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Report

Foresight Topic
“Traceability for Environment”

18 December, 2015



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Foresight Topic “Traceability for Environment”

Brainstorming Report

18th December 2015



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BRAINSTORMING

“Traceability of Innovative Materials and their Interactions with the Earth System”

November 12th - 13th, 2014

National Research Council of Italy, Rome, Italy - Library Room A



**Rapporteur and Author
Augusta Maria Paci
WG Thematic Coordinator**

1. INTRODUCTION

1.1 Background

Among foresight methodologies, *Brainstorming* is a method used in groups to support creative thinking and opinions exchange in fields not ordinary for the group members in order to stimulate the generation of new ideas, acceptance of different approaches and in order to develop knowledge elements for common grounded developments.

The Brainstorming was organized by the Coordinators of the Working Group Environment of the Science and Technologies Foresight project of the National Research Council of Italy. The Foresight S&T Project and its Working Groups aim at activating an experts' related process for discussing ideas, confronting experts' opinions and delivering inputs for a policy thinking that can define a programme of research areas to be investigated with a forward-looking approach. This Brainstorming aims in particular at starting the development of a collective knowledge and at stimulating confrontations of opinions on the future of innovative materials and their interactions with society and the environment. The outcome of the Brainstorming that involved scientists of international reputation aims at devising research related aspects that respond to the big issues described in the Societal Challenge of the European Framework Programme H2020. This report builds on the results of the discussion around the topic "Traceability for Environment" and aimed at developing - through this non-disciplinary theme - to develop a foresight and holistic view into possible research areas that require knowledge integration and interdisciplinary perspectives.

The expert group was composed by foreign and Italian high-level experts with different disciplinary backgrounds and discussed the proposed Topic on the 12th -13th of November 2014:

- What point of views from disciplinary fields can represent research needs that can be developed and what generic areas of human/nature interests can be foreseen in relation to the Topic
- Which are the strategic issues that underpin Science and Technology domains and that in the future need to be addressed by research directions.
- Who in Society is involved in the process and how to ascertain key aspects that complement S&T in a societal perspective.

The CNR Foresight project's specific rules and methods have been applied by the coordinators to this Brainstorming with regard to preparatory materials, before hands round of experts' interviews, meeting preparatory Note (see Appendix: Preparatory Notes), other supporting materials such as templates, summaries of experts' opinions and so forth. A social dinner was also organized to facilitate informal exchange of opinions.

The discussion was moderated by a foresight project member, the duration was 2 full days, the expert group composition was balanced, all invitations and administrative matters were carried on before and after the event. In particular coordinators dedicated intensive effort to prepare the selected Topic "Traceability for Environment" for this Brainstorming":

- The meeting was non-disciplinary and the invited experts were encouraged to give their knowledge in a field not directly related to their specialty and to work out ideas in a form not requested in typical scientific disciplinary events. This required two cycles of interviews with the experts - followed by supporting documentation for the Brainstorming.
- relating broadly to a capability that in the future would be part of S&T application areas in order to originate new types of information, this area is not covered by a specific and directly related S&T. Tracing, Tracking and Marking capabilities are currently functions related to technology and current

applications are in agro-food chains, manufacturing goods and related technologies fulfilling societal and economic interests.

- relating to a future capability, the need to foresight in a more defined S&T area was highlighted during the Project's Group discussions. To gather and confront opinions from different experts' perspectives for the selection of topics was therefore important to move from the output of the Brainstorming towards a Face to Face event.
- The preparation phase examined three specific areas of S&T:
 1. Innovative materials enabling performances and function interactions
 2. Manufacturing and Internet of Things within sustainable products, processes of industrial chains and the circular economy
 3. Environmental interactions within adaptation and mitigation strategies.

Due to the openness of the Topic Traceability, the risk of having a too generic Brainstorming outcome was raised. The title 'Traceability of innovative materials and their interactions with the Earth system' was decided. Therefore, the identification and selection of experts from academia, government institutions and the private sector required an intensive task with direct contacts and desk research. Eight experts - out of 20 - represented academia, research institutions and private sector – and a Preparatory note was distributed to the invited experts to form a common ground for discussion.

Intensive communication with experts of highly specialized profile were aimed at preparing experts to exchange views in the Brainstorming for an interdisciplinary and future oriented discussion.

Overall, relevant aspects in the mid-long term horizon emerged from the Brainstorming: in particular, that S&T research direction will be more and more context-driven by the combined societal-environment challenge.

1.2 Purpose of the Brainstorming

The Topic "Traceability for Environment" challenged the experts since the interview phase. Nevertheless, they provided cases where their disciplinary oriented expertise contained relevant S&T elements related to the proposed topic. Experts were willing to share views. Specific inputs are reported in the following Experts' detailed Point of view table.

The Brainstorming (see the Appendix: Agenda) started with an initial session with six disciplinary high-level presentations followed by a moderated discussion:

1. Chemistry (two expert in two strategic domains Green Chemistry and Critical materials),
2. Geo-physics (2 experts in strategic domains such as Multi-scale modelling and Eco- systems),
3. Engineering and ICT for Manufacturing research technologies (2 experts from Circular manufacturing and Production Systems technologies)
4. Moral Theory (1 expert in Ethics)
5. Complexity (1 expert on Complexity)
6. Evidence based foresight (1 expert in foresight study for policy development)

Table n.1: Disciplinary views with PATHWAYS from the experts' presentations

| | |
|--|--|
| <p>Chemical sciences</p> | <ul style="list-style-type: none"> • Bio-derived material and Fossil based materials: the intrinsic difference today consists that C14 can distinguish any bio-derived material from any fossil based material even in blends. • Endangered elements are widely used in material (Land-sea trace chain). The need of Recycle and Replace will not be an option, replacement with earth abundant elements requires huge research. • “ Vast difference”: natural relative abundance of some elements(Earth upper continental crust and rarest materials) (NA) • The only unlimited extraterrestrial resource for planet Earth: solar radiation • Products: quality of present “standard materials” enabling tunability and stability compared to “alternative materials” • Products: Mid term (10 years) research needs to reduce the number of elements in, e.g., electronic devices, Reduce mixing of elements to enhance traceability, Enable standardized disassembly protocols • Products: Long term Research for adequate replacements for any applications, reduce energy consumption of recycling by at least 50%, Target a standard > 80% recycling rate • Complementary initiatives regarding awareness raising, regulations, and strategy to full recycle, international agreements regarding resources competition, etc. • OVERALL WARNING about lower-grade applications: recycling and <i>downcycling</i> with materials already being used in past articles. |
| <p>Physical sciences</p> | <ul style="list-style-type: none"> • Innovative materials such as nano-materials: CNT, metals, QD, etc or suspension, colloids, particulate need to be considered through: spatial scales of interest :local to global and temporal scales of interest: seasonal <u>to multi-decadal</u>. - Detection methods for nano-materials and the study of concentration in the environment can consider the use registries when available, of environmental transport pathways (advected particles chemically interacting with the substrate); sedimentation properties with implications for air, soil and water (aquifers); for detection in the wild and laboratory with experiments for studying the Interactions with natural biogeochemical cycles • OVERALL NEED of specific modelling approaches with spatial and temporal scales and study of focused effects on specific ecosystem components • Transdisciplinary approach for Seasonal, Multi-annual and Multidecade Predictions to understand & monitor risks for tracking innovative materials. (ex. Global Climate Change and climate services) • The dynamics of Translation and Transformation of matters in time (short for products) and in decades (deserts and forests). • Different forms of matter undergo different kinds of translation and mixing and chemical reactions with each other in the fluid environment. • Mobile materials change in how they are translated (eg from movement of particles in the air to movement in biological or artificial systems ,as in ‘Silent Spring’ ,Carson 1962 (JH) • Risks of new interactions require reducing these impacts , by studying and controlling every way in which matter is emitted into the environment • Raise awareness of polluting material in local environment and hence (with the data provided as input to environmental modelling) estimates of the environmental risks . (Magro&Carruthers 2014). • OVERALL WARNING: global interactions among atmospheric gases , biological micro-organisms , and human influences: many aspects of the environment and physical nature of the earth’s surface will change significantly even if the global emissions of GHG stop growing in the next 50 years . • Fluid dynamics related “eddy mixing” determined by chemical reactions, biological processes and societal factors • The “fluid environment” needs system analysis focusing the 4 processes involving materials dispersion in the environment with different and more detailed regional , sub-continental scale approach. • System modelling of regional fluxes of different materials and eddy mixing. • Study of chaotic behaviour: the nature of flows and curves and other environmental processes for actions or transformations happening faster than information transmitted or material transported (eg formation of algae in slow moving rivers) suddenly and chaotically and unpredictably reduction of fluxes of clear water across a region) • Flux curves and supercritical conditions within short time scales as consequence of societal influence due transformations and societal processes in biological or artificial systems. |
| <p>Engineering and ICT sciences (Manufacturing)</p> | <ul style="list-style-type: none"> • Circular design is a trend that aims at improvements in materials selection and product design. The linear industrial production model is reaching its limits • Production technologies looks to Cyber-physical systems, Internet of Things and Internet of Services that are the present stage of developments. Needs are related to smart materials, smart machines to deliver smart products. Enormous big data streams can be harvested and analysed for resource-efficient production. • eco-design of products including the reverse cycle aim at cost-reduction. Steel and CO2 savings from leasing instead of selling home service products. Subsequent processing of secondary material streams. • end of products lifecycle needs technology track of whereabouts and condition of materials (RFID). • “Efficiency” needs tracking through “interconnectedness” • Predict the design of material properties and optimize processes taking into account both length and time scales influences and effects. Materials characterizations of components through mechanical separation and chemical |

| | |
|-------------------------------|--|
| | <p>processes both for value key metals and for Non-metal fraction recycle.</p> <ul style="list-style-type: none"> • New and reused articles are both dealt in circular manufacturing that includes multiple paths ("comet circle"). Articles are circulated as much as possible. The shortfall in articles is newly produced. • Production systems have in place tracking mechanisms: AIS (Article Information Sheet), MSDS (Material Safety Data Sheet), RFID (Radio Frequency Identification) that are embedded in life cycle units. In the future to realize circular manufacturing, a system approach is needed to trace different items. • the reduction of environmental load is more efficient in the inner loop of production systems. Future systems should consider which item is circulated in which loop beyond the aspect of materials. (ST). • Life-cycle planning and process design and article industrial & management system engineering represent needs to consider, together with socio-techno-business factors. In the near future the present product life cycle approach is insufficient. • Conversion process from chemical substances to articles needs to consider the supply chain perspective and the need to assess that chemical substances and the mass in articles remain unchanged. The present transfer of information on chemicals from upstream to downstream companies of today uses communication tools such as: MSDS: Material Safety Data Sheet, AIS: Article Information Sheet. • A sound material-cycle society requires a System of policy measures to educate, promote establish middle-ground and responsible attitudes with targets. |
| Philosophical sciences | <ul style="list-style-type: none"> • The behavioural wrong attitudes in society toward science need to be addressed in the light of Citizen Science. • There is a need to develop and build the middle-ground and responsible attitude with targets of societal interest • It is advisable to have a dynamic segmentation of positioning related to distinctive group/communities in society: ideological, cognitive and ethical problematic, collective rationality |
| Mathematical sciences | <ul style="list-style-type: none"> • Large-scale Models are needed and are sophisticated (multi-physics, multi-scale, exotic constitutive models of materials, etc.). • Today and in mid term these models will be less precise and expensive to maintain and to use. • Vulnerability assessment is a need • Detection of fragility in high-tech systems and products. require critical complexity and measuring modelling targeted to this issue. • Unexpected behaviour and measure is core to Complexity. |
| Foresight disciplines | <ul style="list-style-type: none"> • Foresight driven by Grand Societal Challenges moves foresight outcomes into approaches that enable and require integration of qualitative + quantitative approaches. Storylines => meta-modelling/indicators => quantitative scenarios are needed to share a participatory process • Emerging issues hold strong implications for the EU Research and Innovation policies that are unable to be dealt with by traditional programming and planning methods and tools. • Foresight outcomes can influence positive or very positive dynamics in science and technology policies –considering both reactive or anticipatory changes • Dynamic management and integration of both “perseveration” and “looking beyond scenarios” are possible through foresight processes. |

Overall, the Brainstorming achieved a good level of interdisciplinary approach, was rich of friendliness, sense-making, kindness, respect and with moments of fierce debate. This made this Brainstorming a positive and learning experience.

Foresight supports confronting existing research areas with new fields of knowledge and stimulates interdisciplinarity approaches helping to co-share approaches for future advanced results.

2. Experts’ starting comments on the meaning of Traceability

Experts’ talks referred to traceability and future research perspectives under different angles and the remarks highlighted in particular that:

- Materials can be traced by their chemical characteristics. In particular, heavy metal elements have peculiar spectroscopic fingerprints that, in principle, may enable their unambiguous identification at any stage of their lifecycle.
- The limit of detection represents the biggest challenge as they are normally utilized in tiny amounts (e.g. in electronic devices).
- Regarding material design the need is to be sought by (a) reducing the number of metal elements embedded in materials and devices; (b) limiting as much as possible their mixing;

- The smartest the production, the easiest the collection/recycling of materials to secure elements that occur to a very limited extent in the Earth's crust, reducing the dispersion.
- Materials - genuinely derived from biomass - can be identical to materials made with oil based chemicals, this will require certain answers in the near future of products and processes. Intrinsic differences can be better than "tags".
- Production systems have in place mechanisms for specific items management (Bill of material structure) with huge data and forward-looking needs will require a system approach to related to a single technology (ST) to trace different items. This is a system issue.
- Role and relevance of people perceptions of technological progress (technophobia/philia, and eco crisis, delivery of technologies) need considerations in future by research areas.
- Scenarios developed by foresight studies will support policy orientation providing mixed and dynamic monitoring.

2.1 Discussion

The discussion on future developments started asking what would be more desirable in a future oriented perspective. This session aimed at stimulating experts forward-looking opinions on Traceability and to discuss ideas for directions that could be further explored for advising S&T developments in the coming years towards a "needs driven approach", even if key enabling technologies areas, such as advanced materials, industrial advanced production and environmental sciences, were examined in their main trends and research and innovation strategies.

It was agreed that future products will enhance through innovative materials performances and societal lifestyles. It was also agreed that future S&T developments of innovative materials can not predict and explain the fate and consequences on environment, health and society. Solutions for environmental dispersion are to be investigated.

The common present statements from this discussion pointed out the following main messages:

- Innovative Materials are the solutions to many present problems.
- Industrial Production is in a dynamic transformation, smart production and factory chains are key changes, bottom-up production will grow and change industrial approaches
- People attitudes are positioned, new attitudes are the enablers for the future
- Policies – reactive or anticipatory – can pave the way to advancing solutions
- More context driven programmes than technology-driven benefit Society and Industry

Regarding the relation of S&T to Traceability, the following considerations emerged:

1. The solutions require integration, increased functions and overall a system approach
2. The present linear thinking is only partially mitigated by present circularity approaches and strategies, end of life industrial production and manufacturing.
3. For a zero-impact shift, the top down production model (from the creation of the material) is to be confronted/replaced with a bottom-up production model (converging technologies).
4. Recycling of as many elements as possible is essential as is replacing rare elements by earth-abundant ones.
5. The model change and the bottom –up model require system approach and strategic decisions on the kind of technologies needed in 20 years ahead.
6. Model improvements require technologies not yet available
7. Emerging frictional costs (damage, health etc) motivate policy and decision-makers due to relevance for overall societal wealth

8. Understanding what is not possible or sustainable: the biosphere circular system requires to make things in a different way
9. Durability, reliability and quality aspects: Hybridization in organic is possible but inorganic runs for robustness
10. Reduction is the goal in many sense: priorities should be needs driven
11. Society may be not able to absorb technological progress
12. Stakeholder concept may be critical and influence behaviours
13. In the globe, there co-exist many societies and big differences
14. Research can provide good ideas, but good attitudes are complicated, they require a change in mindset

3. Context-driven areas for foresight workshops

During the Brainstorming discussion and building on the experts opinions, the following main areas on future context changes emerged as promising S&T directions:

1. **Resource optimization for manufacturing** (or smart/disruptive manufacturing/technologies for resource optimization/breakthrough for resource optimization in future manufacturing) related to the widespread use of smart manufacturing, critical materials scarcity, risks and costs, emerging competition factors, product extreme personalization, production based on smart materials (derived from abundant materials, hybrid materials), personalization of products to satisfy the fundamental human needs: food, health, transport, energy, safety & security.
The context-driven need is to reduce the environmental load that leads to a new way of manufacturing (from the design to end of products) which must include traceability, i.e. the capability to trace the processes that every material undergoes during its life, and to trace its uses.
The S&T challenge is to face with a short-term urgency (optimization of rare/finite resources in a linear development of technologies) with knowledge integration (design, manufacturing, disassembling) and a long term revolution for the sustainable production (bottom-up production) including the capability to manage the societal aspects/impacts/acceptability.
2. **Eco-Safe system-oriented processes** related to the widespread of contamination due to waste and uncontrolled end-of-life products from the age of mass-production
The S&T challenge is due to the diffusion of cosmetics waste, solar filters, plastics, electronics, drugs etc. and to the dispersivity of artificial elements (nano-particles behavior) in the environment and in the agro-human food chain.

Awareness areas for future S&T were also considered part of the above areas and require:

- **Measurements** related to climate change and complexity of accumulation dynamics.
- **Communication** of transparency and education of citizens and research communities.

The emerged two areas for foresight workshops, highlight that a future perspective for science and technology development can combine both domains and discuss Nano-info-cogno-bio and societal technologies (NBICS) for Nature-oriented products and processes to focus pro and cons of nature based solutions in many areas (from manufacturing) and so meet potential mixed societal, earth and economic problems and new values in future societies. All experts outlined in the Brainstorming:

- Zero impact
- Mixage of materials
- Scarcity and abundance of natural resources

- Circularity as a natural cycle
- High end societal products
- Societal values
- Switch point between Perseverance and Looking beyond foresight scenarios

The following forward-looking areas representing research areas are summarized with details and with Mid-term (MT) or Long-Term (LT) horizon:

| Extreme resources optimization for smart manufacturing | Mid-term | Long-Term |
|---|---|---|
| <p>The challenge is creating great stress due to a mix of critical materials, advanced robotics (CPS), risks, cost reduction, business competition, extreme personalization, regulations.</p> <p>The wide area of industrial production and manufacturing is under dynamic stresses and will change in the future due to extreme pressure.</p> <p>A mixture of factors will form hybrid drivers of change context driven related to environmental-health-societal issues.</p> | <ul style="list-style-type: none"> • Present personalization of products to satisfy fundamental human needs continue to represent a major trend. • Smart manufacturing bottom-up applications driven by cost reduction. • Production processes and technologies crossing supply boundaries: • Smart manufacturing data streams beyond life-cycle • Production Process integration (disruptive technologies for innovative processes based on ICT, production, manufacturing, maintenance, disassembling) • Consumers and society included in the production | <ul style="list-style-type: none"> • Future smart products and Materials with extreme properties to achieve performances need • smart materials full design (micro processes, micro-scale applications) • chaotic and agile interactions, data streams consumers /society/industrial production (infonomics) • flows of waste and flux of matters with environment/health/societal consequences • social-centered society value cases for business (global and local key performance indicators) • Increased use of earth abundant materials |
| <p>Particle oriented Technologies for transparent Eco-Safe processes</p> <p>Challenged by innovative materials, products based on advanced technologies have been highly diffused (cosmetics waste, solar filters, plastics, electronics, drugs etc.) . The dispersivity in the environment and in the human being of nano-particles behavior is a need for health monitoring on diseases, soil/air/water contamination by uncontrolled end-of-life products.</p> | <p>Mid-term</p> <ul style="list-style-type: none"> • shift from circularity of manufacturing goods and processes. • article degradations and the re-use of parts (machine design) • purification technologies for re-use and recycle for end of life processes • technologies for recycle related to “urban mines”. • regulations for solutions meeting markets, societal and climate demand • ensuring transparency in materials and products: in bio-processes, bio-derived materials, endangered critical materials. | <p>Long-Term</p> <p>Particle Tracking and Tracing technologies for next generation materials released industrially reliable inventory of recovery of critical materials mix reduction in materials for advanced hyperspectral analysis materials imaging</p> |
| <p>Technologies for fragility detection</p> <p>Identification and detection of critical factors in extreme performing products and processes relate to many aspects. Options between bio-derived and fossil-based material together with full-design production processes. These imply smart identification and the development of new detection and imaging technologies and machines in the following sub-areas</p> | <p>Mid-term</p> <ul style="list-style-type: none"> • Personalized recovery for specific critical materials in target high tech products and components (ITO-indium tin oxide). • technologies beyond Recycle to meet manufacturing sectors demand, production processes quality, • product modularity beyond life-cycle, • global supply chains with related business value models; • Customized process for trace and recovery of strategic critical materials (i.e. phosphorous) as the demand for global supply | <p>Long-Term</p> <ul style="list-style-type: none"> • The replace option: Smart performing products with equivalent materials made by S&T on earth abundant metals (graphene, SbSnOx) • LT: Mixed Measurements • climate change damages • metrics and parameters of depreciation of environment • pathways of sedimentation related to nano materials, properties of new eco-systems. • measurements for concentration/accumulation dynamics, geo-physical contexts, advanced modeling and models, socio-economic behavior models (cities, transport, energy, waste etc) |

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“Traceability of Innovative Materials and their Interactions with the Earth System”

November 12th - 13th, 2014

National Research Council of Italy, P.le Aldo Moro, 7, Rome, Italy - Library Room A

AGENDA

Wednesday 12th

13:15 - 13:45 Participants' welcome point and light lunch

Session objectives: Develop a new way of looking at Environment with high-level experts with background in environmental sciences, production research, green chemistry, cognitive sciences and with experts from manufacturing firms, climate services, complexity systems, foresight studies. Collect stimulus, radical ideas, problems and opportunities to develop forward looks at environment considering:

Session topics:

1. Can innovative materials be traced by their own characteristics. Whether and how enable traceability during the complete life-cycle, independently from the dispersion in the environment and into future materials, products, processes and services
2. How can innovative materials be designed to include traceability as an integrated function or property. What intrinsic aspects and technologies can allow early understanding and prediction of negative interactions
3. Is foreseeable a modeling approach to understand and to extrapolate the interactions with the Earth system for a sustainable progress. Which priority domains will require traceability (manufacturing, internet of things, food, health, ...)

14:00 - 14:30 Welcome and Introduction to session objectives
Ezio Andreta (*S&T Foresight Project Coordinator, It*), Stephen Taylor (*Facilitator, AREA Science Park, It*), Francesco Tampieri and Augusta Maria Paci (*Environment WG Coordinators, CNR, It*)

14:30 - 15:45 Experts' stimulus on the three topics:
Julian Hunt (*Emeritus Professor and Lord of Chesterton, Uk*), Nicola Armaroli (*CNR, It*), Shozo Takata (*Waseda University, Jp*), David Cole-Hamilton (*St. Andrew University, Uk*) Mario De Caro (*UniRoma3, It*)

15:45 - 16:15 Share ideas and coffee break

16:15 - 17:15 Experts' stimulus on the three topics:
Cristina Cristalli (*Loccioni, It*), Antonello Provenzale (*CNR, It*), Jacek Marczyk (*Ontonix, It*), Andrea Ricci (*ISIS, It*)

17:15 - 17:45 Share ideas

17:45 - 18:00 Priority domains?

20:00 Dinner

Thursday 13th

Session objectives: Domain related aspects, problems and opportunities for radical ideas, technology developments and prioritization

Session topics:

1. Which are the conditions for the harmonization of different strategies of development
2. Investigate domain related long-term needs with pros and cons (avoiding perfect solutions). Wishful conditions such as R&I, money, morals and laws matters

9:30 - 10:15 Boosting radical ideas and circumstances (domain, place, culture, market) useful to traceability (*All experts*)

10:15 - 11:00 Share ideas and coffee break

11:00 - 12:30 Closing remarks and light lunch

WEBSTREAMING: request login and PW to padula@itc.cnr.it and to dipasquale@itc.cnr.it. Write in the request personal details: name, surname, email. Comments and questions can be posted in a related Web forum.



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Preparatory notes for the Brainstorming about 'Traceability of innovative materials and their interactions with the Earth system'

The general objective of this foresight exercise is to imagine how the society will be in say 30 years and how to reach such target. As far environmental issues are concerned, the challenge is to balance technological development and natural and human environment care towards a sustainable society. In the Background Document¹ three interacting big areas have been identified: Earth and human system, efficiency in production, bio-based products and green chemistry. The three aspects: bio-economy, circular economy, climate services together with intelligent harmonization of environmental strategies (in a worldwide perspective) are drivers for developing economies and employment with the consciousness of the interaction among the complex Earth system. Educational issues are of overwhelming importance for societal acceptability.

The focus of the brainstorming is the search of new approaches and technologies enabling to understand, control and foresee the interactions: what we call 'traceability', which will replace the paradigm of a production driven by societal requests and industrial needs, a subsequent analysis of the environmental (both natural and societal) impacts and the application of adaptation and mitigation actions. Traceability can represent the key tool for the control of the life cycle of new materials and products, from the initial production to the end of the planned use and to the following steps (recycle, disposal, dispersion in the environment, ...) with its unavoidable transformations. According to this view, the future development of a complex and interconnected society will be driven by the balanced needs of improving the quality of life and minimizing the costs of the unwanted impacts on the Earth system: traceability will be the tool to get these targets.

In the brainstorming of Nov. 12th - 13th specific aspects of traceability of materials, with special attention to functional materials, will be discussed together with more wide problems of societal relevance.

Pervasiveness of innovative and (multi)functional materials² is foreseen in the future to face the needs of innovation and of enhanced performances in different sectors (food, health, manufacturing, energy, transport, safety, ...).

The brainstorming aims to investigate and eventually propose interdisciplinary approaches, methods and technologies in order to:

¹ For prospective interactions with the Earth system, refer to the "Background Document Intelligent traceability for Environment" of the Thematic Group Environment" Final report, May 2014. This document contains also case studies discussed with the invited experts.

² For concept of R&D on Materials technologies, refer to: 1.3.1. *Cross-cutting and enabling materials technologies: Research on materials by design, functional materials, multifunctional materials with higher knowledge content, new functionalities and improved performance, such as self-repairing or biocompatible materials, self-assembling materials, novel magnetic materials and structural materials, for innovation in all industrial sectors, particularly for high value markets, and including the creative industries* in the document: COUNCIL DECISION of 3 December 2013 establishing the specific programme implementing Horizon 2020 - the Framework Programme for Research and Innovation (2014-2020) and repealing Decisions 2006/971/EC, 2006/972/EC, 2006/973/EC, 2006/974/EC and 2006/975/EC (Text with EEA relevance)(2013/743/EU).

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- enable to trace the life-cycle of different materials;
 - allow to understand and predict their interactions with the Earth system; being a full prediction impossible, it will allow to identify the critical aspects of the prediction;
 - start to investigate the conditions for a balanced approach to sustainable development.

This technological and modeling challenge could (will) be met:

- by understanding whether intrinsic properties or characteristics of functional materials can enable their tracing;
- by designing (multi) functional materials in such a way to embed the identification characteristics and functions necessary for traceability;
- by developing a proper network environment (Internet of things) to manage and exploit the massive flux of data originated by the material traceability.

The brainstorming aims to envisage potential mid- and long-term developments of new materials with special reference to:

- ensure the traceability during their complete life-cycle, independently from their dispersion in the environment (soil, water, atmosphere, living organisms);
- account for occurrence of transformations: both 'unwanted' transformations produced for instance by the aging or by an hostile environment, and 'active' transformations, i.e. functionalities of active (personalized) new materials;
- develop open-access methods and technologies for the material identification; in particular, low-cost portable devices will be key tools to reach a better societal consciousness;
- understand and forecast the interactions of materials with the Earth system to prevent undesired effects;
- develop modeling tools for scenario simulations in support to economical and socially sustainable policy decisions.

During the brainstorming the experts will contribute to imagine the future developments of the (multi)functional materials in their scientific and technological field of interest. Experts from non-technological disciplines are expected to envisage environmental and social issues.

The basic questions will be:

- can (functional) materials be traced by their own characteristics?
- how (functional) materials can be designed to include traceability as an integrated function or property?
- Is foreseeable a modeling approach to understand and to extrapolate the interaction of materials with the Earth system (the environment) for a sustainable progress?
- which are the conditions for the harmonization of different strategies of development?

APPENDIX: Participants' Expertise

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| Dr. Nicola Armaroli | Research Director, Institute of Organic Synthesis and Photoreactivity (ISOF) of National Research Council (CNR), Italy; Member of the Editorial Board of Chemistry-A European Journal, Photochemical & Photobiological Sciences (Royal Society of Chemistry) http://www.isof.cnr.it/ |
| Prof. David Cole-Hamilton | Professor of Chemistry, St. Andrews University, Scotland; President of the Dalton Divisional Council, Royal Society of Chemistry http://www.st-andrews.ac.uk/chemistry/ |
| Ing. Cristina Cristalli | Research for Innovation Manager, Loccioni http://www.loccioni.com |
| Prof. Mario De Caro | Professor in Moral Philosophy, University "Roma Tre", Italy; Visiting lecturer in Philosophy, Tufts University, Massachusetts http://www.uniroma3.it/ |
| Prof. Julian Hunt | Lord Hunt of Chesterton, Emeritus Professor of Climate Modeling at Department of Earth Sciences - University College London; Honorary Professor of Mathematics at University College London http://www.ucl.ac.uk/es/people/staff/emeritus/hunt |
| Dr. Jacek Marczyk | President, R&D, Partner, Ontonix, Italy http://www.ontonix.com/Jacek-Marczyk-PhD.htm |
| Dr. Augusta Maria Paci | Technology Director, National Research Council of Italy Member of the Executive Board of CNR Foresight SandT Project Member of the Expert Group 'Strategic Foresight for R&I Policy in H2020' (SFRI) Member, H2020 AG LEIT –NMBP, Vice chair and Rapporteur on WG on Impact www.cnr.it |
| Dr. Antonello Provenzale | Research Director, Institute of Atmospheric Sciences and Climate, National Research Council, Torino, Italy http://www.to.isac.cnr.it/ap/ |
| Ing. Andrea Ricci | Vice-President of ISIS Innovation for Sustainability, Italy http://www.isis-it.com/wordpress/about-us/our-team/ricci/ |
| Prof. Shozo Takata | Department of Industrial and Management Systems Engineering School of Creative Science and Engineering Waseda University, Japan http://www.waseda.jp/top/index-e.html |
| Dr. Francesco Tampieri | Research Director, National Research Council of Italy (*retired in 2015) Member of the Executive Board of CNR Foresight S&T Project www.cnr.it |

APPENDIX: Scientific Experts by Disciplines and CVs

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| Chemical sciences | Green chemistry | Prof. David Cole-Hamilton |
| | Material technologies | Dr. Nicola Armaroli (CNR) |
| Geo-physics | Multi-scale modelling | Prof. Julian Hunt |
| | Eco- systems | Dr. AntonelloProvenzale (CNR) |
| Engineering and ICT | Circular manufacturing | Eng. ShozoTakata |
| | Production Systems technologies | Eng. Cristina Cristalli |
| Philosophy | Ethics | Prof. Mario de Caro |
| Mathematical Sciences | Complexity | Dr. XXXX |
| Foresight | Quantitative Foresight | Eng. Andrea Ricci |

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| Dr. Nicola Armaroli | Research Director - Institute for Organic Synthesis and Photoreactivity, CNR, Bologna, Italy. http://www.isof.cnr.it/content/armaroli-nicola |
| | <p>Nicola Armaroli got the PhD in chemical sciences in 1994 from the University of Bologna. After post-doctoral research in the USA and Italy, in 1997 he joined the CNR, becoming Senior Research Scientist in 2002 and Research Director in 2007.</p> <p>His scientific activity is concerned with the photochemistry and photophysics of coordination compounds, carbon nanostructures and supramolecular materials. This research is of interest both in fundamental science and technological applications such as solar energy conversion and novel materials for lighting.</p> <p>He has given invited lectures at international conferences, universities and research centers worldwide. He serves as a referee for the most important scientific editors and for national and international funding agencies and private companies and foundations. He has run European projects as CNR principal investigator or coordinator in the frame of COST, FP5, FP6, FP7 programmes, funded by the European Commission. To date he has published over 170 papers and review articles on international journals and 5 books. His current h-index is 53. He is member of the editorial board of Chemistry-A European Journal, associate editor of Photochemical & Photobiological Sciences, chairman of the Working Party on "Chemistry and Energy" of EuCheMS, director of <i>Sapere</i>, the first Italian scientific periodical.</p> <p>Nicola Armaroli is a consultant and science communicator for the general public on the issues of energy, natural resources and environment. He was awarded the 2001 Grammaticakis-Neumann International Prize in Photochemistry and the Premio Letterario Galileo 2009 for science dissemination.</p> <p>http://scholar.google.com/citations?user=2fBm2Z8AAAAJ http://www.researcherid.com/rid/B-9094-2009</p> |

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| Prof. David Cole-Hamilton | Professor of Chemistry, St. Andrews University, Scotland; President of EuCheMS; President of the Dalton Divisional Council, Royal Society of Chemistry http://www.st-andrews.ac.uk/chemistry/ |
| | David Cole-Hamilton received his BSc (1971) and PhD (1975) degrees from Edinburgh University. Subsequently, he was a Postdoctoral Fellow (1974-75) and a Lecturer (1974-78) with Sir Geoffrey Wilkinson at the Imperial College in London. Later on he moved to the University of Liverpool where he was appointed Lecturer (1978-83) and Senior Lecturer (1983-85). In the mid-eighties he moved to the University of St. Andrews where he was appointed Irvine Professor of Chemistry (1985-date). Throughout the years he has written over 330 peer-reviewed papers and has examined over 80 PhD theses. He has been awarded numerous prizes such as a number of Best Teacher in Chemistry Honours Classes and is currently President of the Dalton Division of the Royal Society of Chemistry. |

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| Dr. Cristina Cristalli | <p>Research for Innovation Manager, Loccioni</p> <p>http://www.loccioni.com</p> |
| | <p>Cristina Cristalli is graduated in Electronic Engineering at University of Ancona, Italy in 1990 and received her Ph.D. in Bioengineering from University of Bologna in 1995. From January 1994 to July 1995, she was researcher at the Electronics Design Center of Case Western Reserve University in Cleveland (OH) and fellow at the National Science Foundation Engineering Research Center for Emerging Cardiovascular Technology at Duke University. She then worked (1996-98) as R&D engineer at Instrumentation Laboratories, Milano.</p> <p>At present she is the Director of the Research for Innovation team of the Loccioni Group, industrial company in the sector of measurement. Her main research fields are measurement and signal processing techniques as well as robotics for industrial applications.</p> <p>She was coordinator of a “Marie Curie Industry Host Fellowships” and she is involved in several FP7 EU projects.</p> <p>Her scientific works have been published in different books and journals and Conference Proceedings.</p> |

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| Prof. Mario De Caro | <p>Professor in Moral Philosophy, University “Roma Tre”, Italy; Visiting Professor in Philosophy, Tufts University, Massachusetts</p> <p>http://www.uniroma3.it/</p> |
| | <p>Mario De Caro teaches Moral Philosophy at Università Roma Tre. Since 2000 he has also been teaching at Tufts University. He received his first degree and his PhD in Philosophy at University of Rome "La Sapienza". He spent two years at MIT as a Visiting Graduate Student and one at Harvard University as a Fulbright Fellow.</p> <p>He is Associate editor of the Journal of the American Philosophical Association, forthcoming for Cambridge UP in 2015 and a member of the editorial and scientific boards of several international journals. He is Vice President of the Consulta Filosofica Italiana, a former President of the Italian Society for Analytic Philosophy, and a member of the American Philosophical Association on whose Committee on Academic Career Opportunities and Placement he served 2009-2013.</p> <p>He has given invited talks at more than one hundred academic institutions in ten countries, including Oxford University, Harvard University, Princeton University, Dartmouth College, University of Notre Dame, Tufts University, Boston College, University of Massachusetts (at Amherst), Case Western Reserve University, Indiana University (at Bloomington), University of New Hampshire, College of the Holy Cross, Institute Jean Nicod (École Normale Supérieure, Paris), Paris 1 Panthéon-Sorbonne, Paris IV-Sorbonne, Bonn, Heidelberg, Bamberg, Bern, Genève, Universidad Autónoma de Madrid.</p> <p>He has been a consultant for academic issues of the governments of Canada, Portugal and Belgium. He contributes regularly to the cultural section of the Italian national daily newspaper Il Sole 24 Ore and has written for The Times, La Repubblica, La Stampa, and Il Manifesto. He is an author and host of the 63 installments of the TV show Zettel, broadcasted by RAI, the public Italian television. The asteroid 5329 Decaro is named in his honor. In Italy he has published three volumes and about fifty scholarly articles and edited fifteen volumes. He has also published articles in German, Spanish, and Romanian.</p> |

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| Prof. Julian Hunt | <p>Lord Hunt of Chesterton, Emeritus Professor of Climate Modeling at Department of Earth Sciences - University College London; Honorary Professor of Mathematics at University College London</p> <p>http://www.ucl.ac.uk/es/people/staff/emeritus/hunt</p> |
| | <p>Julian Hunt had been a Professor of Climate Modelling in the Department of Space and Climate Physics, and Earth Sciences, (since 1999). Before that he was at the University of Cambridge where he was Professor of Fluid Mechanics. His current position is Visiting Fellow of the Malaysian Commonwealth Studies Centre in Cambridge University. He is still a Fellow of Trinity College.</p> <p>He is also a J.M. Burgers visiting professor at the Delft University of Technology, Visiting Professor at Arizona State University, Pierre Fermat Visiting Professor in Toulouse, Academic Director of the Lighthill Risk Network, Deputy Director of the Lighthill Institute of Mathematical Sciences and President of ACOPS (Advisory Committee on Protection of the Sea). He is a Fellow of the Royal Society. He has honorary degrees from Salford, Bath, East Anglia, Warwick, Grenoble, and Uppsala.</p> <p>In 2001 he was awarded the L.F. Richardson medal for non-linear geophysics by the European Geophysical Society. He was Director-General and Chief Executive of the Meteorological Office from 1992-1997, and was created a Baron in the House of Lords (with the title Lord Hunt of Chesterton) in May 2000. He is chairman of Cambridge Environmental Research Consultants Ltd., which is working world wide on air pollution modelling and forecasting; he helped found it in 1986.</p> <p>He is also a Project Advisor for the Global System Dynamics and Policies Project. In his research, he has developed new approaches to modelling turbulence, atmospheric flows around buildings and over mountains, and the dispersion of environmental pollution.</p> |

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| Dr. Jacek Marczyk | <p>President, R&D, Partner, Ontonix, Italy</p> <p>http://www.ontonix.com/Jacek-Marczyk-PhD.htm</p> |
| | <p>Dr. Marczyk, the founder of Ontonix, has over three decades of innovation, R&D and product development experience in various sectors such as aerospace, automotive, off-shore, computer hardware and software. He holds an MS in Aeronautical Engineering (Politecnico di Milano), MS in Aerospace Engineering (Politecnico di Torino) and a Ph.D in Civil Engineering (Universidad Politecnica de Catalunya). In the mid 1990s he has introduced to the industry the first commercial tool for large-scale stochastic simulation, ST-ORM.</p> <p>He has pioneered innovative methodologies for uncertainty and complexity management and has published eight books on stochastics, simulation and complexity management. During his career he has held various executive positions and has worked for companies such as EADS, BMW AG, Centric Engineering Systems, ESI, Silicon Graphics, Tecnomare, EASi and MSC Software.</p> <p>He founded Ontonix in 2005, two years after developing the Quantitative Complexity Theory (QCT). In 2013 he founded Assetdyne. Holder of a US Patent, Dr. Marczyk has developed a new complexity-based theory of risk and rating (book). He has lived and worked on four continents and is fluent in five languages. He is member of the Cryonics Institute.</p> |

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| <p>Dr. Antonello Provenzale</p> | <p>Research Director, Institute of Atmospheric Sciences and Climate, National Research Council, Turin, Italy</p> <p>http://www.to.isac.cnr.it/ap/</p> <p>Antonello Provenzale has a doctoral degree in Physics, at the University of Turin, (1987). Scientific interests are: Climate dynamics; geophysical flows; climate-biosphere interaction; climate impacts on ecosystems and the hydrologic cycle. He was Member of the Editorial Board of the journal Water Resources Research of the American Geophysical Union in the period 2008-2009. Contractor of EU projects: "Two-dimensional turbulence, vortices and geophysical flows" (1993-1995), "Variability of the North Atlantic Storm Track" (1995-1997), "Stirring and Mixing" (2002-2006), "ACQWA" (2008-2013) and of several national projects. He was Vice-president for Europe of the Committee for Mathematical Geophysics of the International Union of Geodesy and Geophysics (IUGG), from 2001 to 2007. Member of the GFD Core Faculty Group of the Summer Program on Geophysical Fluid Dynamics at the Woods Hole Oceanographic Institution. Coordinator of the CNR section on "Dynamical Climatology" from 2005. Coordinator of the Torino branch of ISAC-CNR from 2009.</p> <p>He is author of about 120 publications in the peer – reviewed international scientific literature (ISI journals) and Editor of four volumes and of two journal special issues.</p> |
| <p>Ing. Andrea Ricci</p> | <p>Director of ISIS Innovation for Sustainability, Italy</p> <p>http://www.isis-it.com/wordpress/about-us/our-team/ricci/</p> <p>ISIS Vice President, Andrea joined ISIS in 1981. He received his engineering degree at Ecole Centrale (Paris, France) in 1977. His key qualifications include: sustainability policy analysis and impact assessment, forward looking analysis, energy studies and information systems, transport studies and information systems. He participated and coordinated many EU RTD projects, among which: EFONET (FP7); NEEDS (FP6), FLAGSHIP, PASHMINA and URBACHINA. He served as evaluator of EU RTD proposals within FP4, FP5, FP6 and FP7, and he also contributed to the ex-post evaluation of several EU RTD Programmes (International Cooperation, Environment, Bioeconomy). Counting more than 100 international publications, he is also author of a number of EU reports (DG RTD) ("Assessing the Social and Environmental Impacts of European Research", "The overall socio-economic dimension of community research in the fifth European framework programme"). He has recently served as the Rapporteur of the EC Working Group "Global Europe 2030 – 2050". Fluent in Italian, English and French, He has also a very good knowledge of Spanish.</p> |
| <p>Prof. Shozo Takata</p> | <p>Prof. Dr.Eng. at Department of Industrial and Management Systems Engineering, School of Creative Science and Engineering, Waseda University, Japan</p> <p>http://www.waseda.jp/top/index-e.html</p> <p>Shozo Takata is a Professor at the Department of Industrial and Management Systems Engineering at Waseda University in Tokyo, Japan. He received a doctoral degree in engineering in the Department of Precision Machinery Engineering at the University of Tokyo, Japan in 1978. He worked at Toyo University as a lecturer and associate professor from 1978 to 1990, and at Osaka University as an associate professor from 1990 to 1992 before moving to Waseda University as a full professor.</p> <p>His research interests are in life cycle engineering focusing on design and management of reuse and recycling system for the circular manufacturing, maintenance engineering focusing on optimum planning of maintenance polices from the aspect of product and facility life cycle management, and business model design for facilitating the product life cycle management in circular manufacturing. He is a fellow member of CIRP.</p> |

APPENDIX: Suggested priorities for research in production and manufacturing

After the discussion, experts were asked to summarize provide their priorities for S&T. Regarding Circular manufacturing the following table was provided:

| Production and manufacturing | Processes | Enabling S&T areas |
|---|---|---|
| Life cycle development | life cycle planning – determination of life cycle strategy, life cycle options, and business options | life cycle simulation – simulating the life cycle of whole products delivered to the market for certain period of time for calculating LCC and environmental impacts |
| Reuse and recycling | <ul style="list-style-type: none"> - closed loop recycling of synthetic material - urban mining of rare metal/rare earth - refurbishment/reconditioning/rebuilt/remanufacturing technologies - reuse management (matching between supply and demand) - Business modeling for circular economy - business modeling of environmentally benign PSS - modeling of life cycle business - development of b2c solutions business | |
| Customer acceptability of circular economy | | |
| Effects on reducing environmental impact and resource consumption Government policymaking for promoting circular economy | | |

APPENDIX: Brainstorming Background Documentation

Background Document: Intelligent Traceability for Environment' Final report in May 2014

The challenge of balancing technological development and natural and human environment towards a sustainable society, was reported in the Background Report and referred to the following three areas: Earth and human system, efficiency in production, bio-based products and processes. The Background Document was discussed with the experts and revised taking into account observations received. WG published “Background Document: Intelligent Traceability for Environment’ Final report in May 2014 explaining the overall foresight approach and reporting critical exempla in three case studies. The case studies proposed key areas for taking experts’ attention during the interviews. Experts’ comments to the Background Document were inserted in the revised edition.

INTRODUCTION TO THE TOPIC of the BRAINSTORMING

Large theme covering many aspects. Need to focus areas of great potential interest and see in Traceability a capability for keeping track of info a way to introduce transparency in materials and products (specific items) This requiring short term integration and interiorization of knowledge in materials.

The Topic of the Brainstorming “Traceability” was therefore not directly discussed in the first part of the Brainstorming as it was new to the experts. All experts agreed that it requires to be focused and formulated in order to become a new pathway for knowledge development to provide future solutions for benefits in several areas of socio-economic relevance. For the purpose of the Brainstorming the below meaning for Traceability was initially shared with experts.

Presently, Traceability is considered important for LCA, for secondary raw material and important in the recovery opportunities for metals: material flow analysis tracks content of products and their end of life and a lot of technologies are delivered to meet these purposes.

In the future Traceability can represent solutions for the control of materials in related products, from the initial material for production to the end of the planned use with its unavoidable transformations (recycle, disposal, dispersion in the environment).

Looking forward, Traceability will redefine the circular economy and respond with better efficiency to societal requests, industrial needs and to environmental (both natural and societal) analyses of impacts. Traceability reflects a complex and interconnected society driven by needs of a balance between improving the quality of life and minimizing the costs of the unwanted impacts on the Earth system. Experts discussed about tracing what happens to materials and on the ability to trace how materials will be in use, particularly considering the endangered materials and their availability.

