, or materials that prove harmful to the environment at the end of their life cycle with benign nanomaterials, should be should be strongly advocated.

The aspect of respecting the cultural norms of a society is an important one. Care should be taken to understand such norms and introduce novel technologies into societies in respectful ways that are mindful of cultural morays. This will facilitate the acceptance of these technologies, thereby improving the quality of life for many.

Life Cycle Perspectives

Raw Material Extraction and Processing

Benign raw materials should be used to minimize adverse impacts on human health and the environment. Manufacturing and processing techniques should be employed that incorporate efficient use of materials, energy, and other resources. Extraction and processing techniques that are flexible will enable alterations to be incorporated with minimal capital expense and difficulty.

Environmental Release – Product Manufacturing and Transport

Steps should be taken to eliminate major releases to both the work and natural environment. Protection of workers from releases in the facility and protection of the general public from releases to the environment can be avoided through well designed practices and workplace hygiene activities. The transport of products with care will minimize releases during transport of primary material products.

Environmental Release – Product Use

The use of nanomaterial-enabled technologies may result in the release of materials through consumer use. The release of materials from the designed or intended use of the product by the consumer may occur. In addition, releases from the unintended use of products (children mouthing objects) can also occur. Consequently, steps should be taken to eliminate or minimize the release of toxic materials from specific products. The use of benign materials, whenever possible, should be encouraged.

Product End of Life

To the extent possible, products should be designed for reuse or recycling capability. The reduction of waste material and the reduction in the amount of raw material required will positively impact human health and the environment. Care should be taken to avoid materials that result in toxic releases at the anticipated end of their life cycle, or that are impossible to recycle or reuse. The increase in the numbers of reusable materials will greatly reduce the environmental footprint of industry.

Policy Considerations

There are many governmental agencies and departments tasked with determining policies and regulations related to environmental protection. Consequently, the responsible development and use of sensing devices will be a critical interest to these organizations as policy needs are assessed.

Some application will enable improved environmental protection. This can occur in a variety of ways including the development of more efficient, inexpensive, and rapid sensing technologies that will enable existing polluted areas to be efficiently and cost-effectively cleaned.

However, there are concerns regarding the interaction, overlap and oversight of the regulatory authorities, both within countries and across countries. As industry continues to operate globally and as environmental protection is increasingly managed holistically, it is critical that these agencies adapt consistent policies and regulations.

This collaboration will become especially important once products with nanomaterials begin to be manufactured on a mass scale and start to dominate the marketplace. It is essential to clearly delineate the authority and capacity of these organizations in order to ensure a smooth transition of valued and important products to consumers while maintaining the health and welfare of the manufacturing workers, the general public, and the environment.

Session Schedule

Topic	Speaker	Stakeholder type	Time
Recent advances in microfluidic device applications for environmental monitoring and ecotoxicological assessments	Prof. Tae-Hyun Yoon, (Hanyang University, Korea)	Academia	30 min/ 20min
New methods to measure environmental exposure in real time	Hans Jürgen Grimm (Grimm Aerosol, Germany)	Industry	30 min
Chemical and biochemical sensing with silicon nanostructures	Michael J. Sailor (University of California - San Diego, US)	Academia	30 min
Coffee Break			20 min
Sensors as tools for quantitation and cytotoxicity studies of engineered nanomaterials	Omowunmi Sadik (State University of New York-Binghamton, US)	Academia	20 min
Nanomaterial based environmental sensing	Sung IK YANG (Kyung Hee University, Korea)	Academia	20 min/ 30min
Crystalline nanowires of semiconducting metal oxides as a new generation of gas sensors	Alberto Vomiero (CNR, Italy)	Academia	20min
Exposure and dose relationships of particulate matter in the environment	Robert Muir (Naneum Ltd, UK)	Industry	20 min
Micro- and nanotechnology enabled platforms for environmental monitoring	Ashwin Seshia (Cambridge University, UK)	Academia	20 min
Penal Discussion			30 min

ABSTRACTS

Recent Advances in Microfluidic Device Applications for Environmental Monitoring and Toxicity Assessments

Tae Hyun Yoon, Department of Chemistry, Hanyang University, Seoul, Korea

During the last few decades, increasing numbers of microfluidic device applications in the area of environmental monitoring and biological assays were reported, due to the ever-increasing demand for in-situ real time monitoring and high-throughput toxicological assays. In this presentation, I will give an overview on recently published studies on the applications of micro total analysis system (TAS) or Lab-on-a-chip for environmental monitoring and toxicological assessments. This presentation will also cover current status of important components of these novel platform technologies, such as fabrication methods and materials of microfluidic devices, types of detection methods (e.g., electrochemical, optical and fluorescence) and (bio)chemical sensors used for this novel approach as well as the author's perspectives on future directions for environmental monitoring and toxicological assessments using microfluidic devices.

New Methods to Measure Environmental Exposure in Real Time

Hans Grimm[1], Jürgen Spielvogel[1], Markus Pesch[1] and Lothar Keck[1], [1]GRIMM AEROSOL Technik GmbH & Co. KG, 83404 Ainring, Germany

During the handling of nanomaterials there is the risk that nanoparticles are released in airborne state, and these nanoparticles might be harmful to health when inhaled by the employees. Thus, monitoring of nanoparticle concentrations is recommendable.

Therefore Grimm has developed many different methods to measure this fine"dust"

1. Beginning from a portable Aerosol Spectrometer, measuring the particle size distribution and the concentration at indoor, work-place and even in the environment.
2. This was extended with a NANO measurement instrument, called "Nanocheck", which is intended for fast and easy assessment of nanoparticle exposure risks. The instrument consists of a corona charger, a condenser, and a Faraday Cup Electrometer, and it measures total number concentration and mean size of nanoparticles.
3. High precision validation /calibration systems such as "Scanning Mobility Particle Sizers" (SMPS), which employs a Differential Mobility Particle Sizer (DMA) and a Condensation Particle Counter (CPC), where added.
4. Furthermore, instruments measuring finer as 1 manometer complete our product line of our Electrometers.
5. Outdoor nano and micro particle sizer, able to measure the atmospheric conditions and concluding them in official mass concentrations, such as PM-10 and PM-2.5 and PM-1 are also available and used world-wide.
6. The newest technologies call for "speciation technologies" consisting of methods to

determinate the semi volatile compounds as well as

With these new and different methods we can detect limits in count and mass values for inhalable, thoracic and alveolic mass fraction in the different work place conditions.

This presentation will show examples and results obtained with these new methods.

Chemical and Biochemical Sensing with Silicon Nanostructures

Michael J. Sailor, Department of Chemistry and Biochemistry, University of California - San Diego, United States

Nanotechnology enables the fabrication of complex miniature devices that can be used to detect traces of chemicals in the air, in water, and in the body. However, several problems limit the fidelity of microsensors: nanostructured sensors are subject to corrosion-induced zero point drift, they can absorb molecules that interfere with detection of their targets, and they are limited in their ability to identify specific analytes. Nanostructured porous silicon possesses many properties that can be harnessed to solve these chemical detection problems. Prepared by electrochemical etching of silicon in HF-containing electrolytes, porous silicon can be used to build multi-stage nanoscale reactors: the size and shape of the pores can be used to separate molecules, enzymes can be entrapped to perform specific catalytic reactions, and the photonic properties provide highly sensitive and label-free detection.[1, 2]

The photoluminescence and reflective optical response of porous silicon is sensitive to chemical adsorbates, allowing the design and construction of small, low power sensors for chemical and biological compounds.[3] Of particular interest are reflective systems, in which detection of chemicals or biomolecules is achieved by monitoring the change in the spectrum of light reflected from the material. This usually derives from a change in refractive index that occurs when analyte is captured in the pores or on the surface of a film. This presentation will discuss the synthesis and properties of porous Si films, microparticles, and nanoparticles, and their application to environmental separations and sensing problems.

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Sensors as tools for Quantitation and Cytotoxicity Studies of Engineered Nanomaterials

*†*Sadik O. A., †Samuel N. Kikandi, †Qiong Wang, †Ailing Zhou, †Nian Du, Fenix Garcia & **Katrina Varner*

†Department of Chemistry, State University of New York-Binghamton, NY, United States; **US-EPA/NERL, Characterization Research Division, Las Vegas, United States

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The discovery of fullerenes in 1985 has ushered in an explosive growth in the applications of engineered nanomaterials and products. Some of the special properties that make nanomaterials useful may also cause them to pose hazards to humans and the environment. Positive cytotoxicity and genotoxicity have been reported for the water-soluble C_{60} aggregates (nC_{60}), despite its low hydrophobicity. Nanomaterials also offer new possibilities for the development of novel sensing and monitoring technologies. Nanosensors can be classified under two main categories[1]: (1) sensors that are used to measure nanoscale properties; and (2) sensors that are themselves nanoscale or have nanoscale materials or components. The first category can enhance our understanding of the potential toxic effects of industrial pollutants. This is an area of critical interest to detection and risk assessment, as well as for monitoring of environmental exposure[1,2.] The second category can eventually result in lower material cost, reduced weight and power consumption[3]. In this presentation, the first category of sensors will be described based on ultrasensitive portable UPAC sensor for monitoring the cytotoxicity of engineered nanomaterials including fullerenes, dendrimers and metal nanoparticles. The presentation will also involve the second category of sensors focusing on the mechanism of molecular recognition, material design and characterization, sensing efficiency as well as potential application for improving environmental quality.

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Nanomaterial Based Environmetnal Sensing

Sung Ik Yang, Department of Applied Chemistry, Kyung Hee University, Korea

Currently, nanotechnology has been received much interests since their significant implications including order-of-magnitude increases in computer efficiency, advanced pharmaceuticals, bio-compatible materials, surface coatings, catalysts, sensors, and pollution control. Nanotechnology deals with the matter at dimensions between 1 and 100 nm and involves imaging, measuring, modeling, and manipulating matter at nanoscale. Unusual physical, chemical, and biological properties of nanoscale materials can enable nanotechnology to solve the current problems including energy, medical, sensor, and environmental problems. In particular, nanotechnology is promising for chemical, environmental, and biochemical monitoring.

Carbon nanotubes, Semiconducting nanowires, and metal nanoparticles have been received intense interests due to their potential applications in real-time and on-site detection of ions, small molecules, proteins, and viruses with high sensitivity and selectivity. The unique optical properties of plasmonic nanoparticles have led to the development of label free chemical and environmental sensor since the surface plasmon resonance is sensitive to the local environment. Semiconductor nanowires and Single-walled carbon nanotube based sensors have been fabricated for the detection of small chemicals and biomolecules with high sensitivity, where the electric field is produced through the charge accumulation at the surface.

In this talk, recent results on the development of nanosensors and the application of nanostructures in the field of environmental analysis will be presented.

Crystalline Nanowires of Semiconducting Metal Oxides as a New Generation of Gas Sensors

Alberto Vomiero, Researcher at National Council for Research (CNR) - National Institute for the Physics of Matter (INFM) SENSOR Lab, Brescia, Italy

Quasi-1D nanostructures of semiconducting metal oxides such as zinc, tin or indium oxides are presently investigated to produce an emerging class of sensing devices These materials, due to their peculiar characteristics and size effects, show novel physical properties compared to those of the bulk. Beyond the capability to control the elemental composition, control over the particle shape and size distribution is continuously pursued because many applications of nanostructures exploit the properties related to crystallographic features. The extraordinary potential of crystal engineering has been recently exploited for electronics, pigments, cosmetics, and ceramics. Semiconducting nanowires are promising also for the field of bio-nanotechnology and chemical sensing.

The deposition of metal oxide nanostructures can be obtained by evaporation/condensation technique starting from metal oxide powders. Two basic process, namely vapor-solid (VS) or vapor-liquid-solid (VLS), are recognized to drive the growth of the nanowires. The simplicity of the vapor phase condensation method with respect to the technology of silicon processing and to other top-down approaches, as well as the capability to control the thermodynamic conditions makes this approach highly promising for nanostructure fabrication. The as-synthesized oxide nanostructures are pure, structurally uniform, and single crystalline.

Metal oxide semiconductor interactions with the surrounding atmosphere are known from more than four decades; their sensing properties are based on surface reactions with gases in the atmosphere that cause a change in the semiconductor’s conductance due to charge transfer between the adsorbate and the adsorbent. We have studied the conductive property of the multi-wires sensing device in atmospheric environment, and we have performed an investigation on the sensing capability toward gases and vapors such as NO_2, an oxidizing gas of great importance for air-quality monitoring in urban areas, and CO, ethanol and ammonia. The response is enhanced as the lateral dimensions of the nanowires decreases, as expected. The greatly enhanced surface/volume ratio magnifies the role of surface states - a crucial feature for gas sensitivity. The response is reproducible and the recovery of the air signal conductance is complete after the target gas removal.

Furthermore the optical properties of 1D nanostructures can change as a function of the different environments. The visible photoluminescence of tin and zinc oxide nanowires is quenched by nitrogen dioxide at ppm level in a fast (time scale order of seconds) and reversible way. Besides, the response seems highly selective toward humidity and other polluting species and it is maximized at room temperature. This feature could be interesting for application of nanowires as selective optical sensors operating at room temperature. The experimental evidences foresee the development of a new class of stable metal-oxide multiparametric gas sensors based on electrical and optical transduction mechanisms.

Exposure and Dose Relationships of Particulate Matter in The Environement

B. Gorbunov [1], R Muir[1], H Gnewuch[1], [1] Naneum, CEH, University of Kent, Canterbury, UK

Widely accepted metrics for monitoring air quality are based upon a fraction of airborne particle mass such as PM_{10}, $PM_{2.5}$ as these represent the fractions deposited in the human respiratory tract.

Although PM 10 levels have been steadily reducing in many countries these metrics can cause uncertainties in health risk evaluations as they take no account of the effect of deposition efficiency, due to variation of particle sizes, on the exposure – dose relationship.

This paper presents data which investigates the total aerosol identifying the mass fraction which represents the highest risk.

Exposure and dose have been evaluated using conventional OH sampling kit and a size resolving wide range aerosol sampling system (Nano-ID) at various working places and in the general environment. Nano-ID enables particle size distributions to be obtained across the entire airborne particle size range from 1 nm to 30 micro meter in diameter. Anthropomorphologically produced nanoparticles, including incidentally produced particulate matter such as lead and respirable silica and engineered nanoparticles such as CNT and nanosilver, were investigated. Mass concentration size distributions were used to determine the exposure and the accumulated dose by applying verified ICRP models to determine the aerosol size fraction representing the greatest health risk.

The total mass concentration of nanoparticles and the nanoparticle mass fraction (i.e. sizes less than 100nm) varies considerably, e.g. for lead aerosols determined at working places mass concentration ranged from 0.6 □g/m^3 to 50 □g/m^3 and the mean size from 17 nm to 300nm. The nanoparticle mass fraction of aerosols was found to vary from 10% to 80%. The proportion of total mass of particles deposited in the respiratory tract of workers varied from 0.2 to 0.7. The evaluation of health risk based upon PM_{10}, $PM_{2.5}$ and other defined respirable fractions of the particle mass does not take account of levels of particle deposition in the respiratory tract and will therefore overestimate or underestimate the health risk considerably by up to a factor of 3.5.

Micro- and Nanotechnology Enabled Platforms for Environmental Monitoring

Ashwin A. Seshia Nanoscience Centre, Cambridge, UK

Low cost monitoring of the natural and built environment is increasingly important in a number of different applications dictated by engineering towards a more sustainable future. This includes monitoring the quality of air, water and food, optimising soil and irrigation conditions for agriculture, meteorological research and early warning systems for natural disasters, monitoring large scale built and ageing infrastructure, improving the energy efficiency of existing industrial processes and developing solutions for green technologies including carbon capture and storage. Micro- and Nanotechnologies are now beginning to provide solutions to drive these applications by enabling new platforms for low cost and minimally disruptive monitoring of the natural and built environment.

Two particular application scenarios will be described in detail. The first one involves low-power wirelessly networked sensor platforms embedded seamlessly within the environment to provide large scale and continuous time data on physical and chemical properties. These sensor nodes are being developed to operate at very low power levels to make energy scavenging possible and to transmit on local event triggers. An ongoing research project at Cambridge is examining the feasibility of deploying these wirelessly networked monitoring systems for ageing underground infrastructure. The second application involves portable and highly sensitive gas detector platforms by scaling miniature mass spectrometers and related sensor systems. These platforms can be utilised for air quality monitoring and applications involving the trace detection of toxic chemical species. In both of these applications, the dimensional scaling and system integration enabled by micro- and nanotechnology is a significant contributor towards achieving practical systems that are low cost, low power, portable and integrate high sensitivity detection.

PARALLEL SESSION THREE - CLEAN CAR TECHNOLOGY

Context for the Session

Reduction in the emission of NOx, Particulate Matter (PM), SOx, and other pollutants has become one of the greatest challenges to the future of the environment. Air pollution by nitrogen oxides (NOx) from combustion can cause serious environmental problems, particularly in urban areas. The use of nanotechnology for successful emission control and reduction in, for example: exhaust purification; development of new fuels; advanced catalysts; and other technologies are highly likely to be realized in the near-term.

Fuel cells are devices which electrochemically convert the energy of a fuel into electricity with much higher efficiencies than are seen with conventional chemical processes. As such, fuel cells can, potentially, be used in a wide variety of applications that should alleviate some of the energy/environmental issues described above. Polymer Electrolyte Membrane Fuel Cells (PEMFC) and Solid Oxide Fuel Cells (SOFC) are the systems under active development using nanotechnology, with potential markets including, for example, replacement of the car engine, and for use in auxiliary power units (APU).

Background on the Emission Reduction and Fuel Cell Technology for Automotive Applications

An improvement in the efficiency of, and a reduction in, the environmental load imposed by vehicles is necessary in preventing global warming and generally protecting the environment. Furthermore, regulations are tightening worldwide with respect to reducing CO_2 emissions, by improving fuel efficiency, and reducing the emission of environmental pollutants such as NOx, PM and so on. Highly-efficient engines, such as lean-burn engines and common-rail diesel engines, have been studied extensively with the aim of improving their fuel efficiency. However, the amount of NOx emission from these highly-efficient engines has increased due to an increase in their combustion temperature and pressure. Furthermore, conventional three-way catalysts cannot fully decompose NOx because of the high concentration of oxygen in the exhaust gas. It has proven difficult to have both an increase in fuel efficiency and a cleaner exhaust gas. Furthermore, SOx in the engine exhaust needs to be greatly reduced in order to increase the life of the exhaust catalysts. Emission purifying technologies that have already been developed have a number of problems including: increased consumption of fuel; and the emission of harmful substances resulting from the use of ammonia that needs to be present as a reducing agent. The establishment of an innovative NOx purification technology, that meets the tightening legal regulations on exhaust gas emissions, is essential in putting highly-efficient engines into practical use.

Fuel Cells are another potential technology that is being developed in order to put clean cars on the road. EV and FC cars are being studied vigorously, and will one day replace the internal combustion engines currently used. Polymer electrolyte fuel cells (PEFC) and solid oxide fuel cells (SOFCs) are the most likely candidates to be realized and eventually marketed for these types of applications. However, there are many problems still to be solved including reliability, cost reduction, longevity and so on. There are currently a large number of research programs around the world trying to solve many of these issues that are potentially show-stoppers for their commercialization.

Advances in Emission Reduction Technology and Fuel Cells for Car Applications

A promising purification technology, run under high oxygen concentrations and using selective reduction catalysts, is currently under active development. Technologies for reducing the amount of sulfur in fuels have also been achieved in order to reduce the amount of SOx in the engine emissions and thus improve the life of the exhaust catalysts. Furthermore, the development of novel deNOx and PM reactors, to substitute current catalyst converters and diesel particulate filters, is also in progress. Electrochemical reactor technology for NOx decomposition is an exciting application of nanotechnology in use. This should allow better electrocatalytic selectivity of specific decomposition reactions for defined harmful molecules, in the electrochemical cells, to occur.

PEMFC fuel cells have already been demonstrated for a number of decades in both buses and other vehicles up to one hundred kW output power. Solid Oxide Fuel Cells (SOFC), although somewhat behind in terms of development due to issues related to the use of ceramics at high temperatures, are slowly being implemented into applications such as small power generators. The essential electrochemical reactions, in these types of electrochemical reactors, occur on the nano-scale reaction zones in the electrodes. Thus, nano-particles play a crucial role in enhancing these reactions by, for example, forming a reactive network. The design and fabrication of interfaces and matrices of nano-particles has the potential to allow for what is often termed hyper-ionic conductivity. The reaction in an SOFC is the electrochemical conversion of a material's chemical energy to electric energy. The reverse of this is known as electrolysis (sometimes undertaken in a SOFC in reverse, known as a solid oxide electrolyzer cell (SOEC)) whereby the reaction can be electrodecomposition of water. The most important factors to consider for the electrochemical reaction are mobility of the ionic species, and the microstructural control of the electrodes and electrolyte, to allow for the enhancement of the chemical and/or the electrochemical reactions.

Environmental and Health Considerations

Application of nanotechnology for the reduction of car emissions could mean that human beings drive near-zero emission engine systems with high energy efficiency. Not only would this reduce the emissions of NOx, PM, and other pollutants, but would also reduce the carbon footprint. The technologies described above not only contribute in reducing air pollutants in urban areas, but also in the reduction of man-made global warming.

There are basically three underlying themes in the session:

- Theme 1: Fuels and Catalysis development
- Theme 2: Electrochemical reactor development
- Theme 3: Fuel cell development (SOFC and PEM)

These three themes will now be discussed in general terms, and will be developed during the session:

Theme 1 – Fuels and Catalysis Development

Development of new fuels for the reduction of components from the engine emissions that are harmful to catalysts. Nano-catalyst technology could not only reduce harmful emissions, but could also decrease the amount of noble metals, such as Pt, used in the catalysts. Novel technology to disperse the nano-catalyst particles throughout the structure could produce prolonged catalyst activity.

Theme 2 – Electrochemical Reactor Development

Reduction of NOx emissions can be achieved not only by catalytic NOx decomposition but also by electrochemical decomposition. The successful decomposition of NO gas into oxygen and nitrogen, in a primitive electrochemical cell, was first demonstrated over 25 years ago. Recently, however, advances in nano-science have allowed for the fabrication and testing of electrochemical reactors, for NOx and PM decomposition, based on nano-scale control of the electrodes. These electrodes show enhanced activity, with efficiencies much higher than catalytic convertors presently used. Finally, an anode with a controlled nanostructure is expected to be used in a new type of electrochemical PM purifier, showing an enhanced oxidation reaction.

Theme 3 – Fuel Cell Development (SOFC and PEM)

Fuel Cells (both PEMFC and SOFC) and other clean energy devices, for “green car” applications, will be discussed in this section. Here one can understand how nanotechnology permits to improve the understanding of the behaviour of the energy conversion achieved within elements constituting a PEM fuel cell. Long-haul trucks need electrical energy even during standstill periods, either to provide air condition and electricity to the driver during rest periods, or to operate necessary electric equipment. From an environmental point of view, it is not desirable to idle the main engine during these periods. Instead, diesel fuel operated fuel cells, so called auxiliary power units (APUs) can take over this task using only a fraction of the fuel. However, high temperature fuel cells with a high power density require novel material solutions that can be produced at low cost. Nanotechnology has been employed to develop novel, redox stable and cheap ceramic cells and novel ceramic cell contact ribs that can be operated at 850°C. Furthermore, Ceramic electrochemical (SOFC-type) reactors are envisaged to become commercially viable due to their high-efficiency and operability at intermediate temperatures (under 650 °C). Volumetric power densities of more than 2 kW/liter are expected by improvement of materials, accumulation of fine parts, and assembly of them into high performance modules. Under these circumstances, one would expect them to be used in applications such as auxiliary power units (APU) and small size cogeneration systems. When hundreds of these sub-millimeter tubes are precisely mounted in a porous electrode matrix and are thus accumulated as ‘cubes’, we can obtain high volumetric power densities. Micro tubular SOFC’s have been successfully fabricated and have demonstrated excellent performance with a power density of 1W/cm^2 at below 600^{o}C, and reaching 3W/cm^3 in one sugar cube sized system. Furthermore, development of novel ceramic fabrication processes for integration of these SOFC’s into cubes and cube-accumulated prototype modules have realized micro honeycomb type cell stacks with a cell integration density of 250 multilayered tubes per 1cm^3 in a porous electrode.

Session Schedule

Topic	Theme	Speaker	Stakeholder type	Time
Novel catalytic technologies for car emission reduction	1	Hideaki Hamada (Research Centre for New fuels and vehicle Technology, AIST, Japan)	Research Institute	30 min
Nanostructured electrochemical reactors for NO decomposition	2	Sergey Bredikhin (Institute of Solid State Physics, Russian Academy of Sciences, Russia)	Research Institute	30 min
Nanostructured electrochemical reactors for NOx/PM decomposition and micro SOFCs	2 and 3	Masanobu Awano (Advanced Manufacturing Research Institute, AIST, Japan)	Academia	30 min
Coffee Break				20 min
Ceramic Nanotechnology for Green Transportation	3	Michael Stelter (Fraunhofer-Institut für Keramische Technologien und Systeme, Germany)	Research Institute	30 min
Improvment of PEM fuel cells for car application: From stack characterisation to tailored electrodes nanostructured materials	3	Patrick Achard (Centre Energe'tique et Proce'de's - Center for Energy and Processes, MINES ParisTech, France)	Academia	30min
Panel Discussion				40 min

ABSTRACTS

Novel Catalytic Technologies for Car Emission Reduction

Hideaki Hamada, National Institute of Advanced Industrial Science and Technology (AIST), Japan

Catalytic after-treatment plays an important role to reduce harmful compounds in car emissions such as CO, hydrocarbon (HC), NOx and PM. Lately, various state-of-the-art catalytic technologies based on nanotechnology have been developed for gasoline and diesel cars in order to meet the recent stringent emission standards.

Three-way catalyst (TWC) now works quite effectively to reduce exhaust emissions from gasoline-fueled cars. Normally, a component with high OSC (oxygen storage capacity) is added to TWC to increase the A/F window. Toyota has recently developed homogeneous CeO_2-ZrO_2 solid solution materials covering whole Ce/Zr ratios and having high OSC. They have also succeeded in improving the catalyst durability by inhibiting the sintering of CeO_2-ZrO_2 by Al_2O_3.

"Intelligent catalyst" developed by Daihatsu is another example of the application of nanotechnology to exhaust catalyst. The catalyst is actually Pd catalyst supported on composite perovskite oxides featured by long catalyst life. While the particle size of active Pd grows steadily on Al_2O_3 causing catalyst deactivation, Pd on perovskite does not sinter because Pd metal is incorporated into the structure of perovskite under lean conditions and deposited again on perovskite under rich conditions. They have also succeeded in the preparation of new intelligent Pt- and Rh-based catalysts by manipulating the structure and composition of perovskite. On the other hand, Nissan and Mazda have commercialized TWC with less amount of platinum by using materials to inhibit its sintering.

Hydrocarbon adsorber TWC system has been developed by Nissan. This system can remove cold-start HC emission by using zeolite-based HC adsorber added to TWC. When the temperature of the exhaust gas is low at cold-start, the zeolite removes HC by adsorption, and after the temperature gets higher, the adsorbed HC is desorbed and reduced over TWC. In this system, the structure of zeolite is important to determine HC adsorbing capacity. Zeolites with larger pore size can adsorb large-size HC, indicating shape selectivity. The loading of Ag to zeolite was found effective to increase the HC adsorbing capacity.

The development of novel catalytic technologies to remove NOx emitted from diesel and lean-burn engines has attracted much attention, since there is a so-called trade-off problem between NOx emission and fuel economy concerning engine combustion improvement. Three types of catalytic NOx removal systems have been investigated: 1) NOx storage reduction (NSR) 2) SCR (selective catalytic reduction) of NOx with urea (urea-SCR), 3) SCR of NOx with hydrocarbons, H_2 or CO (HC-SCR, H_2-SCR, CO-SCR).

The NSR system originally developed by Toyota enables NOx removal by using a combination of TWC catalyst and NOx storage compounds such as alkali and alkaline earth metal oxides, in cooperation with engine control. Under lean conditions the NOx storage compound absorbs NOx, which are then desorbed and reduced by the function of TWC under stoichiometric-rich conditions. Recently Honda developed a new NSR catalyst containing CeO_2 and zeolite-based materials as catalyst components. Their catalytic system is more efficient for

NOx emissions at low temperatures, claiming the presence of NH_3 intermediate. Urea-SCR using V_2O_5/TiO_2 or ion-exchanged zeolite-based catalysts is an application of well-known NH_3-SCR and expected as a practical NOx removal system mainly for heavy-duty diesel vehicles. HC, H_2, and CO-SCR, found by Japanese researchers including our group, are considered as a more ideal method because the fuel and fuel-derivatives can be used as reducer. Since HC-SCR is comprised of a series of complicated parallel and sequential reaction steps, there are many factors affecting the catalytic activities. Although no catalytic systems have been put to commercial use regarding HC, H_2, and CO-SCR, the development of high-performance catalysts is still desired.

Nanostructured Electrochemical Reactors for NO Decomposition

Sergey Bredikhin, Institute of Solid State Physics Russian Academy of Science, Russia

The electrochemical reduction of nitric oxide in the presence of the excess oxygen is reviewed. To solve the problem of effective electrochemical reduction of nitric oxide in the presence of the excess oxygen the concept of artificially designed multilayer structure proposed. Our investigations have shown that substitution of traditional cathodes by the nanostructured multilayer electro-catalytic electrode leads to a dramatic decrease in the value of the electrical power required for NO decomposition. It was shown that nanostructured multilayer electro-catalytic electrode should consist at list from three main functional layers: Cathode; Electro-catalytic electrode; Covering layer, in order to operate as an electrode with high selectivity. The values of current efficiency in such reactors increase up to 20% and the values of the NO/O_2 selectivity up to 25. These results indicate that this new type of nanostructured electro-catalytic reactor can be used for practical applications and such systems should substitute traditional catalytic systems for exhaust gas purification.

Nanostructured Electrochemical Reactors for NOx/PM Decomposition and Micro SOFCs

Masanobu Awano, National Institute of Advanced Industrial Science and Technology (AIST)

Ceramic electrochemical reactors, with high conversion efficiency and reactivity for both energy production and chemical conversion, could be realized in, for example, electric power generators (SOFC), synthesis of hydrogen, and the decomposition and purification of environmental pollutants. Significant improvements in the selective purification of NOx in exhaust gases containing oxygen, using a novel electrochemical reactor, have been achieved by means of nano-scale control of an electro-catalytic layer in the electrochemical cell through a self organization process. Furthermore, two new types of electrochemical reactor have been developed. Firstly, PM/NOx clean-up reactors make it possible to oxidize particulate matters (PM) in emissions simultaneously with deNOx, through redox reactions, in an electrochemical cell. Furthermore, an interactive ceramic reactor, composed of the deNOx electrochemical cells with a thermoelectric ceramic power module, operable without any external power supply, has been developed to apply the energy conversion from exhaust-waste heat to electric power.

Ceramic electrochemical SOFC-type reactors are envisaged as potential products, due to their high-efficiency and operability in the intermediate temperature range (under 650°C). Possible power densities of more than 2kW/liter are expected for applications such as auxiliary power units (APU), and small size cogeneration systems, by the improvement of materials, accumulation of fine parts, and assembly of those parts into a high performance module. Tubular SOFC's, with sub-millimeter diameters, enable us to obtain a high volumetric power density when they are accumulated as 'cubes', were hundreds of these sub-millimeter SOFC tubes are precisely mounted in a porous electrode matrix in a volume of one cubic centimeter. Micro tubular SOFCs have been successfully fabricated and have been demonstrated to have excellent performance with a power density of $1W/cm^2$ under 600^oC, and reaching $3W/cm^3$ in one sugar-cube size by means of nanoscale control. Furthermore, development of novel ceramic fabrication processes for integration of SOFC's to cubes, and cube-accumulated prototype modules, has realized micro honeycomb type cell stacks with a cell integration density of 250 multilayered tubes.

Ceramic Nanotechnology for Green Transportation

Michael Stelter, Head of Department Modules, Systems and Environmental Technologies
Fraunhofer Institute for Ceramic Technologies and Systems, Dresden, Germany

Ceramic technologies in general do contribute to modern energy technologies to a large extend, as ceramics provide a very broad and diverse range of material properties that can be used to face the current challenges. The talk will, in it's first part, give some insight in how ceramics can be used to improve the eco-efficiency of transportation systems.

Example 1: Fuel cell auxiliary power units

Long-haul trucks need electrical energy even during standstill periods, either to provide air condition and electricity to the driver during rest periods, or to operate necessary electric equipment. From an environmental point of view, it is not desirable to idle the main engine during these periods. Instead, diesel fuel operated fuel cells, so called auxiliary power units (APUs) can take over this task using only a fraction of the fuel. However, high temperature fuel cells with a high power density require novel material solutions that can be produced at low cost. Nanotechnology has been employed to develop novel, redox stable and cheap ceramic cells and novel ceramic cell contact ribs that can be operated at 850°C.

Example 2: Cheap and effective solar cells

Battery powered electric vehicles only provide an ecologically friendly alternative to internal combustion engine driven cars if electricity can be produced in an effective and eco-friendly way. Solar cells can produce clean electricity. However, grid parity is not reached yet, partly because of still lacking efficiency. The efficiency and cost of manufacturing of solar cells can be improved in part by an improved front side contacting layer that uses less precious material such as silver, uses less energy to be produced and has a higher conductivity, thus covers less of the solar cell's area. Nanotechnology has been employed to develop new inks with higher conductivity and lower sintering temperature.

Example 3: Automotive Exhaust Treatment Sensors

Upcoming environmental regulations in the automotive sector such as EU6 and US T2B5 will lead to cleaner combustion engines. However, a large amount of new sensors will be needed in future vehicle powertrains. To still provide mobility at an attractive and affordable price point, new technologies will be needed to produce complex exhaust sensors in large quantities at low prices. Nanotechnology has been used to demonstrate that a lot of crucial exhaust sensor principles such as diesel soot or NOx sensors can in future be produced in multilayer technology at low prices in mass production, making automotive exhaust aftertreatment systems affordable for emerging economies.

Outlook to Ceramic Nano Powder Processing and Conclusion

In the examples it will be shown, that using nano powders many ceramic systems relevant for green car technologies can be made cheaper or more reliable or can be improved in their functionality, which increases their eco-impact. It is characteristic to the ceramic processing, that a lot of health issues will arise from handling nano scaled ceramic powders in a production environment. These issues and how they can be handled will be highlighted in the talk. On the other hand, however, once the ceramic is sintered, the nano properties of the powders are replaced with the (improved) properties of the bulk ceramic. Effectively, this means that nano health issues in the world of ceramic are strictly limited to the rather controlled production phase, not the end user or the recycling phase in the product life cycle.

Improvment of PEM Fuel Cells for Car Application: From Stack Characterisation to Tailored Electrodes Nanostructured Materials

Patrick Achard, Centre Energétique et Procédés - Centre for Energy and Processes - MINES ParisTech

The research team « Energetics, Materials and Processes » has been established in 1990 within the research Center Energy and Processes of MINES-ParisTech. The work presented here is situated at the crossing of two main research axis of this team:

- First of all an axis is devoted to energy storage and conversion mainly focusing on hydrogen technologies and fuel cells at system level – the lab has been equipped with test benches permitting to characterize fuel cells stacks with a rated power up to 15 kW. This lab was designed to participate to the first European project aiming at designing and realizing a hydrogen and fuel cell powered car in 1994 ie the FEVER project (Fuel cell Electrical Vehicle for Extended Range). This project was led by Renault, our lab was the only one university type laboratory.

- Secondly, another axis is devoted to studies on materials permitting to solve energy problems or to improve energy efficiency. This axis is called Energy and Advanced Materials. Here the work is mainly focused on sol/gel process and the class of materials called aerogel like materials. An intense effort has been done on polymeric materials obtained thanks to that process permitting to get carbonaceous materials after pyrolisis. Those materials are nanostructured, nanoporous and monolithic and present a good electronic conductivity. Their nanostructure can be tailored by adapting the parameters of the sol/gel process., so one can get an appropriate pore size distribution for example. Those materials appear to be good candidates for electrodes of supercapacitors and PEM fuel cells. For those devices, noble metal catalysts have to be deposited within the nanostructure.

On those basis the lab acquired the know-how permitting to realise PEM fuel cells MEA's (Membranes Electrode Assemblies) and developed it's own MEA's based on the referred materials and a test bench permitting to calibrate them. For the electrode itself, triple phase contact appears to be essential. The carbonaceous studied materials appear to be model materials permitting to evaluate the different contributions to the lowering of the efficiency of a PEM monocell.

Here one can understand how nanotechnology permits to improve the understanding of the behaviour of the energy conversion achieved within elements constituting a PEM fuel cell.

PARALLEL SESSION FOUR - CELLULOSE NANO FIBRES

Session Overview

Nanotechnology is the manipulation of cellulosic materials measuring 100 nm or less in at least one dimension. Natural fibers have well established their reputation as reinforcement to plastics. Nowadays, a great deal of attention has been paid to cellulosic nanofibrillar structures as components in nanocomposites because of their wide abundance, their renewable and environmentally benign nature, and their outstanding mechanical properties. However, it is difficult to liberate cellulosic nanofibrils efficiently from different sources of materials, and the fibrils lack compatibility with a variety of plastic matrices. The water-swellable nature of cellulose, especially in its non-crystalline regions, also can be a concern. In addition, the strong inter- and intra-molecular hydrogen bonding can result in agglomeration or entanglement of the nanofibrils. Once these happen, many of the beneficial properties we are targeting will be lost.

The good news is that these challenges have been greatly addressed, and significant progress has been achieved. This allows the nanofibrils with the advantages they offer to be used in a wide range of high-tech applications, such as, aerospace building materials, packaging materials, medical scaffolds, and optically transparent films. This conference session and panel will discuss research advances and commercialization activities involving cellulose nanofibre derived from biological matter including bacterial nanocellulose, plant-based cellulose nanocrystals and cellulose nanofibres.

In the first part of the session, leaders in their respective areas will highlight recent developments in their fields emphasizing the regulatory aspects of the commercialization process. In the later part, a panel of five experts will debate the issues and challenges relating to health and safety underpinning the policy framework necessary to develop a safe way to the economic utilization of this novel cellulosic material.

Jurisdictions worldwide are presently working on various frameworks to deal with the presence of nanomaterials in the marketplace. In Canada, new materials (including nanomaterials) are controlled under the New Substances Notification Regulations (NSNR) of the Canadian Environmental Protection Act. As part of this program, a risk assessment examining any potential adverse effects of the new substance on the environment or human health, must be conducted. The Canadian pulp and paper industry is presently exploring the use of nanocrystalline cellulose (NCC), prepared through the acid hydrolysis of cellulose in kraft pulp, as a novel additive for a number of different products and applications. While current pilot facilities have the capability of producing kilograms of NCC, full-scale facilities are expected within the next few years that would have production capacities of >1 tonne per day. As this work progresses, a key industry mandate is to develop this technology in an environmentally sound manner. As such, environmental and human health assessment studies that are aligned with Canada’s NSNR have been initiated. Our test protocol involved an in-depth battery of acute and chronic whole organism tests as well as cell viability and cellular uptake investigations. To date, this ecotoxicological characterization of NCC has not revealed it to be a substance of environmental concern. Further testing is on-going to assess mammalian toxicity and to examine potential exposure scenarios.

In the area of production and use of nanocellulose materials, two questions can be asked:

- Do these emerging nanomaterials present new safety and health risks?
- How can the potential benefits of cellulose-based nanomaterials be realized while avoiding any possible risks?

The biological activity and exposure (location, component, duration) need to be evaluated since data are lacking. Therefore, it is proposed that key areas such as those proposed by NIOSH (hazard identification, hazard characterization, exposure assessment, risk characterization and management) be evaluated through national and international collaboration on cellulose nanotechnology. While large differences in the chemical composition and physical characteristics of nanocellulose (particularly, cellulose nanocrystals) are evident, one possible scenario is to use, as a benchmark, the documented assessment and regulatory and policy issues applied to carbon nanotubes. Given the unique characteristics of cellulose, it is expected that few concerns, if any, will be developed. However, more important are the implications, to the environment, that the production of such cellulose nanostructures could have. This is especially the case since concentrated acid solutions, large amounts of water, and energy consumption are required to produce these materials. Education and training on the following topics should be the focus of any regulatory effort: nature and extent of hazards and exposure, nature and extent of risk, limitations of controls and protection and medical surveillance guidance, and impact to the environment during use and disposal of materials used in the manufacture of nanocellulose.

Session Schedule

Topic	Speaker	Stakeholder type	Time
Introduction	Mohini Sain (University of Toronto, Canada)	Academia	10 min
Bacterial cellulose as a building block for novel materials	Alexander Bismarck (Imperial College London, UK)	Academia	25 min
Overview of cellulose nanocrystals and nanofibres: The science and technology – A European perspective	Denilson Da Silva Perez (New Materials Div., FCBA, France)	Research Institute	25 min
Coffee break			30 min
Global overview of bio-nano composite technology	Mohini Sain (University of Toronto, Canada)	Academia	25 min
Ensuring the safety of manufactured nanocrystalline cellulose: A risk assessment under Canada's new substances notification regulations	Brian O'Connor (FP Innovations, Canada)	Research Institute	25 min
Nanocellulose –Materials, functions and environmental aspects	Orlando J. Rojas (N. Carolina State University, UK)	Academia	25 min
Panel Discussion			45 min

ABSTRACTS

Bacterial Cellulose as A Building Block for Novel Materials

Jonathan J. Blaker, Koonyang Lee, Anne Dellile, Julasak Juntaro and Alexander Bismarck[1)]

1) Department of Chemical Engineering, Polymer & Composite Engineering (PaCE) Group, Imperial College London, South Kensington, London, UK

Considering the current environmental, societal and political issues especially in the way we use materials, a pressing need for innovative, sustainable and recyclable materials can be identified. Industry and consumers need to move to greener materials to divert (valuable) materials from waste streams. Materials made form renewable resources are attractive but should perform at the same level (or better) than conventional engineering materials we aim to replace. It will be shown how anisotropic nanometre sized bacterial derived cellulose can be utilised as a building block for new materials namely to produce *hierarchical composites, true nanocomposites* and *renewable highly macroporous nano-composites*. Bacterial cellulose offers many attractive properties, its fibrils have diameters between 10 nm to 100 nm with a high crystallinity (~90%) and Young's modulus similar to glass fibres; it has a highly hydrophilic character due the many hydroxyl groups on the surface, which are useful sites for modification.

The production of cellulose by bacterial fermentation in static and agitated culture will be discussed. Starting from this, we will show that it is possible to produce composites, which combine nano- and micrometre sized reinforcements within a renewable polymeric matrix to obtain hierarchical composite structures. We present a novel route to tailor interfaces in natural fibre reinforced polymers by attaching bacterial cellulose to natural fibre surfaces. Bacterial cellulose was successfully coated on to the fibres by culturing cellulose-producing bacteria, *Gluconacetobacter xylinus* BPR 2001, in presence of natural fibres. This natural fibre modification method does not affect the fibre tensile properties significantly; however, it results in a massive improvement of the interfacial shear strength, a measure of practical adhesion, between the modified fibres and renewable polymer matrices as well as unidirectional natural fibre reinforced composites with improved tensile strength parallel as well as perpendicular to the fibres.

Besides using bacterial cellulose directly as a reinforcement for (nano)composites we will demonstrate that it can be used if suitably modified to stabilise very concentrated emulsions, which can be used as template to produce very high porosity macroporous cellulose nanocomposites. Emulsion templating has emerged as an effective route for the synthesis of porous polymers with a well-defined morphology since the latter is defined by the structure of the emulsion template. Pickering emulsions are emulsions that are solely stabilised by small particles. We prepared renewable nanocomposite foams from acrylated epoxidized soybean oil (AESO) and hydrophobised bacterial cellulose whiskers. The hydrophilicity of bacterial cellulose whiskers was tailored by esterification of some of the cellulose whisker hydroxyl groups with organic acids. We were able to produce very concentrated Pickering emulsions by combining small amounts of the modified bacterial cellulose (<1 vol.-%) with AESO and water. The photopolymerisation of the continuous monomer phase of the emulsion resulted in green highly porous bacterial cellulose nano-composite polyPickering foams with rather interesting physical and mechanical properties.

Overview of Cellulose Nanocrystals and Nanofibres: The Science and Technology - A European Perspective

Denilson da Silva Perez[1)] *and Alain Dufresne*[2)]

1) Institut Technologique FCBA

2) PAGORA Grenoble INP, Grenoble, France

Cellulose is not only the most available natural polymer on earth, but also one of the most interesting, naturally existing, supramolecular structures. From a quite simple chemical structure (two molecules of anhydroglucose composing a cellulobiose unit), an amazing 3D network formed by hydrogen bonds leads to a complex structure formed by nano-domains of crystalline structure co-existing with amorphous cellulose. This crystalline structure is responsible for its intrinsic strength and its relatively high chemical stability. The potentials of exploiting its supramolecular structure from a technological point of view, allied to its availability and renewability, place cellulose as an excellent candidate for the sustainable development of new high-performance and high added-value materials.

However, the main cellulose-based product, paper, is mass-produced and, quite often, single-use oriented (printing and writing or packaging). Cellulose micro- and nano-fibres seem to be one of the ways of better exploiting such potential than the usual cellulosic fibres. In this presentation, the production of micro/nano-fibres is described in two parts: the first part is devoted to the state of the art about the cellulose microfibrils existing in nature. The second part describes the different approaches used for isolate them as cellulose micro/nano-fibrillated or nanocristals (whiskers) as well as the main applications.

Different techniques have been developed in the last years for the production of micro- or nano-fibrillated cellulose. In most cases, chemical or enzymatic pre-treatments are needed in order to weaken the structure of the fibre walls before the isolation of the microfibres. The separation of cellulose microfibrils is performed by different equipments able to disintegrate the ultrastructure of the cell wall while preserving the integrity of the microfibrils. Different "homogenizers" have been used by different European R&D teams and will be commented and compared.

Cellulose nanocristals are different products composed only by the crystalline portion of the microfibrils. They are obtained by acidic hydrolysis using concentrated sulphuric acid and are formed by cellulosic elements measuring few hundreds of nanometers of length depending on the starting raw material.

Scale-up of these technologies for larger production is nowadays under study. The main challenges and difficulties to pass from science to technology will be pointed out and discussed during the presentation.

Golobal Overview of Bio-Nano Composite Technology

Mohini Sain, Director, Centre for Biocomposites and Biomaterials Processing, University of Toronto, Canada

Nanotechnology is the manipulation of cellulosic materials measuring 100 nm or less in at least one dimension. Natural fibers have well established their reputation as reinforcement to plastics. Nowadays, a great deal of attention has been paid to cellulosic nanofibrillar structures as components in nanocomposites because of their wide abundance, their renewable and environmentally benign nature, and their outstanding mechanical properties. However, it is difficult to liberate cellulosic nanofibrils efficiently from different source of materials, and the fibrils lack compatibility with a variety of plastic matrices. The water-swellable nature of cellulose, especially in its non-crystalline regions, also can be a concern. In addition, the strong inter- and intra-molecular hydrogen bonding can result in agglomeration or entanglement of the nanofibrils. Once these happen, many of the beneficial properties we are targeting will be lost. The good news is these challenges have been greatly addressed and significant progresses have been achieved. This allows the nanofibrils with their advantages to be used in a wide range of high-tech applications, such as, aerospace building materials, packaging materials, medical scaffolds, and optically transparent films. This presentation will discuss research advancement and commercialization activities of cellulose nanofibre derived from biological matter including bacterial nanocellulose, plant-based cellulose nanocrystals and cellulose nanofibres.

Ensuring the Safety of Manufactured Nanocrystalline Cellulose: A Risk Assessment under Canada's New Substances Notification Regulations

Brian O'Connor, Ph.D., FPInnovations-Paprican Division, Pointe Claire, Quebec, Canada

Jurisdictions worldwide are presently working on various frameworks to deal with the presence of nanomaterials in the market place. In Canada, new materials (including nanomaterials) are controlled under the New Substances Notification Regulations (NSNR) of the Canadian Environmental Protection Act. As part of the program, a risk assessment examining any potential adverse effects of the new substance on the environment or human health, must be conducted. The Canadian pulp and paper industry is presently exploring the use of nanocrystalline cellulose (NCC), prepared through the acid hydrolysis of cellulose in kraft pulp, as a novel additive for a number of different products and applications. While current pilot facilities have the capability of producing kilograms of NCC, full scale facilities are expected within the next few years that would have production capacities of >1 tonne per day. As this work progresses, a key industry mandate is to develop this technology in an environmentally sound manner. As such, environmental and human health assessment studies that are aligned with Canada's NSNR have been initiated. Our test protocol involved an in-depth battery of acute and chronic whole organism tests as well as cell viability and cellular uptake investigations. To date, this ecotoxicological characterization of NCC has not revealed it to be a substance of environmental concern. Further testing is on-going to assess mammalian toxicity and to examine potential exposure scenarios.

Nanocellulose: Materials, Functions and Environmental Aspects

Orlando J. Rojas 1,2), Janne Laine2) and Monika Österberg2)

1) North Carolina State University, Department of Forest Biomaterials, Raleigh, United States

2) Helsinki University of Technology, Department of Forest Products Technology, Finland

In the past decades nanotechnology has been greatly developed but it has been until very recently that the visibility of cellulose as a nano-structured material has emerged to the central stage of technical and scientific discussions. Cellulose is the most abundant biopolymer on earth that offers interesting options as replacement of non-renewables in high-performance applications. Unique attributes of cellulose-derived nanomaterials include their hydrophilicity, biocompatibility, stereoregularity, biodegradability, chemical stability, multichirality and the ability to form superstructures.

In this presentation we will discuss cellulose nanocrystals and nanofibrillar cellulose in the development of light-weight structural materials, composites and coatings. Also, a question to be addressed is whether these emerging nanomaterials present new safety and environmental risks. It would be expected that their utilization would contribute to alleviate (environment, pollution, health, etc.) impacts of current inorganic or mineral nanomaterials. A conclusion that will be drawn is that the biological activity and exposure (location, component, duration) of nanocellulose materials need to be evaluated. It is proposed that key areas as those proposed by NIOSH (Hazard identification, hazard characterization, exposure assessment, risk characterization and management) be addressed through national and international collaborations on cellulose nanotechnology. While large differences in the chemical composition and physical characteristics of nanocellulose are evident one possible scenario is to use, as a benchmark, the documented assessment and regulatory and policy issues applied to other nanomaterials. Given the unique characteristics of cellulose, it is expected that few concerns, if any, are to be developed. However, more important is the implications, to the environment, that the production of such cellulose nanostructures could have. Education and training on the following topics should be the focus of any regulatory effort: nature and extent of hazards and exposure, nature and extent of risk, limitations of controls and protection and health surveillance guidance and impact to the environment during use and disposal of materials used in the manufacture of nanocellulose.

PARALLEL SESSION FIVE - SITE REMEDIATION

Context for the Session

Environmental applications of nanotechnology include new methods to clean up hazardous waste sites. One such application involves injecting nanoscale zero-valent iron particles (nZVI) into contaminated groundwater. This technology is in use in full-scale remediation projects with encouraging success. Nanoscale iron holds promise in cost effectively addressing challenging site conditions, such as where dense nonaqueous phase liquids (DNAPLs) are present in contaminated aquifers.

Nanoparticles can be highly reactive due to their large surface area to volume ratio and the presence of a large number of reactive sites. This allows for increased contact with contaminants, thereby potentially resulting in rapid reduction of contaminant concentrations. Because of their minute size, nZVI particles may pervade very small spaces in the subsurface and remain suspended in groundwater, which could allow the particles to travel farther than macro-sized particles and achieve wider distribution. As discussed in the “Limitations” section below, bare iron nanoparticles may not travel very far from the injection point. However, researchers are investigating surface modifications to the particles to improve their mobility and stability.

In addition to nanoscale zero-valent iron, researchers are developing nanotechnology-enabled membranes and also investigating particles such as self-assembled monolayers on mesoporous supports (SAMMS™), dendrimers, carbon nanotubes, and metalloporphyrinogens to determine how to apply their unique chemical and physical properties for site remediation (U.S. EPA, 2008A).

Session Overview

This session focuses on the use of nanotechnology for hazardous waste site remediation and contaminant reduction. The aims will be to discuss:

- The maturity and the market potential of different applications;
- Challenges and needs for further research;
- The potential environmental and health risks associated with these technologies; and,
- Strategies to promote safe and responsible development.

The session will provide time for perspectives from stakeholders including researchers developing new remediation technologies, industrial and other end users and will include discussions about potential risks and benefits.

The session will last approximately 3.5 hours including a coffee break and will run in parallel with another session. A moderator will introduce speakers, monitor time, and manage questions. A rapporteur will capture the major findings of the presentations and discussion.

Example: Nanoscale Zero-Valent Iron Used For Site Remediation

Most of the bench-scale research and field application of nanoparticles for remediation at full-scale have focused on nanoscale zero-valent iron and related products.

Background

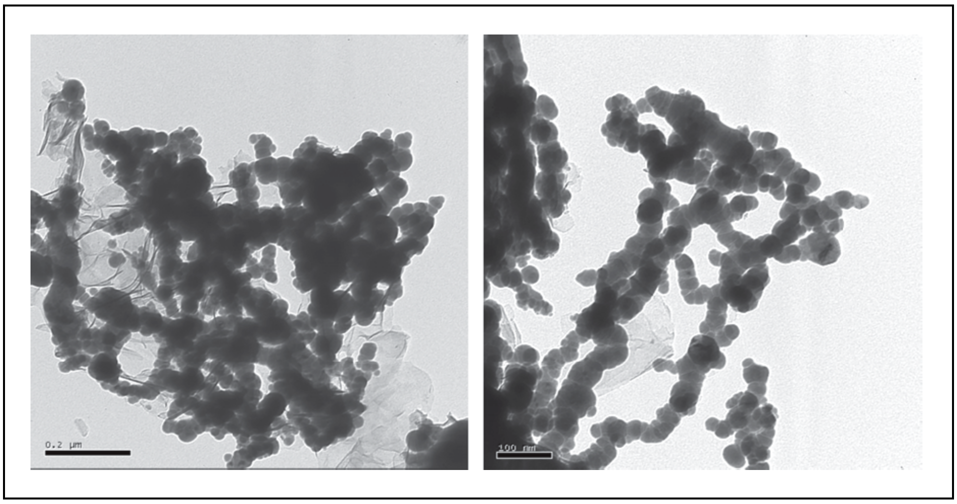
Early treatment remedies for groundwater contamination were primarily pump-and-treat operations. Because of the relatively high cost and often lengthy operating periods for these remedies, the use of *in situ* treatment technologies is increasing.

Since the early 1990s, hazardous waste site project managers have taken advantage of the properties of metallic substances such as elemental iron to degrade chlorinated solvent plumes in groundwater. One example of an *in situ* treatment technology for chlorinated solvent plumes is the installation of a trench filled with macroscale zero-valent iron to form a permeable reactive barrier (PRB) (ITRC 2005). However, PRBs can only remediate contaminant plumes that pass through them; they do not address dense non-aqueous phase liquids (DNAPL) or contaminated groundwater that is beyond the barrier.

Recent research indicates that nanoscale zero-valent iron (nZVI) may prove more effective and less costly than macroscale ZVI under similar environmental conditions. For example, in laboratory and field-scale studies, nZVI particles have been shown to degrade trichloroethene (TCE), a common contaminant at hazardous waste sites, more rapidly and completely than larger ZVI particles. Also, nZVI can be injected directly into a contaminated aquifer, eliminating the need to dig a trench and install a PRB. Research indicates that injecting nZVI particles into areas within aquifers that are sources of chlorinated hydrocarbon contamination may result in faster, more effective groundwater cleanups than traditional pump-and-treat methods or PRBs.

Figure 1 shows transmission electron microscope (TEM) images of nZVI.

Figure 1.Transmission electron microscope (TEM) images of iron nanoparticles (Zhang, 2006)

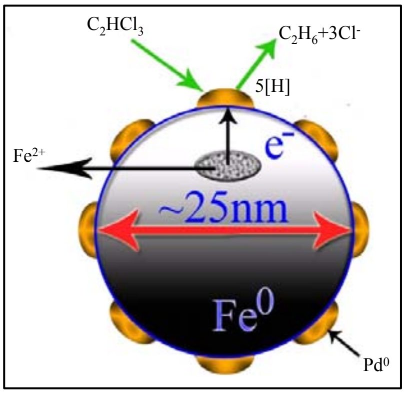


Note: The scale bars in the figure are 200 nm.

Nanoparticles such as nZVI, bi-metallic nanoscale particles (BNPs), and emulsified zero-valent iron (EZVI) may chemically reduce the following contaminants effectively: perchloroethylene (PCE), TCE, cis-1, 2-dichloroethylene (c-DCE), vinyl chloride (VC), and 1-1-1-tetrachloroethane

(TCA), along with polychlorinated biphenyls (PCBs), halogenated aromatics, nitroaromatics, and metals such as arsenic or chromium. Two of the important degradation reactions for chlorinated solvents are reductive dechlorination and beta elimination. Beta elimination, which occurs most frequently when the contaminant comes into direct contact with the iron, follows the pathway of TCE + Fe0 → HC Products + Cl- + Fe2+/Fe3+ (U.S. EPA, 2008A). Reductive dechlorination, which occurs under the reducing conditions fostered by nZVI in groundwater, follows the pathway of PCE→ TCE→ DCE→ VC→ ethene (Elliot, 2006).

Figure 2. Reaction of iron in a bimetallic nanoscale particle with TCE (image courtesy of Wei-Xian Zhang, Lehigh University)



Advances

Nanoscale iron particles can be modified to include coatings such as polyelectrolyte or triblock polymers (Saleh, 2007), or can be encased in emulsified vegetable oil droplets (Hydutsky, 2007; He, 2007). Some nanoparticles are made with catalysts that enhance the intrinsic reactivity of the surface sites (Tratnyek, 2006).

BNPs can be injected by gravity or by pressure feed (Gill, 2006). Research is ongoing into methods of injection that will allow nanoparticles to better maintain their reactivity and increase their access to recalcitrant contaminants by achieving wider distribution in the subsurface. Creating nZVI on site can reduce the amount of oxidation the iron undergoes, thereby reducing loss in reactivity. Researchers in green chemistry have successfully created nZVI in soil columns using a wide range of plant phenols, which, according to the researchers, allows greater access to the contaminant and creates less hazardous waste in the manufacturing process (Varma, 2008).

Limitations

- Studies have shown that nanoparticles may not achieve widespread distribution in the subsurface due to agglomeration prior to complete dispersion within the soil or groundwater matrix, limiting the radius of influence.
- Passivation is another factor that may limit the effectiveness of iron nanoparticles. If nZVI is being used, improper handling can result in the iron becoming oxidized and passivated prior to reacting with the contaminants.
- A challenge with evaluating the effectiveness of nanoparticle injection is monitoring the distribution of injected particles in the subsurface. It is therefore important to identify the appropriate parameters to measure performance.

Researchers have developed methods, some of which are in use commercially, to improve the mobility of iron nanoparticles within aquifers and to optimize contact between the nanoparticle and contaminant. Ongoing studies are evaluating surface coatings and other modifications that would reduce agglomeration of nanoparticles and maximize subsurface mobility (Phenrat, 2008).

Other Nanomaterials with Remediation Applications

Researchers are developing a variety of nanomaterials for potential use to adsorb or destroy contaminants as part of either *in situ* or *ex situ* processes. These particles include SAMMS™, ferritin, dendrimers, and metalloporphyrinogens. The stage of development ranges from bench to pilot scale.

Self-Assembled Monolayers on Mesoporous Supports (SAMMSTM)

Some materials can be made with surface functional groups to serve as adsorbents to scavenge specific contaminants from waste streams. SAMMS™ particles consist of a nanoporous ceramic substrate coated with a monolayer of functional groups tailored to preferentially bind to the target contaminant. The functional molecules covalently bond to the silica surface, leaving the other end group available to bind to a variety of contaminants. According to researchers, SAMMS™ particles maintain good chemical and thermal stability and can be readily reused or restored (Fryxell, 2007). Figure 3 shows a schematic of a functionalized nano-sized pore within a SAMMS™ particle. The particle has a large surface area to allow for quick sorption kinetics.

Contaminants successfully sorbed to SAMMS™ particles include radionuclides, mercury, chromate, arsenate, pertechnetate, and selenite (Mattigod, 2003; Tratnyek, 2006). According to the SAMMS™ Adsorbents Web site (http://sammsadsorbents.com/page/resource-center), SAMMS™ has shown positive results in pilot scale tests in the remediation of mercury in well water with a high concentration of dissolved solids, aqueous mercury in low concentrations, highly radioactive mercuric waste, and gaseous elemental mercury.

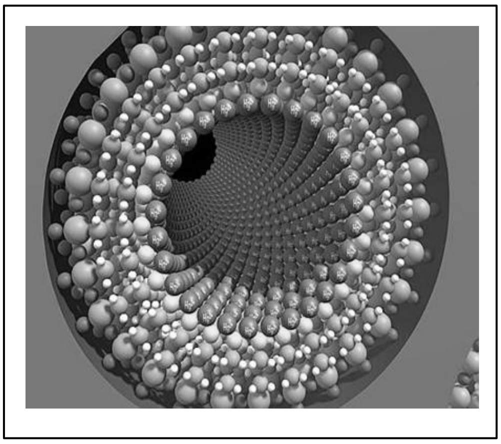


Figure 3. Schematic of functionalized nano-sized pore within a SAMMS™ particle (modified from Mattigod, 2004)

Nanotubes

Nanotubes are engineered molecules most frequently made from carbon. They are electrically insulating, highly electronegative and easily polymerized. Nanotubes have also been made from titanium dioxide and have demonstrated potential for use as a photocatalytic degrader of chlorinated compounds (Chen, 2005). Bench-scale research has shown titanium dioxide nanotubes to be particularly effective at high temperature, capable of reducing contaminant chemicals by greater than 50 percent in three hours (Xu, 2005).

Other Nanomaterials

Researchers are investigating additional nanomaterials that might have applications for site remediation or contaminant reduction. Bench-scale tests using ferritin, an iron storage protein, have indicated that it can reduce the toxicity of contaminants such as chromium and technetium in surface water and groundwater to facilitate remediation (Temple University, 2004). Like titanium dioxide, ferritin is photocatalytic; in one bench-scale project, the addition of visible light caused ferritin to reduce toxic, water-soluble hexavalent chromium to the less toxic trivalent chromium, which is not water soluble and precipitates out of solution.

Dendrimers are hyper-branched, well-organized polymer molecules made up of three components: core, branches, and end groups. Dendrimer surfaces terminate in several functional groups that can be modified to enhance specific chemical activity. Fe^0/FeS nanocomposites, synthesized using dendrimers as templates, could be used to construct permeable reactive barriers for the remediation of contaminated groundwater. Bench-scale research has indicated that dendrimers have flexible delivery options (Diallo, 2006).

Metalloporphyrinogens are complexes of metals with naturally occurring, organic porphyrin molecules. Examples of biological metalloporphyrinogens are hemoglobin and vitamin B_{12}. Batch-reactor experiments have shown that metalloporphyrins are capable of reducing chlorinated hydrocarbons such as TCE, PCE, and carbon tetrachloride under anoxic conditions to remediate contaminated soil and groundwater, with some structures showing a reduction of TCE and PCE by greater than 99 percent from the original concentration (Dror, 2005).

Membranes

Researchers are also using nanotechnology to develop membranes for water treatment, desalination, and water reclamation. These membranes incorporate a wide variety of nanomaterials, including nanoparticles made of alumina, zero-valent iron, and gold (Theron, 2008). Carbon nanotubes can be aligned to form membranes with nanoscale pores to filter organic contaminants from groundwater (Mauter, 2008; Meridian Institute, 2006).

Products for Emergency Response

Companies are developing nanomaterials for use in cleaning up spills or other accidental releases of hazardous materials.

FAST-ACTR

NanoScale Corporation is marketing its product, *FAST-ACT®*, as a chemical containment and neutralization system that first responders can use to clean up toxic chemical releases of industrial chemicals or chemical warfare agents (NanoScale, 2008).

Nanowire membrane for oil spills

A group of researchers at the Massachusetts Institute for Technology (MIT) have developed a "paper towel" for oil spills that is comprised of a membrane or mat of potassium manganese nanowires. According to the researchers, the nanowire membrane selectively absorbs oil with high efficiency. The oil can be recovered by heating the mat, which can then be reused. The membrane, which appears to be impervious to water, may have additional uses in water filtration (Thomson, 2008).

Environmental and Health Considerations

While nZVI is the most widely used nanoparticle in site remediation, knowledge is limited on the fate and transport of iron nanoparticles in the environment, and little research has been done on the potential toxicological effects these nanomaterials might pose. There are insufficient data on the potential for bioaccumulation of nanoparticles in environmentally-relevant species (Kreyling, 2006) and there have been few studies on the effects of any nanoparticles on environmental microbial communities (Klaine, 2008).

Agglomeration often affects transport of iron nanoparticles in the subsurface. The particles may become associated with the aquifer matrix as oxidized iron particles after reacting with contaminants. Under standard environmental conditions (aerated water, pH 5 to 9), Fe^{2+} will readily and spontaneously oxidize to Fe^{3+} and precipitate out of the groundwater as insoluble iron oxides and oxyhydroxides. Preliminary research indicates that polymers and surfactants stabilize nanoparticle suspensions in aquifers, inhibiting their agglomeration and allowing greater dispersal without compromising the ability of the iron to remediate contaminants (He, 2007). While increased mobility would allow more efficient remediation, it could also result in the possibility of the nanomaterials migrating beyond the contaminated plume area, seeping into drinking water aquifers or wells, or discharging to surface water during the remediation process.

U.S. EPA's Office of Research and Development (ORD) published a Draft Nanomaterial Research Strategy (NRS) in January 2008. The initial emphasis of the NRS will be to evaluate and assess the extent to which nanomaterials and products impact the environment and human health. Results from this research will directly inform future policy decisions regarding how to address possible adverse implications associated with the production, use, recycling, or disposal of nanomaterials and nanoproducts (that is, products containing nanomaterials). Initially, a smaller portion of the proposed research will focus on beneficial environmental applications, such as more effective control technologies and enhanced production processes that reduce emissions and releases of conventional pollutants. As the program evolves over time, ORD will augment its efforts in this area (U.S. EPA, 2008B).

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Session Schedule

Topic/ Focus	Speaker	Stakeholder type	Time
Nanotechnology for Site Remediation	Marti Otto (USEPA, Washington, DC, US)	Government	25 min
Surface-modified iron nanoparticles for remediation: synthesis, characterization and transport	Subhasis Ghoshal (McGill University, Canada)	Academia	25 min
Reactive nanoparticles for in situ groundwater remediation – Optimizing the benefits and mitigating the risks with surface coatings	Greg Lowry (Carnegie Mellon University, US)	Academia	25 min
Coffee Break			30 min
Status of nZVI technology: Lessons learned from north american and international field implementations	Jean Pierre Davit (Golder Associates, Italy)	Industry	25 min
Deployment of nZVI to soil for polychlorinated biphenyl remediation: impacts on soil microbial communities	Liz Shaw (University of Reading, UK)	Academia	25 min
Overall research trends in nano-based water treatment technologies which have been recently applied in South Korea	Young Haeng Lee (KIST, Korea)	Academia	25 min
Panel Discussion			30 min

ABSTRACTS

Nanotechnology for Site Remediation

Marti Otto, Technology Innovation and Field Services Division, EPA, Washington, D.C. United States

Emerging nanotechnologies are contributing to innovations in semiconductors, memory and storage technologies, display, optical and photonic technologies, energy, biomedical, and health sectors. Nanotechnology also is contributing to the development of new environmental applications for pollution prevention, contaminant treatment, and hazardous waste site cleanup. The presentation presents a snapshot of nanotechnology and its current uses in site remediation.

Hundreds of thousands of sites in the United States (U.S.) have been identified with varied degrees of contamination. More than 80% of hazardous waste sites identified by the U.S. Environmental Protection Agency's (U.S. EPA's) Superfund program have contaminated groundwater. This is particularly important considering that over half of the U.S. population relies on groundwater for drinking. Once groundwater is polluted, its remediation is often protracted, costly, and sometimes infeasible.

Early treatment remedies for groundwater contamination were primarily pump-and-treat operations. This method involves extracting contaminated groundwater via wells or trenches and treating the groundwater above ground (*ex situ*) using processes such as air stripping, carbon adsorption, biological reactors, or chemical precipitation. Some of these processes produce highly contaminated wastes that then have to be disposed.

Because of the relatively high cost and often lengthy operating periods for these remedies, the use of *in situ* treatment technologies is increasing. One example of an *in situ* innovative treatment technology for chlorinated solvent plumes is the use of nanoscale zero-valent iron (nZVI). nZVI can be injected directly into a contaminated aquifer. nZVI is in use in full-scale projects, with an encouraging measure of success. This technology holds promise in remediating sites cost-effectively and in addressing challenging site conditions, such as where dense nonaqueous-phase liquids (DNAPLs) are present in contaminated aquifers.

The U.S. Environmental Protection Agency published a fact sheet on the use of nanotechnology for site remediation. (See http://clu-in.org/542F08009.) EPA collected information on over 25 sites where nanotechnology has been tested for site remediation.

The presentation discusses environmental applications of nanotechnology and its current uses in hazardous waste site remediation. The talk includes a discussion of concerns regarding potential effects of engineered nanomaterials on human health and the environment and of the need for additional research on the safe application of the technology for site remediation.

Surface-Modified Iron Nanoparticles for Remediation: Synthesis, Characterization and Transport

Subhasis Ghoshal, Department of Civil Engineering, McGill University, Montreal, Quebec, Canada

In recent years, there has been significant interest in employing zero-valent iron nanoparticles (nano iron) for remediation of sites contaminated with toxic and hazardous compounds such as chlorinated solvents, arsenic and chromium. Nano iron particles have been found to be very efficient in eliminating pollutants such as chlorinated organic compounds, chromium and arsenic that have been found to contaminate groundwater aquifers. Several field tests and laboratory experiments have suggested that the transport of nano iron on subsurface porous media is severely hindered, and it is attributable in part due to the tendency of the nano iron to agglomerate and thus be retained in soil pores. Recent studies show that modifying the surfaces of nano iron with polymers, polyelectrolytes and surfactants make nano iron more transportable. Surface modifications that provide enhanced transport and yet retain their reactivity will significantly enhance our ability to remediate contaminated sites and aquifers.

The presentation will discuss techniques for bottom-up synthesis of polymer-coated nano iron particles, and the characteristics of the resulting particles. Techniques for measuring the size, surface charge, surface chemistry, chemical composition, chemical and colloidal stability of the particles will be discussed. An example of how bottom-up synthesis can be tuned to produce particles of various sizes will be presented. Particle size has significant effect on the transport and longevity of particles. Results from laboratory experiments to evaluate the transport of the surface modified particles in packed columns of granular porous media under selected environmental conditions will be presented. A pilot-scale field study in Canada, where iron nanoparticles and a polymeric dispersing agent was used for remediation of a chlorinated solvent-contaminated site, will be discussed. The potential improvements needed to implement effective nano iron remediation will be discussed.

Reactive Nanoparticles for In Situ Groundwater Remediation: Optimizing the Benefits and Mitigating the Risks with Surface Coatings

Gregory V. Lowry, Civil & Environmental Engineering Center for Environmental Implications of NanoTechnology, Carnegie Mellon University, United States

Novel reactive nanomaterials, such as Fe^0 nanoparticles (NZVI), offer the potential for highly efficient targeted delivery of remedial agents to subsurface contaminants. The primary challenge to application is selecting appropriate surface modifiers that enable emplacement in the contamination zone, but do not adversely impact the particle's reactivity with the contaminant. Surface coatings can also decrease the potential toxicity of the particles. Concomitant optimization of mobility, reactivity, while minimizing toxicity requires a fundamental molecular level understanding of the surface modifiers properties and how they affect nanoparticle deposition. Further, optimizing the surface coating to enhance interaction with the contaminant of interest is possible. Dynamic light scattering and electrophoretic mobility measurements, along with Ohshimas's analysis are used to characterize the layer conformation and properties of different types of common synthetic and natural polyelectrolytes adsorbed onto NZVI. Batch reactivity studies and column and 2-D flow cell studies under a variety of hydrogeochemical conditions and heterogeneities were then conducted on polyelectrolyte-modified NZVI to determine the effect of the adsorbed layer properties and injection conditions on reactivity and mobility. Surface coatings decreased particle reactivity with TCE by up to a factor of 20, and eliminated the particles bactericidal properties. The magnitude of the effect depended on the adsorbed layer conformation of the polyelectrolyte as explained using the Scheutjens and Fleer train-loop-tail conceptual model for homopolymer sorption. More polydisperse samples containing larger particles (several hundred nanometers) are less mobile than monodisperse samples containing only small particles (<100nm) due to a greater tendency to agglomerate during transport. The concentration of the injected Fe^0 nanoparticle suspensions also impact mobility. This study emphasizes the important role of aggregation on nanoparticle transport, and the role of organic macromolecules on the transport and toxicity of NZVI used for groundwater remediation.

Status of nZVI Technology: Lessons Learned from North American and International Field Implementations

J.P. Davit[1), M. Pupeza[1), F. Gheorghiu[2), and M. Borda[2)

1) Golder Associates – Europe

2) Golder Associates – United States

With nearly 10 years of experience, Golder Associates Inc. (Golder) is a leader in the manufacture and implementation of nano-scale zero-valent iron (nZVI) for environmental remediation applications. Golder has designed and implemented nZVI injections in the United States, Canada, Europe and Australia including, ten (10) pilot-scale studies, ten (10) bench-scale studies and one (1) full-scale implementation. Golder's global experience has led to several significant advancements in the technology including, verifying the need to include palladium (Pd) as a catalyst for *in situ* treatment using mechanically crushed material, verifying the need to include a surface modifier (e.g., soy powder) to enhance the mobility of nZVI in the subsurface, and establishing the enhanced treatment potential of combined nZVI/enhanced bioremediation alternatives. In addition to these advances in implementation, Golder is also advancing the types of nZVI used in the field including the manufacture of mechanically crushed nZVI through licensing with Lehigh University and in-well precipitated nZVI. Golder continues to stay involved in the research and development efforts taking place in the academic sector with several key industry-academic partnerships and is actively exploring advanced injection technologies for the more efficient delivery of the material to the sub-surface. Findings from Golder's most recent applications will be discussed.

Deployment of nZVI to soil for polychlorinated biphenyl remediation: impacts on soil microbial communities

Emma L. Tilston[1), Laurence Cullen[1), Geoff R. Mitchell[2), Chris D. Collins[1), Liz J. Shaw[1)

1) Department of Soil Science, University of Reading

2) Centre for Advanced Microscopy, J.J. Thomson Physical Laboratory, University of Reading

Zerovalent iron (ZVI) is a reducing agent that can reductively dehalogenate a broad range of chloro-organic compounds and has therefore successfully been used in environmental remediation, particularly in the subsurface. ZVI particles at the nanoscale (nZVI) are characterized by high surface area-to-volume ratios and studies to date have concluded that nZVI particles are more effective in contaminant breakdown than their micro-scale equivalent.

With the development of particle stabilisation methods (e.g. water-soluble polyelectrolytes) to minimise aggregation and adhesion, nZVI technology could potentially be extended from the cleanup of the saturated subsurface to the remediation of contaminated unsaturated soils. For example, soil contaminated with polychlorinated biphenyls (PCBs), an important class of toxic, bioaccumulative and recalcitrant soil contaminants could be a useful target for nZVI remediation. For the remediation of PCB-contaminated soil, the following two-step strategy can be envisaged: (1) Deployment of nZVI to dehalogenate the most recalcitrant higher chlorinated PCB congeners; (2) Use of microbial remediation to remove the resulting lower chlorinated PCBs that are much more amenable to aerobic microbial catabolism and cometabolism.

A significant constraint to the success of the above strategy and the wider application of nanoremediation technologies is that we do not know whether, in the short term, nanoparticles impact upon the diversity and activity of soil microbial communities responsible for bioremediation of chlorinated and non-chlorinated aromatics. Further, adverse impacts to microbes will not only undermine soil natural attenuation functions, but, could also have implications for microbial plant symbiotic and plant nutrient mineralization functions important for the long-term revegetation and stabilisation of the site.

This talk will outline experiments funded by the Natural Environment Research Council (UK) Environmental Nanoscience Initiative to investigate nZVI impacts on microbial communities using the above PCB remediation scenario. The experimental aims were to characterize the effects of nZVI and the stabilizer polyacrylic acid (PAA) on general soil microbial activities (ammonia oxidation potential, dehydrogenase activity) and numbers and activities of chloroaromatic-degrading microorganisms. An additional aim was to evaluate post-treatment effects on plant-microbe interactions with plant species commonly used for site revegetation (*Trifolium repens* and *Lolium perenne*).

Overall research trends in nano-based water treatment technologies which have been recently applied in South Korea

Young Haeng Lee, Center for Environmental Technology Research, Korea Institute of Science and Technology, Seoul, South Korea

This presentation reviews the researches on the nano-based water treatment technologies currently conducted by researchers in center for environmental technology research at Korea Institute of Science and Technology (KIST). Environmental conditions as well as environmental laws in South Korea are first introduced. Furthermore, the improvement of water quality over past decade is reviewed in detail. Current researches on the application of nano-based technologies (i.e., zirconium mesostructures, gold nanoparticles supported on titania, nanoscale zero-valent iron particles, and etc.) to the water and wastewater treatments system are covered. Brief highlights are made on the membrane-based technologies and membrane-coupled biotechnologies for the water treatment. Therefore, this presentation provides an overview of the chronologically developed environmental policies corresponding to the change of environmental issues, and outlines the researches on the nano-based water treatment technologies successfully applied to solve the current environmental problems in South Korea.

PARALLEL SESSION SIX - BETTER BATTERIES ENABLED BY NANOSCALE INNOVATION

Context for the Session

Improved batteries offer substantial opportunities for environmental benefit. Paired with more environmentally friendly power generation – photovoltaics and wind power are examples – batteries promise reductions in greenhouse gas emissions and improved air quality on a scale that could have a real and positive impact on global warming. Converting automobiles and light trucks to battery power, assuming the ideal of environmentally friendly energy sources for recharging, could result in reduction of GHG emissions by nearly 320 million metric tonnes[12] of carbon in the United States alone. This figure is approximately 17 percent of total US emissions.

The economic opportunities that could flow from development of better battery technologies have led to the development of a number of promising battery types with differing performance profiles and environmental impacts. The field is in a state of rapid growth and evolution that provides an important opportunity for consideration of factors that could impact the environment and human health.

Enhancing the level of understanding of the life cycle impacts of battery technologies as they develop, if possible in conceptual and research and development stages, would help the scientists and entrepreneurs engaged in developing emerging battery technologies to consider and reduce those impacts, through product design changes,. Safer chemical building blocks, energy efficient manufacturing, and environmentally preferable end-of-life scenarios are some of the benefits that could flow from considering the entire life cycle impacts of batteries.

Session Overview

The workshop will explore potential benefits, as well as potential human health and environmental factors in the context of life-cycle analysis. The workshop will include:

- Advances in lithium-ion battery technologies within the context of other developing and existing battery technologies;
- The potential environmental benefits that could result;
- The potential environmental and human health concerns associated with newer and

[12] USEPA, 2008. “Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 – 2006.” April 15, 2008. Accessed on February 10th, 2009 from: http://www.epa.gov/climatechange/emissions/downloads/08_CR.pdf, and D. Sperling and J. S. Cannon (eds). "Driving Climate Change: Cutting Carbon from Transportation," Academic Press, 2006. These calculations do not account for GHG emissions that may stem from sources including battery production, improvements to the electricity transmission grid, and manufacture of solar cells.

developing battery technologies;

- Exploring environmental and human health factors from a life cycle perspective, as well as policies that may promote responsible development.

The session will provide time for perspectives from stakeholders ranging from industries developing new batteries to NGOs who want to ensure that the potential health and environmental impacts of these technologies are considered and addressed.

Background on Battery Technology

Basic batteries create a current by completing two or more electrochemical reactions, using dissimilar metals separated by a salt-bridge or semi-permeable membrane and bathed in electrolyte solution[13].

Batteries have improved substantially since the development of the Voltaic Pile in 1800. They are critical to the function of our infrastructure, our toys, and our safety. Today, among rechargeable battery technologies, lead-acid, nickel-cadmium, nickel metal hydride, and lithium technologies are the most prevalent.

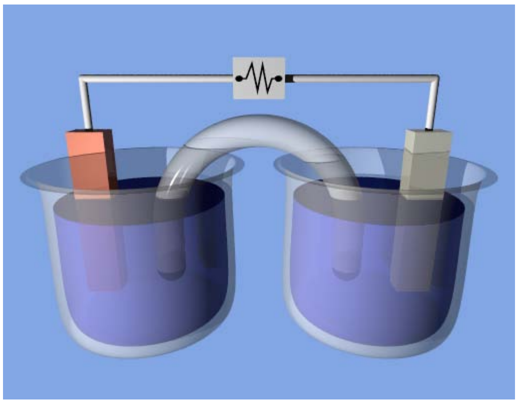

Figure 2 Depiction of an electrochemical cell

A range of energy storage devices are being developed, and may be used in electric vehicles in the future. In addition to electrochemical batteries, fuel-cell batteries use controlled oxidation reactions to generate electric current. Another type of energy storage device is being enabled by advances in carbon nanotubes and nanofibers. These emerging areas have led to improvements in electric double-layer capacitors (supercapacitors) with the potential for millions of discharge cycles. Some of these technologies are being considered in the clean car technology workshop of this conference.

Advances in Battery Technology

Lithium Batteries

Advances in lithium batteries have improved safety and given them high energy density and low self-discharge rates. Newer models have improved the lifespan, fire resistance, toxicity profile, and charging speed, while sometimes trading energy density for power density. Lithium battery technology is a continuing focus of research in both academic and product development settings. Early anodes for lithium batteries were made of graphite. Materials now under consideration for use as anodes include carbon nanotubes, silicon nanowires, and tin nanoparticles.

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[13] Electrochemical Cell, used under GNU Free Documentation License from http://en.wikipedia.org/wiki/File:ElectrochemCell.png.

Carbon Technologies

With their ability to hold and conduct charges, carbon nanotubes (CNTs) and fibers (CNFs) have been patented for use as anodes and supercapacitors. Compared to the traditional graphite or carbon black anodes, which were originally used in lithium ion batteries, CNTs have greater surface binding area for lithium and greater charge/discharge capacity. While supercapacitor (also known as double-layer capacitor) technology has been available for more than 50 years, CNTs, CNFs, and carbon aerogels can be arranged to expose more surface area compared to activated charcoal, and hence carry greater charge. The first vehicles utilizing supercapacitor technologies are now in use.

Other Batteries

Research into batteries using conventional bulk materials continues with many new nickel-metal hydride types appearing each year. These types continue to replace nickel-cadmium batteries for consumer applications. For vehicle applications, they have a higher energy density than lead-acid types and can be cycled many times, but can suffer from short charges, high self-discharge, and poor performance in cold weather.

Environmental and Health Considerations

Environmental Benefits

Innovation in lithium rechargeable batteries is changing consumer use patterns and improving the environmental profile of rechargeable batteries. However, a number of environmental factors are in play; considering these factors could inform which technologies are pursued in the future. For example:

- Rechargeable lithium-ion batteries have a more environmentally preferable toxicity profile than traditional rechargeable lead, nickel-cadmium, or nickel-metal hydride designs;
- Nanoscale silver-zinc batteries are more easily recycled than lithium technologies, which is important because metals mining is associated with significant environmental impacts; and
- Newer designs have so far steadily improved energy density, become lighter, and increased rechargability (both number of cycles and speed of the recharging process).

Development of alternative fuel vehicles is a significant driver for battery research. Newer batteries offer the environmental advantages of potential improvements in energy efficiency, reduced toxicity of battery components, and reductions in automotive emissions compared with vehicles powered by internal combustion engines, although the amount of reductions will depend on the impacts associated with the energy sources used to charge the battery, At the same time, advances in battery technologies offer significant performance benefits over traditional lead-acid batteries. Current generation hybrid electric vehicles (HEVs) typically use nickel-metal hydride rechargeable cells. The latest models use lithium batteries that incorporate nanoscale lithium particles (the size of the particles is necessary to reduce internal resistance, but has the disadvantage of increasing side chemical reactions). Development of organic electrolytes as opposed to aqueous ones allows individual lithium cells to run at higher voltages and, hence, increases the energy density compared to other technologies. Newer polymer designs also allow for flexible batteries, whereas traditional lithium ion batteries use a rigid metal case to hold components in place.

Newer battery designs have the potential to completely replace lead-acid batteries on the electrical grid for applications such as back-up power for telecommunications – while also yielding significant environmental benefits. First, use of these newer batteries would reduce the use of and potential for exposure to lead, a widely identified toxicant. Second, when coupled with renewable energy sources such as solar, wind, and wave, this development has the potential to usher in new possibilities for environmentally safer electrical power, especially at the microgeneration level. Alternative sources currently suffer from electricity generation that is not always well-timed, and a 'smart grid' of batteries would help smooth the peaks and valleys in supply. One idea being field tested is 'two-way' grid hook-ups to use batteries in plug-in vehicles. While numerous issues are presented with the implementation of such a system, improved rechargability of vehicle batteries would go a long way towards addressing outstanding concerns.

Life-Cycle Assessment and Hazard-Based Alternatives Analysis

Raw Material Extraction

The impacts associated with the extraction or mining of raw materials for use in batteries could be explored through life-cycle assessment. The environmental impacts associated with the extraction of lithium (and other components of lithium-ion batteries), and potential recyclability, could be compared to the impacts that might occur with the extraction of lead, silver, and other battery raw materials.

Worker, Consumer, and Environmental Exposures

Exposure scenarios for the range of battery technologies could be compared in the context of a life-cycle assessment. LCA methodologies may provide context to aid understanding of the significance of end-of -life exposure scenarios for nano-scale battery components.

End-of-Life Considerations

Environmentally preferable end-of-life scenarios are a challenge for all battery types. Low rates of recycling and technically complex and expensive recycling processes are the norm, except for lead-acid batteries. In the United States, lead-acid batteries are recycled at rates exceeding 90%. Based on how they have met the challenges of recycling past battery designs, the battery recycling industry should be able to rise to the challenge of recycling the newer battery designs, given good communication and appropriate regulations that do not deter their being recycled. However, difficulties remain in transforming the recycling process into one that is economically sustainable for advanced battery designs.

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Session Schedule

Topic	Speaker	Stakeholder type	Time
Nanomaterial approaches to enhance lithium ion batteries	Brian Landi (Rochester Institute of Technology, US)	Academia	30 min
Understanding the life-cycle environmental implications of nanotechnology in lithium-ion batteries for automobiles	Thomas Seager (Rochester Institute of Technology, US)	Academia	30 min
Life-cycle assessment of lithium-ion batteries for use In hybrid and electric vehicles: Understanding the policies of potential benefits and impacts	Kathy Hart (US EPA)	Government	20 min
Coffee Break			30 min
Effects of CNTs for lithium-ion batteries as additives	Chiaki Sotowa (Showa Denko, Japan)	Industry	30 min
Nanostructures & Zero-Emission Advanced Battery Manufacturing for Zero-Emission Electric Vehicles	Gitanjali DasGupta (Electrovaya, Canada)	Industry	30 min
End of life Issues with batteries: Industrial and consumer recover and reuse/Materials management for batteries	Shane Thompson (Kinsbursky Brothers, US)	Recycler	30 min
Panel Discussion			40 min

ABSTRACTS

Nanomaterial Approaches to Enhance Lithium Ion Batteries

Brian J. Landi, Assistant professor, Rochester Institute of Technology (RIT), United States

There is an ever growing demand for electrical energy storage to support mobile electronics, hybrid-electric/full electric vehicles, and utility scale grid management. Lithium ion has recently emerged as the premier rechargeable battery chemistry due to the increased energy density over other technologies. However, ongoing application demands necessitate higher energy densities to reduce battery mass and volume characteristics. Ongoing research efforts to expand conventional limits have focused on utilizing various carbonaceous and inorganic nanomaterials to increase battery capacity, cycle life, and charge-discharge rates. Of these, some of the most promising developments have been made recently with carbon nanotubes and semiconductor alloys. This presentation will provide a discussion of conventional lithium ion batteries as a necessary framework to describe the potential use of nanomaterials in such an application. As an example case study, details regarding recent work in the NanoPower Research Labs at RIT to enhance lithium ion batteries by replacing the graphitic materials used in the anode with carbon nanotubes (CNTs) will be highlighted. CNTs are a candidate material for this application due to excellent conductivity (electrical and thermal), nanoscale porosity, and as a lithium ion storage material. The presentation outcome will be a summary of current uses of nanomaterials in batteries and a foreshadowing of the potential advantages from this development.

Understanding the Life-cycle Environmental Implications of Nanotechnology in Lithium-ion Batteries for Automobiles

Thomas P. Seager, Golisano Institute for Sustainability, Rochester Institute of Technology, Rochester NY, United States

Nanotechnology is one promising pathway for improving the performance of batteries for electric vehicles and other demanding applications. For example, incorporation of single-wall carbon nanotubes (SWCNT) in Li-ion battery electrodes significantly enhances conductivity and allows increased energy density. Longer-term, SWCNT papers may entirely replace current anode materials, thereby enabling wider adoption of electric and plug-in hybrid vehicles. However, nanomaterials are generally environmentally intensive in their manufacture. Due to low material or process yields and characteristically high energy demands, nanomaterials may have disproportionately large environmental impacts in manufacture that offset gains in use. This presentation illustrates the advantage of a life-cycle perspective in comparison of nanotechnologies on an environmental basis and reports the upstream and process-level energy consumed in production of purified SWCNT papers at the laboratory scale. Some important policy implications are discussed.

Life -Cycle Assessment of Lithium-ion Batteries for use in Hybrid and Electric Vehicles: Understanding the Policies of Potential Benefits and Impacts

Kathy Hart, U.S. EPA, Design for the Environment Program

EPA's Design for the Environment (DfE) Program and the Office of Research and Development (ORD) have formed the Nanotechnologies in Lithium-ion Batteries Partnership NLBP) to conduct a screening-level life-cycle assessment (LCA) of current and future (e.g., single-walled carbon nanotubes [SWCNTs] as anodes) lithium-ion (Li-ion) battery technologies, for use in hybrid and electric vehicles. The partnership may also compare the impacts of using Li-ion batteries with those of using lead-acid batteries, on a functional unit basis (i.e., impacts per kilometer). The goal of this non-regulatory, cooperative partnership is to promote nanotechnology innovations in advanced batteries that result in reduced overall environmental impacts, including greenhouse gas emissions. The partnership also aims to provide information to the advanced automotive battery industry to facilitate product improvements, by identifying which materials or processes within the products' life cycles are likely to pose the greatest impacts or potential risks to public health or the environment.

Nanotechnology is one promising pathway for improving the performance of batteries used in electric vehicles. For example, incorporation of single-wall carbon nanotubes (SWCNT) in battery electrodes significantly enhances conductivity and allows increased energy density. Longer-term, SWCNT papers could entirely replace current anode materials, enabling wider adoption of electric and plug-in hybrid vehicles. However, the manufacture of nano-structured materials uses significant amounts of energy, which can result in significant environmental impacts. This presentation illustrates the need for a life-cycle perspective in the development of nanotechnology applications that have potential environmental benefits.

Effects of CNTs for Lithium-Ion Batteries as Additives

Chiaki Sotowa, Showa Denko K.K., Japan

Lithium-Ion secondary Battery (LIB) is one of the promising batteries in the future. LIB possesses higher energy density than other batteries, and has been adopted cellular phone, mobile PC, power tool, camera, and so on. Now many engineer give huge attentions on LIB as energy source of BEV, HEV, Plug-in HEV and energy storage devices.

This presentation will show how VGCF^{TM} (Vapor Grown Carbon Fiber) works for LIB as additives. VGCF^{TM} has the diameter around 150 nm and a kind of CNT, and has been adopted for LIB as additives for more 10 years.

While charge and discharge cycle of LIB is going, the numbers of contact points between the particles of active material are getting lost and the capacity of battery is fading. VGCF^{TM} exists like a bridge among the particles and keep the paths between the particles, so that the capacity of battery would be prolonged effectively.

In near future, solar and wind power generation systems must play more important role from the point of view on environmental issue, however such generation systems have some problems on stable energy supply. Batteries including LIB can storage and supply energy stably. Such combination of new energy generation systems and battery with long life time must give us comfortable life.

And BEV, HEV, Plug-in HEV have been developed by many auto motor companies. Battery must contribute zero and low emission vehicles. LIB is a candidate of such battery and plays an active role to resolve our global environmental issue.

Nanostructures & Zero-Emission Advanced Battery Manufacturing for Zero-Emission Electric Vehicles

Gitanjali DasGupta, Electrovaya, Canada

Electrovaya has >150 patents on its nanostructured *Lithium Ion SuperPolymer*® battery technology. This is a platform technology that evolves with component improvements, which typically utilize a high degree of nanomaterials. As a North American manufacturer without Far East subcontract manufacturing, Electrovaya faced two critical challenges that have since become core competitive advantages. Firstly, it focused at an early stage on large-format, prismatic cells rather than the conventional small-format, cylindrical cells. As a result, its technology is well suited for automotive and grid applications. Secondly, it had to develop a unique zero-emission battery manufacturing process. As a result, its negligible environmental footprint benefits its community, its clients and its financials. Thus, initial financial and regulatory barriers have in turn become sustainable benefits enabled by nanotechnology.

End of life Issues with batteries: Industrial and consumer recover and reuse/ Materials management for batteries

Shane Thompson, Vice President, Kinsbursky Brothers and Toxco, United States

Batteries: Markets and Definitions

This presentation will give an overview of the battery product market. An understanding of the battery product market is important to understand the 'recycling potential' of the batteries as they reach their end of useful life. This segment of the battery market will enable one to better understand the collection and processes used to gather and recycle batteries. Whenever you have a general discussion on battery collection and batter recycling, understanding the particular product segment that a battery is in, will inevitably determine its ability to be successfully collected and, subsequently, recycled. Additionally, by understanding the relevant battery market segments, you can understand how the issues discussed below effect the collection schemes, recycling systems and the batteries ultimate disposition. For the purpose of this presentation the speaker acknowledges that the industrial and commercial Pb battery industry has a long standing and well defined history of collection and recycling and, as such, I will not go into great detail on this battery market segment with the exception of briefly discussing its relevance in the Kinsbursky –Toxco business model. Rechargeable batteries, which contain both regulated materials as well commodity resources, are the best example of our extractive process and will be the focus of the presentation.

Collection: Regulation and Economics as Key Drivers.

The two key factors that affect battery recycling are: regulatory and economic considerations. The regulatory issues focus on the end of life management of those batteries which contain EPA regulated metals; Pb, Cd and Hg and /or exhibit other characteristics of hazardous waste flammability etc… In addition to the Federal focus, some states have expanded on the Federal regulations. California, for example, regulates nickel and zinc as hazardous substances and batteries, in particular, have been the focus of more local regulatory focus. California Assembly Bill 1125, and New York City Local Law 97 of 2005 are examples of regulation designed to encourage the recycling of consumer rechargeable batteries. The economic considerations with spent batteries center around the extraction of any renewable natural resources; nickel, cobalt, and lead, among others, found in the battery and the associated cost with collecting ,transporting and, ultimately, processing the battery to access the resources contained in the spent battery. This presentation will discuss how both of these factors contribute to the overall collections of spent batteries and as they change they are continuing to have an impact in collections and recycling efforts today and will continue to have a similar impact in the future.

Processing:

This presentation will give an explanation of the Kinsbursky-Toxco approach to battery recycling and will include an overview of battery collections, issues with packaging and transportation of the spent batteries, as well as a detailed overview of the current process technology and improvement of this process technology to meet the future recycling needs of the battery industry, specifically addressing the issues of future battery compositions and the overall increasing quantity of batteries. This presentation will provide information on Kinsbursky-Toxco's application for funds from the DOE to build an advanced battery (Li Ion) recycling plant. This plant will take the novel approach that instead of merely recycling out the commodities and mitigating harmful substances, the process equipment and methodology are designed to extract and process the battery constituents in order to create high purity battery grade materials instead of a modified scrap material. This type of processing would truly close the loop.

Conclusion: How will new materials affect an old system?

A discussion on the ability to integrate batteries containing nano materials into the existing collection and recycling infrastructure. As nanomaterials are emerging as a potential source of higher energy density in batteries, we are examining their presence in the market and the possible effect that their presence would have in the extraction process. Extractive metallurgy has been and most likely will continue to be the process; a defined methodology that can be adapted and/or modified to target specific elements and could apply to CNF, CFT and/or other nanomaterials (Silicon based nano wires etc.). Specifically we are evaluating the possibility of being able to capture and reuse some of these nanomaterials, or how would we put in modifications to collection and recycling process to safely handle and mitigate the effects of the nanomaterials.

PARALLEL SESSION SEVEN - AGRICULTURAL NANOTECHNOLOGY

As an enabling technology, nanotechnology has vast potential to revolutionize agriculture and food systems.[14] Two key applications of nanotechnology are particularly relevant: sensing technology designed to alert growers and others in the agricultural community to soil, moisture, nutrient, pathogen, and related conditions pertinent to growing crops, and nano-enabled technologies intended to enhance performance by improving the delivery of nutrients and agricultural chemicals thereby diminishing the volume of these materials introduced into the environment.

Session Overview

The presenters at this session will offer a variety of diverse perspectives on applications of nanotechnology in the agriculture sector. Their presentations will outline the scientific and technological advances in this area, demonstrate how these applications are benefiting the agricultural sector and the environment, and summarize the challenges innovators, growers, and other stakeholders in the agricultural community face. This Workshop will include:

- An overview of the current state of play regarding applications of nanotechnology to agriculture;
- In-depth review of several nanotechnology applications to demonstrate their utility and how each benefits the environment;
- Review of emerging applications and consideration of how each is expected to benefit the environment and agricultural practices;
- Review of societal impacts resulting from the application of these technologies in the agricultural sector; and
- Review of how potential releases of nanoparticles into the environment are addressed.

The session will last approximately four hours, including a coffee break. It is expected to run in parallel with another workshop. Two moderators will introduce each speaker, monitor time, and generally moderate the session. A Rapporteur will summarize the major findings of the presentations and discussion for the Conference document.

14 *See Nanoscale Science and Engineering for Agriculture and Food Systems*, A Report submitted to Cooperative State Research, Education, and Extension Services, USDA; National Planning Workshop (2002).

Background on Nanotechnology Applications in Agriculture

There are many promising emerging applications of nanotechnology that benefit agriculture and the environment. Nanotechnology has rapidly emerged as an efficient and economical means to enhance farming while limiting environmental impacts. A key goal of the Workshop is to focus on existing and emerging nanomaterials and nanotechnologies with a specific focus on how exactly nano-enabled products and technologies can improve agricultural practices, benefit the environment, and enhance society. Presentations will focus on several developments, including:

- Nanosensors based on using electrochemically functionalized single-walled carbon nanotubes with metal nanoparticles or metal oxide nanoparticles, and metal oxide nanowires and nanotubes to address agricultural byproducts such as ammonia, nitrogen oxides, and other gases. These methods allow the development of high-density nanosensors arrays that have potential application in monitoring agricultural pollutants and to assess the impact of these pollutants on biological and ecological health, and to increase crop productivity while reducing land burden.

- Use of engineered nanostructures as electron transfer devices for biological and agricultural applications.

- Role of nanotechnology in Indian agriculture in furthering sustainable agriculture in targeted areas, including: nanofertilizers for slow release and efficient use of water and fertilizers by plants; nanocides (pesticides encapsulated in nanoparticles for controlled release), and nanoemulsions for enhanced efficiency; nanoparticles for soil conservation; and nanosensors for soil quality and plant health monitoring.

- Applications of nanotechnology to monitor water quality and for water purification.

Human Health, Environmental, and Societal Impacts

While it is difficult to assess with precision the potential impact of these applications of nanotechnology upon human health, the environment, and society, the presenters will endeavor to identify potential impacts and assess their significance. The applications of nanotechnology in developing countries in particular, and their contribution to agricultural productivity enhancement, is an area of significant interest and promise in addressing the consequences of environmental degradation and what some refer to as "technology fatigue." Whether and how nanotechnology can reverse these adverse trends in agriculture and jump-start developments that offer sustainable agricultural practices in developing and developed economies alike is an area of intense interest.

Equally important is consideration of how potential releases of nanoparticles into the environment are anticipated and addressed. This is especially true for agricultural applications, as some environmental releases potentially could be directly into the environment. Whether and how these technologies are being designed to prevent the release of nanoparticles into the environment or otherwise to mitigate potential adverse impacts that could result from the release of materials into the environment or from the biodegradation of nanomaterials must be considered and will be discussed.

Life Cycle Perspective

As a major theme of this conference, presenters will be asked to offer a life cycle perspective. What raw materials are selected, how they are used in the manufacture and production of the technology, and how these technologies are deployed in the environment, along with possible consequences, will be reviewed to enable consideration of their potential impact on energy consumption, materials efficiency, as well as the environmental implications of the technology through production, transport, and use. To the extent the technology involves an environmental release, the potential consequences of the release on human health and the environment will be considered. Finally, the technology will be assessed in terms of its end-of-life utility, opportunities for recycle and reuse, and ultimate disposal.

Policy Considerations

Nanotechnology applications in the agricultural sector raise many interesting and vexing policy issues. While the potential benefits of nanotechnology to agriculture and the environment are well recognized, regulators will be challenged to ensure that sufficient measures are in place to balance the potential for adverse environmental impacts resulting from the release or potential release and/or degradation of nanomaterials into the environment with the many benefits nanotechnology offers.

Global regulatory and governance systems vary considerably throughout the world with respect to managing agriculture and food safety. Care will need to be taken to identify and consider the unique geographical and societal differences that will materially affect the ability of various governance systems to balance these risks and benefits responsibly and comprehensively. Effective policies will need also to recognize limitations on the available data points that will inform regulators and policy-makers of all relevant aspects of the environmental and life cycle implications of nanotechnology and nanomaterials applications in the agricultural sector, and to ensure appropriate measures are in place to assure sustainable agricultural practices that incorporate nanotechnology.

Session Schedule

Topic	Speaker	Stakeholder Type	Time
Nanostructure-enhanced electron transfer devices for agricultural applications	Guigen Zhang (Clemson University, US)	Academia	30 min
Nanotechnology and agriculture in India: The second green revolution?	R. Kalpana Sastry (Nat'l Academy of Agricultural Research, Hyderabad, India)	Academia	30 min
Impact on nano-scale technologies on food and agriculture	Pat Roy Mooney (ETC Group, Canada)	NGO	30 min
Coffee Break			30 min
Nanosensor arrays for real-time monitoring of agricultural pollutants	Ashok Mulchandani, Ph.D. (University of CA Riverside, US)	Academia	30 min
Agricultural policy implications of nanotechnology	Steve Froggett, Ph.D. (U.S. Department of Agriculture)	Government	30 min
Nanotechnology and water purification in Brazil	Victor Bertucci Filho (Embrapa Instrumentação Agropecuária. Brazil)	Government	30 min
Panel Discussion			30 min

ABSTRACTS

Nanostructure-Enhanced Electron Transfer Devices for Agricultural Applications

Guigen Zhang, Department of Bioengineering, Department of Electrical and Computer Engineering, Clemson University, South Carolina, United States

In this talk, I will discuss our pursuit of engineering bridges to link the nano world to the real world we live in. I will present several paradigm-shifting concepts using our engineered nanostructures as novel electron transfer devices for biological and agricultural applications including food and water safety, bioconversion, environmental remediation, and bio-security. Selected case studies along with some promising results will be highlighted.

Nanotechnology and Agriculture in India: The Second Green Revolution?

Kalpana Sastry, R.[1], H. B. Rashmi, N. H. Rao, and S.M. Ilyas

1) National Academy of Agricultural Research Management, Hyderabad, India

It is now well recognized that the relative successes of Indian Agriculture during the 1970s and 1980s, were based on the green revolution technology model of breeding short-duration high yielding cultivars, irrigation and intensive use of fertilizers and other agro-chemicals. Central to this model were the adoption of micro or farm economics- which governed the use of inputs such as land, cultivars, labour, machinery, and chemicals balanced against profits from crop yields, and the macro economics that ensured better prices to farmers and access to inputs and markets. While the green revolution model increased yields and farm incomes substantially, it had relatively less emphasis on efficient and sustainable use of soil nutrients and water. Agriculture in India now faces more formidable challenges of meeting growing demands of the large population for nutritionally safe foods, with limited availability of land and water resources which are increasingly threatened by environmental and climatic pressures. Addressing the emerging challenges requires increasing productivity and incomes per unit of the scarce natural resources is possible only through understanding, integrating and deploying new advancements in science and technology in agricultural production. Among the recent advancements in science, nanotechnology (NT) is fast emerging as the new science and technology platform for the next wave of development and transformation of agri-food systems (Roco, 2003; Kuzma and Verhage, 2006; Scrinis and Lyons, 2007), as well as improve the conditions of the poor (Juma, et al 2005). This enabling, and often disruptive technology base that is panindustrial as well as convergent with other emerging technologies is multifaceted in nature. While it is projected to have the potential to provide large emerging agriculture centred economies like India (Romig et al 2007), it is essential to use the well established technology platforms in the country by creating its own nanotechnology based solutions and industries in the rural sector (Planning Commission, 2007).

Keeping this in view, Government of India initiated a Nano Science and Technology Mission in the country and continues to strengthen it (DST, 2009). Through the Department of Biotechnology (DBT), Government of India has also launched the Nanotechnology Initiative in Agriculture and allied sectors. It is necessary to realise that such investments not only

accelerate such researches in agriculture sector, but also help to ensure that the large National Agricultural Research System in India stays globally competitive. The need to maintain technological parity with global competitors is indeed a critical strategic issue for the agricultural and rural sectors. Emerging technologies can create competitive advantage and commercial success for farmers and agricultural industries as well as benefit rural communities. But it is essential that nanotechnology be extended across the entire agricultural value chain to increase agricultural productivities, product quality, consumer acceptance and resource use efficiencies (Kalpana Sastry et al 2007). Consequently, this will help reduce farm costs, raise the value of production and increase farm incomes. It will also lead to conserving and enhancing the quality of the natural resource base in agricultural production systems.

For all this to happen, a more coherent systems approach is required for planning nanotechnology development and implementation across the agricultural supply chain. Early assessments of where such innovation can contribute towards a enhanced competitive advantage. Equally important, is to identify the commercial partners who can adopt and benefit from new technologies, and assist with their implementation in the large rural sector of India.

In this paper, firstly, a sufficiently general framework and methodology that can also be extended to other emerging technologies is presented for nanotechnology applications across the agricultural value chain. The framework is based on a specially designed database that allows mapping research themes in nanotechnology to specific sectors in the agricultural value chain and enables a rational assessment of the potential applications of nanotechnology in the Indian agri-food sector, identifying and prioritizing research needs across the agricultural value chain, and assessing the societal implications of this emerging technology. This is necessary as the key purpose is also to anticipate environmental and societal impacts so that necessary regulatory mechanisms to ensure that some of the difficulties encountered in introducing new technologies in agriculture (as for GM crops) can be anticipated and avoided or overcome. Several studies (NSF, 2001; Royal Netherlands Academy of Art and Sciences, 2004), have pointed out that this can be done in the case of nanotechnology by informing the public about scientific and technological developments; anticipating environmental and health impacts early through research, and involving the major stakeholders in discussions of the pros and cons of nanotechnology**.** Therefore, this process based framework and methodology for a systematic assessment of the potential for application of nanotechnology across the various links in the agricultural value chain can be useful towards developing a roadmap for integrating nanotechnology into agri-food systems research in India, and help prioritize research investments for relevance, global competitiveness and quick returns. These need to be identified early and actively pursued in national developmental plans. As an illustration, the potential of biosynthetic pathways for nanoparticle production processes and the applications for sustainable agriculture systems in Indian agriculture is explained as a case.

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Nanosensor Arrays for Real-Time Monitoring of Agricultural Pollutants

Ashok Mulchandani[1)] and Nosang V. Myung

1) Department of Chemical and Environmental Engineering, University of California, Riverside, United States

Emissions from animal and crop agriculture have recently received greater attention as a pressing environmental and public health issue. These agriculture byproducts include reactive nitrogen such as ammonia and nitrogen oxides, odor emissions such as organic acids, gaseous sulfur compounds like hydrogen sulfide and particulate materials. Many different crop species and livestock are grown in the United States in widely different geographic areas, climatic conditions, and management practices. Moreover, uncertainties associated with agricultural pollutant emissions arise from 1) limited data availability, 2) inaccurate estimates due to large temporal and spatial variability, 3) diverse characteristics of pollutant emissions from highly dispersed sources, and 4) limited understanding of emission of volatile organic compounds. There is therefore a great need to develop portable, low-cost, and low-power wireless sensor networks to real-time monitor spatial and temporal variations of multiple agricultural pollutants, to better characterize the agricultural environment and assist producers in preventing or mitigating air emission.

In this presentation, we will present our recent results on development of nanosensors based on using electrochemically functionalized single-walled carbon nanotubes (SWNTs) with either metal nanoparticles or metal oxide nanoparticles, and metal oxide nanowires and nanotubes for gases such as ammonia, nitrogen oxides, hydrogen sulfide, sulfur dioxide and volatile organics. The methods allow creation of high-density individually addressable nanosensor array that has potential application in monitoring agricultural pollutants for the assessment of impacts of these pollutants on biological and ecological health and in increase of crop productivity and reducing land burden.

Agricultural Policy Implications of Nanotechnology

Steve Froggett, Scientific Advisor, Office of Scientific and Technical Affairs of the Foreign Agricultural Service, U.S. Department of Agriculture

During this talk, I plan to discuss potential nanotech applications and products for use in production agriculture which will benefit the environment. Agriculture in the 21st century needs to provide for a larger global population, on less land, under changing climatic conditions and will be faced with increased abiotic stresses. Nanotechnology innovations under development will advance agricultural efficiency and precision, enabling a shift to more sustainable food production. Some of these innovations include: more efficient and safer pesticides and fertilizers and field sensor systems which allow the minimal use and targeted application of pesticides, fertilizer and water inputs.

Nanotechnology And Water Purification in Brazil

Victor Bertucci Neto, Embrapa, Agricultural Instrumentation Centre, São Carlos, São Paulo State, Brazil

Nanotechnology is a broad area of research which is having a huge amount of investment in the last years around the world due to its great potential of technological applications and also due to the great improvement that can be promoted on the performance of several types of products and processes in several areas. One of them is Agriculture and Embrapa (a Brazilian Public Institution for Research in Agriculture) is leading most of the researches related to these themes in the country. As far as nanotechnology is concerned, the Brazilian government started a so called Nanotechnology Initiative in 2001, in which Embrapa was particularly involved through its Agricultural Instrumentation Research Unity. Several meetings and conferences were done leading to the establishment of national networks on this field. The interdisciplinary characteristic of these works results in new applications such as nanostructured materials for development of Nanosensors that sense from different mineral waters to blended sample of coffee. Other applications include toxin detection in fresh water in the presence of toxic cyanobacteria, and water decontamination.

PARALLEL SESSION EIGHT - GREENER NANOPRODUCTS

Context for the Session

Nanotechnology has a positive potential not only for economic development. Considerable improvement is also expected with regard to the protection of the environment and human health. Thus, nanotechnology development may increase the efficiency of resources and improve the overall performance of environmental protection.

With the application of nanotechnology, it is possible to increase the efficiency of the use of raw materials over the life cycle of a product and thus reduce the emission of pollutants as well as energy consumption.

Session Overview

The session will include:

- State-of-the-art of applications of products, which help to reduce use of chemicals, materials and energy (development, market-potential), including challenges and needs for further research;
- Determination of potential benefits of these applications;
- Determination of the potential environmental and health risks associated with these technologies;
- Consideration of policies that may promote responsible development and save handling.

Background on Green Products through nanotechnology reducing use of materials and energy

There are several approaches how nanotechnology can reduce the use of chemicals, materials and energy. Materials can be used economically by means of miniaturization, for example in low weight, nanotechnology-based sensors, which are developed predominantly for biomedical and military purposes but are also expected to optimize environmental applications such as specific detection of biological and chemical contaminants. Raw materials can be saved by means of a reduction of coating and layer thicknesses: for nanoscale coating and catalysts with higher specific surface reactivity, for light-weight construction materials optimized by means of nanoparticles, for wear-resistant and low-friction surfaces in mechanical engineering and highly specific membranes used in biotechnology.

As a result of reduced use of chemicals and materials energy can be saved owing to reduced weight or optimized function. For example, silicon dioxide and carbon black nanoparticles are being added to modern car tyre materials for reinforcement. They reduce rolling resistance and thus help achieve fuel savings of up to 10 %.

In some instances dangerous substances can be reduced of the use or can be replaced. For example, the use of paint coatings containing chromium (VI) being harmful to health and the environment will be replaced by metal corrosion protection where surfaces have a nanotechnology-based finish.

Advances in Green Products through nanotechnology reducing use of materials and energy

Advances in lighting

Currently, lighting accounts for between 20% and 25% of the overall electricity consumption. The addition of nanotechnological products (quantum dots (QDs) to light emitting diodes (LEDs)) has the potential to reduce the energy consumed by lighting by ~80% compared to incandescent bulbs.

With new nanotechnology based lighting products 90 % of electric energy will be converted in light. Conventional bulbs convert only 5 – 10 % in light energy, the rest is converted in heat and will be lost. Because the life time is assumed to be more than 50.000 hours you also can expect a significant saving of material in comparison to bulbs which have a life time of only 1.500 hours. Additionally there is no toxic material, for example mercury compounds in the lamps. The energy efficiency of this technology represents a remarkable reduction in electricity production needs, and hence a remarkable reduction in the amount of coal burning that may take place – coal burning being one of the leading sources of carbon dioxide and heavy-metal emissions into the environment today.

Self-cleaning and longer-lasting coatings

Extended lifetimes, increased resilience, reduced requirements for maintenance and replacement – such properties seem to be mundane applications of nanotechnology, but they have a strongly positive impact on the environment.

In the mobility sector, nanostructured coatings prevent bio-fouling without biocides. The same concept is an essential component for nanomembranes that are expected to fight water scarcity by improved water purification. The positive effects of nano-based anti-fouling coatings include not only the replacement of toxic substances, but also reduced energy and maintenance requirements. In a longer perspective, similar nanostructured coatings will prevent microbial growth in medical devices, reducing again the load of disinfectants that pose a hazard to health and environment at present. Architectural nanostructured coatings that repel soil and/or show self-cleaning properties are already commercialized in the construction sector. Such surfaces stay cleaner for longer times, and thus help to reduce material resources in renovation.

Another class of nanostructured coatings makes surfaces more resilient against mechanical stress. Products of inorganic-polymeric hybrid coatings are available that increase the abrasion and scratch resistance, not only for esthetic reasons, but also for prolonged lifetimes and reduced frictional losses with energy savings. On metallic surfaces, thermal spray coating creates a thin layer that is protective and hardening thanks to its nanostructure. Such coated turbine blades for aircraft and for powerhouses, and automobile motor parts resist corrosion and reduce friction. Both increased energy efficiency during use and reduced materials resources for replacement are positive effects for the environment.

Nanocoatings for energy conservation and generation

Nanocoatings can be linked to energy saving and energy generation. Energy saving or special filtering glass for residential window use, self-cleaning glass for greenhouses and anti-reflective glass are three out of many examples of high-end technical applications enabled by nanocoatings. In energy generation, and especially the surging photovoltaic industry, the nanodimension has already made possible increased conversion efficiencies, new cell types and integrated manufacturing methods. In the near future, printed nanocoatings are expected to take solar cell manufacturing to new dimensions with regard to volume and cost efficiency.

Carbon nanotubes in coating application

New solvent less, eco-friendly fouling release coatings for marine applications based on carbon nanotubes do not leach any biocide, heavy metal, or any other substance harmful to marine organisms. There is an obvious environmental benefit of this product compared to the existing solution where other biocides substituted the extremely toxic TBT. Life cycle analysis shows that the risk for human health and the environment is negligible. Similarly protective thermal coatings have been developed containing carbon nanotubes. When used in aerospace or in automotive applications these products are expected to reduce the insulation weight and consequently reduce energy consumption, without increasing environmental and human health risk.

Nanocoatings at buildings

The fabric of a building degrades for various reasons: Natural wear off and weathering as well as vandalism often lead to unscheduled and undesirable maintenance and repairs. Nanotechnology offers a wide range of sometimes inimitable solutions for surfaces of buildings or in the interior. “Nanogate-Technology” is called the combination of nanotechnology with established materials and the safe processing on a wide range of substrates. This technology can be applied to enhance and to protect well known materials and products and to open new and alternative production processes. For example the patented system nanoGuard® StoneProtect drastically reduces the amount of dirt and grime which clings to the surface of tunnels, thus reducing expensive cleaning phases. This saves considerable costs and makes a sustained contribution to the environment and traffic safety. The tunnel does not have to be cleaned as often and no aggressive cleaning agents are needed. Simple treatment with water suffices to free the concrete from the grime. The significantly lower amount of grime sticking to the walls also increases traffic safety, as the exposed concrete can once again reflect light, thus better illuminating the tunnel. Furthermore “Nanogate-Technology” can be used as coating on terrace floors and concrete walls to facilitate the remove of dirt or graffities.

Environmental and Health Considerations

Several nanotechnological applications have benefits for the environment, but across the entire life cycle of the products, including production and end-of-life disposal, there also raise concerns on potential implications for human health and the environment. Little is known, for example, about the release of nanoparticles from products or the fate of the materials when becoming waste. Nanomaterials such as particles may pose a hazard to human health, affect aquatic ecosystems and interfere with wastewater treatment process.

Environmental Benefits

Research on the potential benefits for environmental relief is needed above all with regard to the problems listed below, which have to be tackled on the basis of defined products and methods. Emphasis should be given to calculate the benefits during other phases than the use phase during the life cycle.

Which are the impacts of nanotechnology on raw material input? A quantification of the environmental benefits provided by nanotechnological processes and products would be helpful not only in funding policy, but also and in particular for the formulation of high-tech, climate, and sustainability strategies. Which contribution nanotechnology can make to overcoming existing bottlenecks, for example, with respect to resource efficiency potential?

Life Cycle Analysis and Hazard-Based Alternatives Analysis

However, concrete data substantiating a better environmental compatibility of defined applications have been available only in single cases so far. Thus, some examples have demonstrated efficiency potentials of nanotechnology applications, exemplified by a number of cases and using an approach guided by life cycle assessments. As a result, high ecological efficiency potentials were shown to exist for some applications examined. However, nanotechnological applications are not *per se* associated with beneficial potentials regarding reduced use of raw materials.

The industrial production, implementation and distribution of nanoscopic functional materials are a fact, although many problematic and unknown features convoy this highly dynamic development. It is not only the potential of chemical and/or physical reactivities and interactions nanomaterials may undergo during their production and application. It is the whole life cycle which has to be considered and which poses unprecedented challenges. On one hand there is a need for analytical tools allowing the monitoring of the spatial trajectories, but also the dynamics of the distribution of mobile fractions. New methods and applications will be presented. The problem of resource and supply management has to be discussed. The fact that strategic resources, in particular strategic metals, may be finely dispersed all over the earth's surface when being implemented as nanomaterials in technical devices could imply severe shortages and economic as well as ecological risks for important technologies. Therefore a kind of a dedicated resource and supply chain management as well as of a resource geography or a materials geography may be useful instruments allowing a better traceability and a more sustainable utilization of nanomaterials.

Every single step in materials flow, including exploration, mining, production, distribution, utilization and recycling must not only fulfil l the „usual“ functional and economic requirements but must also meet the ecological and social demands of sustainability.

In order to achieve sustainable product realization, the materials research community must consider the following factors:

- Integration of environmentally benign design, materials, and manufacturing over all stages of the life-cycle
- Exploration and mining of raw materials respecting socio- economic standards and preserving the eco-sphere

- Optimal exploitation of raw materials and natural resources including synergetic utilization of by-products
- Energy efficient production technologies and product distribution, if possible based on regenerative energy sources
- Minimal harmful effects caused by the emission of secondary products
- Durability, recyclability and closed loops
- Traceable and accountable waste management
- Appropriate information and education of the stakeholders in the materials and products.

These issues represent general principles for the implementation of sustainable materials, products and processes.

Each speaker will include an examination of challenges for implementation and of considerations upon policies to ensure rapid and responsible development (see also the questions in the Workshop Guidance).

Session Schedule

Topic	Speaker	Stakeholder type	Time
Quantum Light™ optics for lighting	Seth Coe-Sullivan (QD Vision Inc., US)	Industry	25 min
Self-cleaning and longer-lasting coatings	Wendel Wohlleben (BASF SE, Germany)	Industry	25 min
Nanocoatings for energy conservation and generation	Joe Pimenoff (Beneq, Finland)	Industry	25 min
Break			20 min
The safe use of carbon nanotubes in coating applications	A.J. Lecloux (Nanocyl, Belgium)	Industry	20 min
Preserved, pure and precious – nanoGuard for building and Interior	Michael Overs (NanoGate AG, Germany)	Industry	20 min
Binding particles to patience: Nanotechnology in a true context of sustainability	Ian Illuminato (Friends of the Earth, US)	NGO	20 min
Sustainability and recycling issues	Armin Reller (University of Augsburg, Germany)	Academia	25 min
Panel Discussion			60 min

ABSTRACTS

Quantum LightTM Optics for Lighting

Seth Coe-Sullivan, Co-Founder and Chief Technology Officer, *QD Vision Inc., United States*

QD Vision, Inc. is developing Quantum Light™ optics for solid state lighting devices for sale to commercial and industrial markets later this year. These products will provide large performance enhancements in terms of light quality, color rendering, and color temperature, and simultaneously a reduction in energy use. Currently, lighting accounts for between 20% and 25% of the overall electricity consumption in the U.S. and the addition of this technology to lighting products has the potential to reduce the power consumed by lighting by ~80% compared to incandescent bulbs and by ~33% compared to state-of-the-art LED-based and CFL-based fixtures of equivalent color quality. These step-change improvements to the energy efficiency of lighting around the world are enabled by the quantum dot nano-material that is in the Quantum Light™ optic, and hence it is important to consider the overall environmental pluses and minuses before emplacing such a novel material on the market. When compared to fluorescent or CFL light bulbs, introduction of this technology represents a major reduction in Mercury exposure to individuals due to bulb breakages, and to the environment due to the inefficiency of current recycling procedures for these bulbs. Separately, the energy efficiency of his technology represents a massive reduction in electricity production needs of the nation, and hence a massive reduction in the amount of coal burning that might take place – coal burning being one of the leading sources of carbon and heavy-metal emissions into the environment today. Hence, introduction of this technology represents a large net benefit to the environment both in terms of a reduction in net Cadmium, net Carbon and net Mercury releases to the environment, as well as a reduction in Mercury exposure to individuals in home and office environments.

Self-Cleaning and Longer-Lasting Coatings

Wendel Wohlleben, Nanotechnology Innovation Team, BASF SE, Germany

Extended lifetimes, increased resilience, reduced requirements for maintenance and replacement – such properties seem to be mundane applications of nanotechnology, but they have a strongly positive impact on the environment.

In the mobility sector, nanostructured coatings prevent bio-fouling without biocides. The same concept is an essential component for nanomembranes that are expected to fight water scarcity by improved water purification. The positive effects of anti-fouling coatings include not only the replacement of toxic substances, but also reduced energy and maintenance requirements. In a longer perspective, similar nanostructured coatings will prevent microbial growth in medical devices, reducing again the load of antibiotics that accumulate in the environment at present. Architectural nanostructured coatings that repel soil and/or show self-cleaning properties are already commercialized in the construction sector. Such surfaces stay cleaner for longer times, and thus they help to reduce material resources in renovation.

Another class of nanostructured coatings makes surfaces more resilient against mechanical stress. Products of inorganic-polymeric hybrid coatings are available that increase the abrasion and scratch resistence, not only for esthetic reasons, but also for prolonged lifetimes and reduced frictional losses with energy savings. On metallic surfaces, thermal spray coating creates a thin layer that is protective and hardening thanks to its nanostructure. Such coated turbine blades for aircraft and for powerhouses, and automobile motor parts resist corrosion and reduce friction. Both increased energy efficiency during use and reduced materials resources for replacement are positive effects for the environment.

Nanocoatings for Energy Conservation and Generation

Joe Pimenoff, Senior Scientist, Beneq, Finland

In my talk, I intend to give a comprehensive picture of the different uses of the nanodimension in coatings, today and tomorrow. Most of the globally competitive applications in nanocoatings today are linked to energy saving and energy generating. Energy saving or special filtering glass for residential window use, self-cleaning glass for greenhouses and anti-reflective glass are all examples of high-end technical applications enabled by nanocoatings. In energy generation, and especially the surging photovoltaic industry, the nanodimension has already made possible increased conversion efficiencies, new cell types and integrated manufacturing methods. In the near future, printed nanocoatings are expected to take solar cell manufacturing to new dimensions in the case of volume and cost efficiency.

Concerning the nanodimension and occupational safety, I will clarify what a company like Beneq is doing in order to keep informed about the latest development and findings in nanosafety, what impact the said findings can have on the company's activities and how they are implemented in our work.

The Safe Use of Carbon Nanotubes in Coating Applications

Prof. A. J. Lecloux[1)] *and Dr. F. Luizi*[2)]

1) Nanocyl HSE Manager

2) Nanocyl R&D Executive Director

Any new development of nanomaterials will depend on the risk /benefits balance linked to a given application. Consequently, to take advantage of the potential benefits of carbon nanotubes, it is essential to also have a good idea of the potential risk their use could generate during the life cycle of the product. This implies not only to collect toxicological information but also to be able to measure the potential level of exposure during production and use of carbon nanotubes. In cooperation with the company Naneum, exposure to nanoparticles and carbon nanotubes has been measured at various stage of the life cycle of the product for two main coating applications.

Nanocyl recently developed a new, solvent less, eco-friendly fouling release coating for marine applications, BioCylTM which is based on carbon nanotubes and does not leach any biocide, heavy metal, or any other substance harmful to marine organisms. There is an obvious environmental benefit of this product compared to existing solution and the life cycle analysis shows that the risk for human health and the environment is negligible.

Similarly protective thermal coatings have been developed containing carbon nanotubes.

When used in aerospace or in automotive applications these products could reduce the insulation weight and consequently reduce energy consumption, without increasing environmental and human health risk.

Preserved, Pure and Precious – NanoGuard® for Building & Interior

Michael Overs, Head of Product Management Building & Interior, Nanogate AG, Goettelborn, Germany

Many people safe there money for years to realise their dream of an privately own home. Administrative buildings fulfil not only practical functions, headquarters are one of the most important figureheads for representative purposes. Conservation of value and attractive optics of buildings and interior are central ambitions for private individuals as well as for institutions.

It is often underestimated that the fabric of a building degrades for various reasons: Natural wear off and weathering as well as vandalism often lead to unscheduled and undesirable maintenance and repairs. If directly after one renovation measure was finished at the one end, the next starts at the other end, this will lead to the feeling of living on a building site.

Nanogate AG works on surfaces for building and interior since years. Nanotechnology is one of our most important tools and offers a wide range of sometimes inimitable possibilities to solve the problems. We call the combination of nanotechnology with established materials and the safe processing on a wide range of substrates Nanogate-Technology. Our technology can be used to enhance and to protect well known materials and products and to open new and alternative production processes.

The Södra Länken tunnel system with a total length of about 16 km was treated with nanoGuard® StoneProtect upon the commission of the city of Stockholm. The patented system drastically reduces the amount of dirt and grime which clings to the surface, thus reducing expensive cleaning phases. This saves considerable costs while NanoGuard® moreover makes a sustained contribution to the environment and traffic safety. The Södra Länken tunnel system is the biggest tunnel system in Sweden and the biggest city tunnel in Europe. The constant stress caused by exhausts, tire particles and other grime forces the operator to regularly clean the tunnel walls lined with exposed concrete which is time-consuming and expensive. Each time all traffic has to be diverted which causes considerable indirect costs and a tremendous strain on the entire Stockholm traffic system, the inhabitants and the environment.

The coating significantly reduces the amount of dirt and grime which stick to the walls. The tunnel does not have to be cleaned as often and no aggressive cleaning agents are needed. Simple treatment with water suffices to free the concrete from the grime. The significantly lower amount of grime sticking to the walls also increases traffic safety, as the exposed concrete can once again reflect light, thus better illuminating the tunnel.

Ketchup stains on a terrace after a barbecue can emerge as a problem of permanent duration quickly. Water repellent impregnations only can protect for a short time. The effectiveness on floor areas is limited due to the fact that the dirt can be pressed into the small pores of the material by walking on it. The advantage of most of the water repellent materials is that their effect on the colour and impression is very low. On the other hand, the protection against soiling of thicker coatings which do not have to be categorically water repellent can be much better. Unfortunately, it is important to keep in mind that thicker coatings can affect colour and impression adversely. In fact, there will be no standard solution, neither in the future.

Graffiti has become a big problem for communes, industry and also for private people. According to the German Conference of Cities, Germany has to pay approximately 200 million EUR per year to remove graffiti (source: FAZ). In most cases only the location of a building will decide whether a building is a target for „graffiti artists“, or not. The removal of graffiti is complicated, mostly impossible. Concrete can be cleaned with aggressive solvents, cleaners and cleaning methods absolutely. A wall made of clinker or natural stone definitely not. Our graffiti protection system can not avoid the adhesion of graffiti but it facilitates its simple remove with a pressure cleaner and hot water – efficient and environmental-friendly.

Consistently people think of nanotechnology as a solution of all the problems which could not be solved with common techniques. Unfortunately, also nanotechnology is not the universal miracle cure. Also, in the future, we think we have to tell our customers that we are not able to annul physical and chemical rules. Anyhow, building and interior offers a lot of possibilities to enhance surfaces, to reduce soiling and maintenance and to conserve value. The Nanogate-Technology helps you to spend more time for leisure than for cleaning, maintenance, and it makes sure that representative buildings remain representative.

Picture: Södra Länken Tunnel, Stockholm, Sweden.

Binding Particles to Patience: Nanotechnology in a True context of Sustainability

Ian Illuminato, Friends of the Earth U.S., Washington D.C., United States

Nanotechnology is promoted as a green solution for many global woes. We hear nano will clean our water, make our food safer and more nutritious, and propel our economies towards a new era of growth and prosperity. Sounds promising. Yet, authoritative members of government, the scientific community, civil society, academia, labor unions, and even industry have identified a need for critical assessment and precaution in the development and commercialization of nanotechnologies. Rigorous scientific studies have demonstrated that nanoparticles, employed in many products on the market, have the potential to be toxic to organisms both aquatic and terrestrial. Some nanoparticles have even been found to damage and mutate DNA, an intimate part of the construction of life. When potential problems of this consequence have been reported, a precautionary approach to the widespread use of these manufactured particles would seem to be the natural response.

However, despite these warnings, governments worldwide have yet to demonstrate their commitment to investigating the environmental, health, and safety (EHS) implications of nanotechnology—at least in terms of providing adequate monetary resources for doing so. Nanotechnology is backed by billions of global investment dollars from governments, yet only a 'nano-sized' portion of this money is being invested to support EHS assessments. According to the Woodrow Wilson International Center for Scholars' Project on Emerging Nanotechnologies, less than 3 percent of the $1.4 billion U.S. federal nanotechnology research budget of 2006 was spent on EHS.

Lack of EHS funding and the potential toxicity of nanoparticles are only the tip of the iceberg when it comes to issues surrounding the proliferation of nanotechnologies. We must also acknowledge the fact that manufacturing nanoparticles can be extremely energy-intensive and some of the chemicals used for nano-manufacturing can be highly toxic. Friends of the Earth has argued that in addition to introducing a new generation of toxic chemicals, nanotechnology is also likely to underpin a new wave of industrial expansion and economic globalization that will magnify existing resource and energy use.

What is the true environmental and human health cost of nano-production? It is difficult to answer this question if all of our efforts are focused on ensuring the 'rapid' development of this technology. It is particularly challenging to carefully consider the future of nanotechnology when all resources must be devoted to understanding if nanoproducts that are currently on the market are safe.

What makes a 'greener' nanoproduct? The real question may be: what makes a greener business? And in this case, that may be a business community that chooses to hold back its fervor to market nanoproducts in response to the substantial uncertainty about their safety and effectiveness. Currently, a greener nanoproduct may be a nanoproduct that is not placed on the market at all.

Only a great naivety would suggest that there are no good intentions behind the development of green nanoproducts. However, even the most genuine of intentions for developing green nanotechnologies will not come to fruition if the foundation of these efforts ignores the need for bona fide sustainable growth and development. A challenge of this order will require much more than frameworks and policy measures—a powerful network of diverse stakeholders willing to work together in a true context of sustainability will be essential.

Sustainability and Recycling of Nanomaterials

Armin Reller, Environmental Science Center, University of Augsburg, Germany

The implementation of functional nanomaterials promises to improve the economic and ecological efficiency of many conventional and emerging technologies. Be it in energy technologies, in microelectronics, in cosmetics, etc., nanotechnology certainly allows to reduce the use of commodities and materials and thus opens up many potential improvements. In order to avoid or at least reduce possible drawbacks and risks the following issues have to be considered:

- eco-efficient production pathways under safe working place conditions are indispensable
- the mobility and thus possible trajectories of nanomaterials into the biosphere have to be specified
- dissipation effects have to be minimized, in particular for nanomaterials containing fractions of e.g. scarce metals
- possible bio-activity has to be specified
- applications based on functional nanomaterials afford design concepts allowing reliable and efficient recycling procedures

In summary, any nanomaterial has to be checked by criticality considerations in order to evaluate potentials and risks, not only in terms of economic profitability, but also in terms of eco-efficiency and sustainability.

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OECD Conference on Potential Environmental Benefits of Nanotechnology: Fostering Safe Innovation-Led Growth

15-17 July 2009
OECD Conference Centre
Paris, France

List of Participants

OECD

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The Monitoring and Composition Analysis of Nanoparticles

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Abstract

Taiwan EPA has been devoted in developing analytical tools for monitoring nanoparticles in the atmosphere since 2003. This paper presents part of the results which were implemented by different research projects under the framework of phase I (2003-2008) National Nanoscience Program. Incorporating sampling equipments ELPI and MOUDI into composition analytical series LA-ICP-MS, with the conversion of the particle mobility diameter of SMPS to the aerodynamic diameter, we have collected the real-time data from nanoparticle emission factory, industrial park, highway tunnel, and heavy traffic road-side. Comparing the mass concentration of nanoparticles among the SMPS, MOUDI, and ELPI, fair good agreement is found between the SMPS and MOUDI, the latter oversampled nanoparticles by about 40%. To solve particle bounce problem in ELPI, using greased aluminum foils is recommended.

Keywords: Nanoparticle, LA-ICP-MS, ELPI, MOUDI, SMPS.

Introduction

Taiwan has a National Nanoscience Program. This program coordinates the research efforts from various government organizations to achieve objectives that follow the worldwide nanotechnology development trends. The goals of the program include:

1. Achieving academic excellence, and promoting industrial applications through the establishment of common core facilities and education programs.

2. Bringing up the academic excellence and then creating innovative industrial applications based on the national competitive technologies.
3. Establishing international competitive nanotechnology platforms.
4. Enhancing advanced innovative research to speed up the commercialization of nanotechnology.

This program was formally launched in January 2003 and is scheduled to continue until 2008. An amount of NT $23.2 billion (US $700 million) has been committed to nanotechnology development under the program.

The program has four subprograms: Industrial, Academic Excellence, Core Facilities, and Education Program taking up 61, 21, 16, and 1.3% of the funding respectively. The National Nanoscience Program is entering phase II (year 2009-2014) and has been approved by government.

Taiwan Environmental Protection Administration (TEPA) has its own commissioned projects related to nanotechnology research under the framework of national program. A total budget of NT $60 million (US $2 million) has been granted to 10 main projects in phase I (2003-2008).The focal areas are:

1. Develop possible applications of nanotechnology to environmental issues.
2. Environmental and health impacts of nanoparticles and nanomaterials, and emergency preventions and control.
3. Develop measurement and monitoring methods for the characterization of nanoparticles, either from the combustion/engineering manufactory sources or the natural sources.

In phase II (2009-2014) with the total estimated budget of NT $150 million (US $5 million), Taiwan EPA plans:

1. To continue monitoring technical development and closely working in collaboration with the Council of Labor Affair and Department of Health in order to examine issues that deal with EHS (Environment, Health and Safety).
2. To develop methodologies for exposure assessment and risk assessment.

3. To discover more environmental benefits of nanotechnology by conducting “incubation” and/or “germination” projects.

The Determination of Nanoparticles by LA-ICP-MS <1>

Many analytical problems have been encountered in nano-sized airborne particulate matter analysis; samples are difficult to weight as well as digest, trace elements may be lost or contaminated in the course of the digestion process. Laser ablation (LA) method in conjunction with inductively coupled plasma-mass spectrometry (ICP-MS) allows the rapid, nondestructive analysis of many elements, and this technique thereby averts many of the problems associated with conventional particle analysis methods. However, some difficulties still persist with respect to unstable laser output and the inhomogeneity of filter matrix as well as particulates loaded during the sampling process.

This work presents a novel method of determining nano-sized airborne particles collected by electrical low pressure impactor (ELPI) using LA-ICP-MS. Real samples were collected by ELPI. The ELPI is a real-time particle size spectrometer for monitoring of aerosol particle size in the range of 0.03-10μm on zefluor membrane filter(Pall Zefluor, 25mm diameter, 0.5μm pore size). In this study, ELPI was employed to collect aerosols in 9.970-1.000μm, 1.000-0.108μm and 0.108-0.030μm respectively. Figure 1 shows the photographs of there different ELPI filter samples. To determine the elemental concentration on the filter samples, standard filters were prepared as following: (i) stock solution containing ^{7}Li, ^{53}Cr, ^{59}Co, ^{60}Ni, ^{63}Cu, ^{75}As, ^{89}Y, and ^{121}Sb purchased from Merck were prepared by dissolution of a weighed quantity of the material in HNO_3 and dilution to volume; (ii) droplets of prepared standard solution (~0.5μL) were added on the filter then dried by ultraviolet lamp to simulate the deposition of aerosols on the real samples. Trace amount of methylene blue was added in the solution to identify the spot size and shape. Optimized ablation pattern has been investigated to assure the deposition spots on both real and standard filters can be completely depleted for ICP-MS measurement. A number of standard filters with varying concentration of stock solutions were introduced to evaluate their respective homogeneity by LA-ICP-MS. At least seven sample spots or blanks on each filter were measured. Figure 2 demonstrates that the calibration graphs for the elements, at different concentration levels and atomic numbers, all exhibit similar trends. The prepared standard filters serve as a control while measuring elements in airborne particulate samples by direct analytical methods such as LA-ICP-MS.

Several parameters, including laser energy, beam focus, and carrier gas flow rate, may affect the LA-ICP-MS measurement. The influences of these parameters were thoroughly examined.

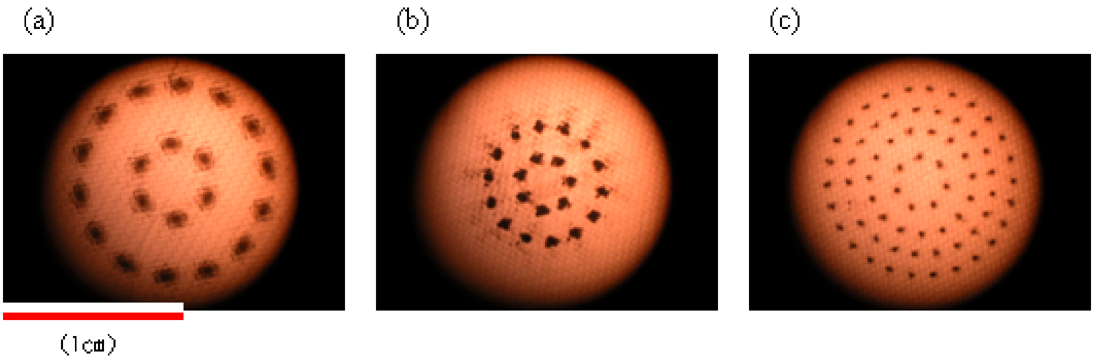

Fig. 1 Photographs of filter samples collected by ELPI in different size distributions: (a) 9.970 ~1.000μm (b) 1.000 ~0.108μm (c) 0.108 ~0.030μm

The Fate of Ultrafine Particles: A Case Study [2]

Sun Beam Metal Industrial Co., Ltd. takes above 65% of market share of hot-dip zinc coating of screws and nuts in Taiwan. In order to decrease the waste yield, zinc dross would be recycled to become a high value-added product – zinc oxide particles. The object of this study is to observe the fate of zinc oxide nanoparticles in the ambient of Yong-An Industrial Park by using ELPI (Electrical Low Pressure Impactor), IC (Ion Chromatograph), LA-ICP-MS (Laser Ablation Inductively Coupled Plasma Mass Spectrometry) and SEM (Scanning Electron Microscope). ELPI could monitor particle size distribution (from 7 nm to 10 μm), number concentration, and collect samples. Three sampling positions at Yong-An Industrial Park were selected. First is Sun Beam Metal Industrial Co., Ltd., and others are downwind places (A) Pei-shin temple and (B) Yong-An industrial park service center where are far 1 km from Sun Beam Metal Industrial Co., Ltd.

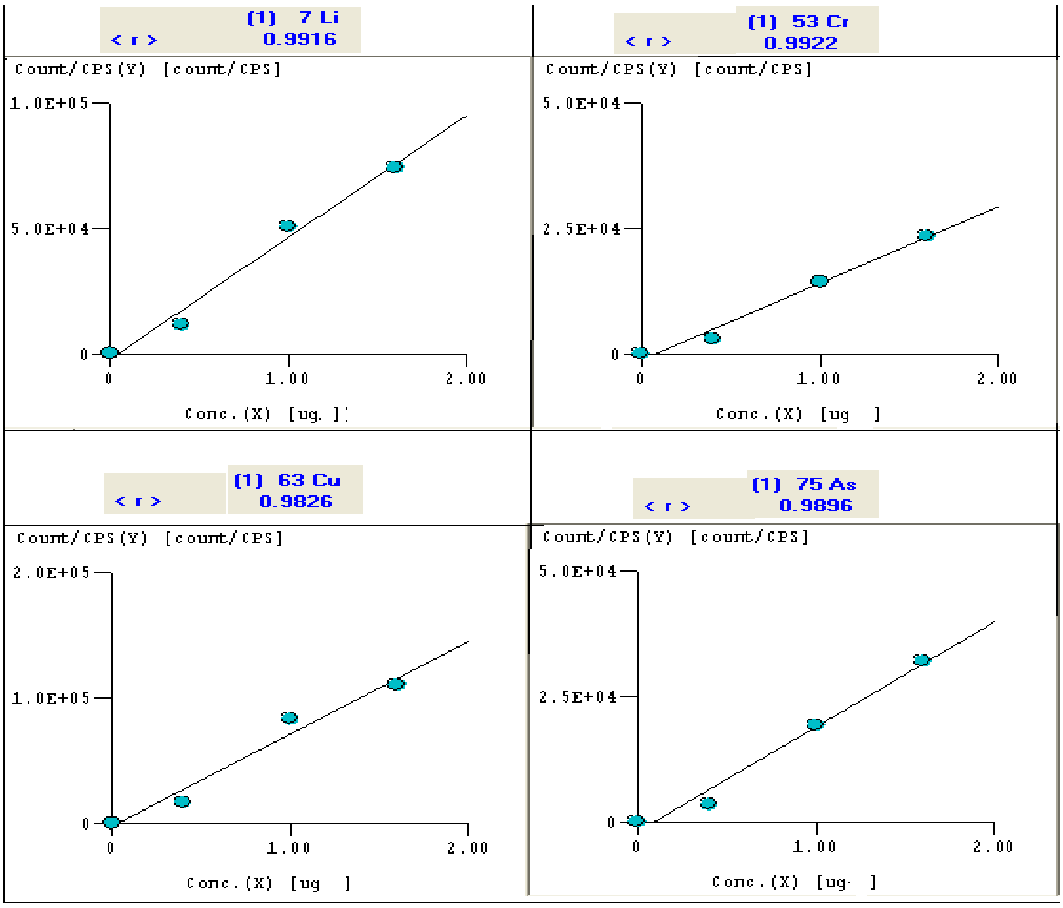

Fig. 2. Calibration curves of ^{7}Li, ^{53}Cr, ^{63}Cu, and ^{75}As, for LA-ICP-MS.

We collected ambient air particles in three size ranges- ultrafine (diameters<1μm, $PM_{1.0}$), fine (diameters between 1 and 2.5μm, $PM_{1.0\text{-}2.5}$), and coarse (diameters between 2.5 and 10μm, $PM_{2.5\text{-}10}$). Three types (Teflon, Quartz and Alumina foil) of filters were used in the ELPI. Each sampling duration lasted 14 hrs. Particles on Teflon filters were analyzed by using the IC to get the concentration of negative charge ions in samples and by using LA-ICP-MS to determine the contents of 75 elements. The samples on the quartz filter were studied by using the JEOL JSM-6330F field emission scanning electron microscope to observe the shapes of those particles. Others on alumina foils will be used in immediately monitoring the number concentration of different size distribution of particles.

Figure 3 shows the number concentration distribution particles in different size at two downwind places. It obviously showed that the size of max counts of particles at place A was about 30 nm which was smaller than that at place B was about in 100 nm. This difference might be caused by different sampling environment. Place A is near the temple, so that some burning increases might contribute nanoparticles in the ambient[3]. The max number concentration of ultrafine particles at place B were more than 1.2 times of that at place A. Place B is near roadway, so that some dust from traffic might be collected and cause the higher number concentration of ultrafine particles than that at Place B[4].

Table 1 shows the metal components of particles which were sampled from three sampling point. There are almost 99% of Zn composed in the particles which was sampled from Sun Beam Metal Industrial Co., Ltd.. However, it obviously showed that there was no Zn existed in the particles sampled from Pei-shin temple and Yong-An industrial park service center. In the meantime, large number of Mg、Al、Mn and Pb in the particles sampled from Place B were found. It might be caused by the dust from traffic.

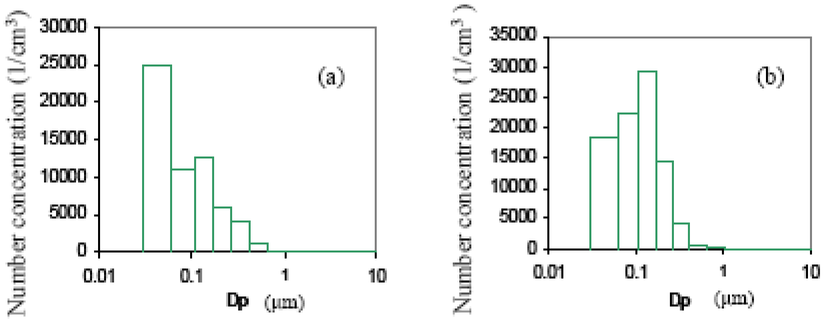

Figure 3. The number concentration of particles in different size distributed at two downwind places from Sun Beam Metal Industrial Co., Ltd. (a) Pei-shin temple (b) Yong-An industrial park service center

Element	Blank	(a)	(b)	(c)
Mg($\times 10^3$)	1.07	55.2	5.67	0.172
Al($\times 10^3$)	5.29	409	11.4	2.8
Ca($\times 10^2$)	7.16	10.1	1.16	1.1
V($\times 10^2$)	2.86	41.3	125	0.605
Mn($\times 10^3$)	1.83	33.7	39.6	0.554
Fe($\times 10^2$)	4.59	178	57.7	1.12
Zn($\times 10^5$)	2.03	0.105	ND	295
Cd($\times 10$)	6.18	19.7	22.7	566
Pb($\times 10^3$)	1.22	51.2	62.9	116

*ND: not detected

Table 1. The metal comparison of integral counts obtained from particles sampled from (a) Pei-shin temple (b) Yong-An industrial park service center (c) Sun Beam Metal Industrial Co., Ltd.

Nanoparticles at a Road Side and in a High-Way Tunnel[5]

Ambient nanoparticles (<100nm) were studied at Poai Street in Hsinchu and in Syueshan high-way tunnel in Taipei, Taiwan, using a TSI model 3936 SMPS, an ELPI (Dekati Ltd.) and two MOUDIs (MSP Model 110) in parallel. In the MOUDIs, greased aluminum foils were used as the impaction substrates of the 1st-9th stages to reduce solid particle bounce, while Teflon (1st MOUDI) or quartz filters (2nd MOUDI) were used at the 10th stage and after filter in order to conduct further chemical analysis for nanoparticles.

To compare the mass concentration of the SMPS with that obtained from the 1st MOUDI, the particle mobility diameter of SMPS was converted to the aerodynamic diameter using an effective density which was related to the ambient relative humidity and water content (Spencer et al., 2007)[6]. After gravimetric analysis of Teflon filter samples, nanoparticles collected by the 1st MOUDI were analyzed by ICP-MS for elements, ion chromatograph for ions. Nanoparticles on quartz samples of the 2nd MOUDI were analyzed by Thermo-Optical Reflection (TOR) method for OC and EC without gravimetric analysis. Nanoparticles were collected at the first (28-55nm) and second (55-93nm) stages of the ELPI using Teflon filters, while the 3rd-13th stages used grease-coated aluminum foils to avoid particle bounce. The two filters were analyzed gravimetrically to determine nanoparticle mass concentration, and chemically to obtain elemental compositions by using LA-ICP/MS.

Comparing the mass concentrations of nanoparticles among the SMPS, MOUDI, and ELPI, fair good agreement is found between the SMPS and MOUDI, the latter oversampled nanoparticle by about 40%. This is due to particle bounce which also observed by Khlystov et al. (2004)[7]. The ELPI oversampled by about 200 to 600% of that of the SMPS also due to particle bounce. In order to solve particle bounce problem in both MOUDI and ELPI, greased aluminum foils will be replaced by oiled glass filter substrates in 1st to 9th stages of MOUDI, and 3rd to 13th stages of ELPI.

Table 2 shows the nanoparticle concentrations and chemical compositions at the sampling sites. Compared to the concentration at the road side, 1.58μg/m^3, significantly higher nanoparticle concentrations were observed in the tunnel during peak, 41.96μg/m^3, and non-peak traffic periods, 14.75μg/m^3.

μg/m^3	Road side	Syueshan tunnel[a]	Syueshan tunnel[b]
organic carbon (OC)	0.565	17.069	5.827
element carbon (EC)	0.221	7.376	2.113
elements	0.286	8.150	4.240
ions	0.324	4.031	1.903
sum of components	1.396	36.626	14.083
gravimetric mass by MOUDI	1.581	41.962	14.748

*a: peak traffic hours (9-12 AM)

*b: non-peak traffic hours (0-6 AM)

Table 2. Ambient nanoparticle concentrations at the present sampling sites.

Reasonable agreement is seen between the mass concentrations determined by gravimetric and chemical analysis with unknown compositions<12%. The OC is the most abundant species at all sites which averages 38% of the total nanoparticle mass, followed by elements, EC and ions.

Conclusion

The obtained data shows that LA-ICP-MS can be used to analyze the nano, sub-micro, and micro airborne particles collected respectively by MOUDI or ELPI. Caution of particle bounce and measure to prevent are crucial in the process.

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附 件 五

Strategies toward Responsible Nanotechnology (2009-2014)

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Summary

This report summarized the current status of the nanotechnology in Environment, Health, and Safety (EHS) issues, including: environmental applications, environmental implications, regulation implementation, and the key challenging issues. A summary of the research achievement carried out by the EPA Chinese Taipei during the 1st phase (2003-2008) period is given for the basis in the 2nd phase (2009-2014) research strategy toward responsible nanotechnology. The Office of Sustainable Development (OSD), EPA Chinese Taipei has drafted out a working plan toward nanotechnology (2009-2014) with the research recommendations, including: **fate, transport, and exposure**; health effect; ecological impact; **risk assessment**; life cycle assessment; **knowledge platform implement**; **measurement technology**; risk management through engineering technology; **risk management through good working practice**; **environmental applications of nanotechnology in remediation and pollution prevention**; **green nanotechnology process development**. The prioritized research recommendations are highlighted in bold type font.

I. Current Status of Nanotechnology in EHS

Nanotechnology has been extensively studied for more than two decades by various disciplines of sciences and engineers. Today it has grown to be a technology platform with charming potential. Some market research institutes forecasted that the nanotechnology related commercial product available worldwide will reach USD 263 billion by 2012 and USD 1.5 trillion by 2015[1]. According to the nanotechnology commercial products inventory in The Woodrow Wilson International Center for Scholars[2], the number of products has increased to 606 items in 184%, since inventory opening in 2006/3; thus clearly indicated its industrial potential.

Due to the higher surface area, nanoparticles inherent higher chemical reactivity. Without thorough understanding the toxic nature of nanoparticles, researchers believed that these materials have to be carefully watched, when applied in the commercial products. Research articles[3,4] have already shown that the nanoparticles are very likely inhaled, ingested and/or absorbed by the human body via the aerial or the supplied water system; thus well distributes within the cellular area to cause the biotoxicity. Animal studies showed that particles with the same chemical composition, nano-sized particles pose more biotoxic effect than the others. Although the chronic toxicology studies of the nanopartlcles are still in its infancy and the results are controversial, a few research articles[5,6] on the toxicology studies of the carbon nanotube have been published.

The knowledge on the environmental impact of nanoparticle is still very limited, due to the lack of reliable scientific data. It is still inconclusive how nanoparticle travels through environmental media (water, aerial) into human body. Some case studies in the water system, including nano zero-valent iron, carbon nanoparticles, and titanium dioxide showed that the behaviors of these nanoparticles were strongly related to their medium. These medium characteristic parameters are: PH value, ionic strength, dissolved organic acids, organic solvent, absorbents, supporting material of the particle.

Though its inherent risks mentioned above, nanotechnology is widely applied in the environmental remediation and the pollution prevention including: [7] the decontamination of chlorinated hydrocarbon compounds by the zero-valent iron particles, removal of the aerial organic pollutants by photocatalysts, the application of carbon nano tube as pollutant absorbent support, and as the barrier in the nanofiltration for water purification. It is expected in the near future that environmental applications of nanotechnology will be in the water purification and the aerial cleanness.

Another key issue is the application of the nanotechnology in the sustainable development including, green process and green energy[8]. These studies focus on the nanotechnology applications in: incretion of the renewable energy conversion yield, development of process with economic energy consumption, incretion of the process yield, reduction of the waste, utilization of safely chemicals and products, incretion atomic economic, development of real-time monitor technology to prevent pollution and reduce the chemical hazard.

The lack of sufficiently scientific hazard evidence hinders the regulation of nanotechnology worldwide. The governance of nanotechnology based on existing regulation framework with voluntary report is generally adopted, and the government shall provide hazard information as much as possible[9.10]. The OECD has drafted out a nano risk framework in 2007/2 for public reference and comment[11]. The USEPA has also proposed a regulation structure for nanomaterial based on the TSCA in 2007[12]. The EU expects the REACH code will be sufficiently capable of regulation toward nanomaterial. The Woodraw Wilson International Center for Scholars published a report in 2007, named "EPA and nanotechnology"[13] which addressed the key issues for EPA and the implementation of regulation framework toward the nanotechnology is prior in the next 5-10 years.

Worldwide top experts have raised five grant challenges for the potential hazards of nanotechnology toward environment, health, and safety for public reference and comments in 2006.[14] These challenges are: to develop strategic programs that enable relevant risk-focused research, within the next 12 months; to develop instruments to assess exposure to engineered nanomaterials in air and water, within the next 3-10 years; to develop and to validate methods to evaluate the toxicity of engineered nanomaterials within the next 5-15 years; to develop robust systems for evaluating the health and environmental impact of engineered nanomaterials over their entire life, within the next 5 years; to develop models for predicting the potential impact of engineered nanomaterials on the environment and human health, within the next 10 years.

"The workshop on research projects on the safety of nanomaterials: reviewing the knowledge gaps" was organized by the European Commission SCHNIHR in Brussels during 2008/April/17th - 18th[15]. Participants were mainly framwork projects researchers, representatives of different risk assessment and risk management related bodies as well as policy makers from Commission services and from other governments, international bodies and industry. The workshop was remarked as a European think tank for future actions. At the end session Dr. Rob Aitken of the IOM gave an evaluation of existing knowledge gaps towards safe nanotechnologies according to the five grand challenges as comparison, which is shown in the Table 1.

II. Phase I Achievements (2003- 2008)

The EPA Chinese Taipei has allocated over USD 2 million in the past six years (2003 - 2008) on the environmental nanotechnology research. The 19 research projects can be categorized in: environmental implication of nanotechnology with 55% of the total budget in 10 projects; and environmental applications of nanotechnology, with 45% of the total budget in 9 projects.

The EPA Chinese Taipei has achieved several novel techniques in aerial nanoparticle sampling, measurement, and monitor technology. The combined systems are ELPI (Electrical Low Pressure Impactor)+LA-ICP-MS (Laser Ablation Inductively Coupled Plasma Mass Spectrometry)+SMPS (Scanning Mobility Particle Sizer) and MOUDI (Multiple-Orifice Uniform Deposit Impactor)+APS(Aerodynamic Particle Sizer)[16,17,18] Regarding to the environmental application research of nanotechnology on pollution prevention, the EPA Chinese Taipei has carried out: zirconium oxide as motorbike oxygen sensor, biological nano-gold in the pollutant removal, nano zero valent iron in the remediation of ground water, treatment of organic and heavy metal pollutants by nanocomposites (CNT/TiO2). Other supporting activities includes: implementing an integrated database of EHS and knowledge bank; the held of forums, conferences, and international symposiums[19] implementing practical good working guide in the nano research laboratory and working places[20]; and life cycle assessment of nano products.

Table 1. Evaluation of existing knowledge gaps towards safe nanotechnologies

Challenge	Open issues / questions / gaps
1. Instruments to assess exposure to engineered nanomaterials in air and water	· Issues of metrics remain unresolved · A universal sampler still some way off · Measurement methods and improved off-line analysis · Discrimination from background · Smart sensors still some way off
2. Effective and relevant nano-toxicity test methods	· Understanding of the underlying mechanisms of harm · Relevance of assays to all potential routes of exposure (inhalation, dermal, ingestion, and injection) · Scaling of assays to high throughput · Need for new assays · Reproducibility of assays · Availability of in-vivo data for validation · Relevance of the respective particles · Unique problems of fibre shaped particles
3. Systems that can predict the potential impact of new engineered nanomaterials	· Availability of validated models for exposure, translocation, dose responses · Prediction of harm based on physicochemical properties · Relevance, reproducibility, and scaling of the systems
4. Systems to evaluate the impact of nanomaterials from cradle to grave	· Lack of data for occupational and consumer exposure, and few systematic attempts to collect such data · Availability of underlying models · Comprehensive investigation of limits of current methods
5.Effective strategic research programmes involving collaboration, communication, and coordination	· No unified top down strategy · Need for bottom up coordination and sharing · Context of emerging research findings often insufficient

Source: reference 15

III Responsible Nanotechnology Six-Year Working Plan (2009 - 2014)

1. Objectives

Carry the achievements of phase I (2003-2008) information-based towards the development of a knowledge-based responsible nanotechnology.

Converting nanoscience-based cutting-edge research into high-quality products, effective processes, and new catalysts or new materials that can benefit to the environment and compete in today's global marketplace, which includes emerging competitors.

2. Strategies

Implement EHS relevant nanotechnology knowledge bank on the basis of information sharing for international feedback, and collaborate.

Develop core and applicable nanotechnology with innovation, instead of follow-up, to reach an improvement of local and international sustainability.

3. Project Implement Principles

Under the authorized responsibility, the EPA Taiwan pushes environmental policy forward with strongly scientific base in law regulation and environmental standards. Both project management and policy implementation are carried forward to meet the mission of the Taiwan National Science and Technology Program for Nanoscience and Nanotechnology (TNSTPNN) for an environmental & ecological friendly, healthy, and sustainable nanotechnology development.

The research teams with strong international competence are screened by the open bid, and the research results are published in the international journal for peer review.

The prioritization principles for the projects are based on: the information gained from the project is valuable in environment or its environmental application; the scope of project is under the EHS integrated project framework; the internationally competitive research tool is applied in the project; the theoretical argument of the project must be based on the nanoscience; the output of the project should be able to solve some government concerned issues in short or long term prospect[21].

4. Key Research Issues in the Next Six Years

Research Recommendation Highlights: [22, 23, 24, 25]

Fate, Transport, and Exposure

The EPA Chinese Taipei should direct fate, transport, and exposure research of the nanoparticles towards: understanding the critical roles of particles on the chemical composition (including non-stoichiommetry), surface chemical composition, surface defect, impurity, and the inclusions; understanding the transformation of the nanoparticle in various environmental condition; understanding the environmental exposure pathway, principal exposure source, and assess the environmental impact of engineering nanomaterial toward specific environmental receptor based on the nano product manufacture; identify environments likely exposed to nanomaterial; establish exposure relationship of particle through routes of inhalation, ingestion, skin/eye contact.

Health Effect

The EPA Chinese Taipei should direct health effect research of nanoparticle under limited resources or for the purpose of complete understanding risk assessment studies to carry out toxicity research of nanoparticle within biological system; validated test methods; understanding the critical role of impurities, intrinsic defects, foreign substance of nanoparticle toward human health; understanding the adsorption and translocation of nanoparticle in biological system.

Ecological Impact

For the ecological impact research, the EPA should direct effort towards: the definition of environment; validated test methods; influence of de-agglomeration for environmental exposure; influence of physical environment of nanoparticles; and understanding exposure routes from environment back to humans.

Risk Assessment

The EPA Chinese Taipei shall collaborate with multi-discipline experts including: physic, chemistry, and biology, on the fundamental science level, to understand the interactions between environment and nanoparticle. The risk perception study should be carried out at current stage.

Life Cycle Assessment[26]

The EPA Chinese Taipei should direct life cycle assessment studies as standard operation procedure towards: the assessment of nano-product under the ISO-framework for LCA (ISO14040:2006) to gather missing relevant data regarding the elementary flows and impacts; to develop user-friendly eco-design screening tools which are suitable to nanomaterials and nanoproducts; using a life cycle approach identify which is green in nanotechnology. The Woodraw Wilson International Center for Scholars has published a report named “Nanotechnology and Life Cycle Assessment: A systems approach to the nanotechnology and the environment”[10], since then LCA has been widely accepted.

Implementation of Knowledge Platform

The EPA Chinese Taipei has already implemented the database in its first phase six-year plan. In 2007, the EPA Chinese Taipei has upgraded the database to knowledge platform. The following effort shall be transferred to the research recommendation “Implementation of Knowledge Platform”.

The EPA Chinese Taipei should strengthen the platform function on the data mining, tools of knowledge management, and interactions between stakeholders; The Web 2.0 information platform is served as dialogue arena, whose function ranges from searching updated information of the environmental nanotechnology and the policy progress, furthermore sharing and exchanging information with various stakeholders. It is hoped that the environment, health, and safety implications of nanotechnology can then be examined from different point of view, thus to reach better understanding of nanotechnology.

Measurement Technology

The EPA Chinese Taipei should direct the measurement technology toward: understanding the surface chemical/physical modification effect to the measurement; the methods for standardizing assessment of particle size, size distribution, shape, structure and surface area; validation of test methods; developing suitable reference material, natural particle background and its influence on exposure measurement and environment fate assessment.

Risk Management through Engineering and Technology Development

The EPA Chinese Taipei has already carried out studies on good working practice and exposure control of the working place. The EPA Chinese Taipei should direct its effort in the future on: examining the nanoproduct or nanomaterial in LCA aspects to reduce the risk; developing database for risk assessment; encourage intra-agent collaboration to develop risk communication material specifically for nanotechnology.

Risk Management with Good Working Practice and Law Regulation

Since there is no sufficient scientific data for regulation so far, the EPA Chinese Taipei should direct the risk management with good working practice and law regulation toward: developing risk management tool for industry to self declares before regulation enforcement; under the current existing regulation framework invite relative stakeholders to join dialogue, before and during the regulation studies.

Development of Environmental Benign Nanotechnology

The EPA Chinese Taipei should direct development of environmental benign nanotechnology towards: encouraging studies on the green nanotechnology; pollution prevention during the manufacture of nanomaterial; and any green technology with nano character.

Development of Green and Sustainable Nanotechnology

The EPA Chinese Taipei should direct development of green and sustainable nanotechnology toward encouraging studies on green nanotechnology with sustainable economic growth and increasing collaboration with the industry stakeholder.

5. Budget

Year	*Budget (K USD)
2009	530
2010	610
2011	700
2012	800
2013	930
2014	1,100

*The budget allocation was estimated at 15% increment yearly.

6. Expected Outcomes

（1）Continuing EHS intra-agency, cross discipline collaboration to support research in the EHS risk assessment.

（2）Implement the technology skill of environmental measurement, monitor, and pollution control toward nanoparticles.

（3）Implement local environmental background exposure database for nanoparticles.

（4）Implement a nanotechnology knowledge bank to provide comprehensive information in the EHS issues for public training and education.

（5）Application of nanotechnology for environment sustainable development, including: green process and green energy.

（6）Application of nanotechnology in environmental remediation and pollution prevention to accumulate the local technology capability in the environmental implications.

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