THE CHALLENGE OF INDICATIONS OF SOCIO-ECONOMIC IMPACT THAT ADDRESS THE COMPLEXITIES:
INSIGHTS FOR TA AND FUTURE-ORIENTED ANALYSES

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Outline

1. Broad entrance: simple indicators of impact of nanotechnology do not suffice
2. What is a Nano Product
3. TA of nano in the present
4. Anticipating on impacts requires future-oriented analyses (or FLA) combined with TA
5. Some examples

PART I

CHALLENGE: SIMPLE INDICATORS OF IMPACT FOR EMERGING TECHNOLOGIES DO NOT SUFFICE

Monitoring and anticipating impacts of nanotechnologies

- There are big promises about socio-economic impacts of nanotechnologies and there are attempts to trace and evaluate them (see OECD/NNI meeting in 2012)

- such attempts are fraught with difficulties, because:
  - there is no linear-causal relation between nanotechnology innovation (cf. co-production).
  - Impacts are heterogeneous, distributed across R&D hubs, value chains and in the eventual use,
  - more often than not it is difficult to disentangle the web of activities and attribute an impact to a single point source.

- This is a generally recognised issue, but still there is a demand for indicators of unilinear impact.

- This is the second main difficulty, the need of policy makers and administrators to have indicators, so that decisions can be made on their basis, without having to go into the complexities of the actual developments.

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The challenge : How can indications of impact be captured in the present and how can they be anticipated
(to be able to monitor progress of nanotechnologies and assess returns on investment?)

PART II

WHAT *IS* A NANO PRODUCT ANYWAY?

Nanotechnology for Greener Cars

A shift in perspective from bionananomaterials impact on the packaging sector (a techno-centric perspective) to an application-centric perspective.

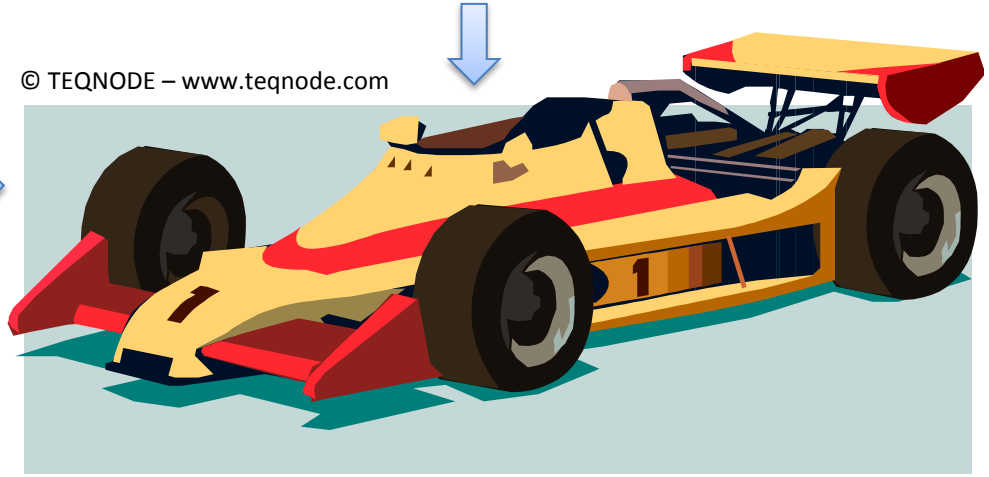
The car as a complex system of technologies provides a number of opportunities for nanotechnology to enable greener vehicles to varying extents

Nanotechnologies to enable higher performance and safe fuel cells and electric vehicles

Nanotechnologies are promising to improve the competitiveness and feasibility of non-fossil fuel energy systems for vehicles. For hydrogen fuel cells, detecting hydrogen leakage is essential, single-walled carbon nanotubes functionalised with palladium are one example of here. Nanotechnologies for more efficient lithium batteries are predicted to enable more efficient electric vehicles.

Reduction in fossil fuel consumption via light-weight nanocomposites

Vehicle weight is one of the major factors that influence the amount of fuel to be used in a vehicle. Light-weight, but still structurally efficient materials offer a means to reduce fossil fuel consumption. Nanocomposites offer a multitude of materials for use in the chassis, the internal structure, the external structure and windscreens.



Tyre innovation to improve performance and reduce abrasion

Carbon black has been used for years as a pigment and reinforcing agent in the automotive industry. For tyres, mixing rubber with other materials can give a better performance, and nanomaterials combined with rubber are offering important advantages such as resistance to wear and tear.

The specific impact of nanotechnologies on making cars greener is difficult to entangle. As an enabling technology, it works in conjunction with other technology components and adds functionalities within a configuration of functional technologies. A nanosensor for hydrogen may enable hydrogen fuel cells to be more suitable for use in cars, though it is not a necessary functional component of the hydrogen fuel cell itself.

Adapted from Robinson DKR (2013) Tracing impacts of nanotechnologies. Forthcoming.

What is a nano-product? Where are the impacts?

Nano can play a role in many sectors (both products and manufacturing processes) and to a varying degree of intensity

Nano-element	Function/role	Enabled innovation	Envisioned product
Nanomaterial	Antibacterial coating	Food processing	Safe Jam / Jelly
Nanocrystal	Photon conversion	Photo-voltaics	Competitive solar cell options
Nanobiosensor	Improved detection	Medical diagnostic	Disease detection
Nanobiopolymer	Biopolymer with Rigid and fluid impermeable	Food and drink packaging	Biodegradable and biosourced packaging

What is a nano-product? Where are the impacts?

Nano can play a role in many sectors (both products and manufacturing processes) and to a varying degree of intensity

1. **Products that utilize** nanotechnology as a small part of much larger product (where nano provides with small improvements)
2. **Nano-enabled products :** whose key functions rely on nano, but still where nano is a small part of the product
3. **Nanotechnology products:** where the product is based largely/solely on nano

Nano-element	Function/role	Enabled innovation	Envisioned product
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Already there is a challenge: Nano enters/enables products in various ways

- The impact pathways of nanotechnologies are different based on different sectors and contexts
- Therefore simple & broad indicators for nano impacts will not suffice.
- **As a first step, one should focus on specific Value Chains to apply TA of how nano is impacting (in the present)**

PART III

TA OF NANO FOR SPECIFIC VALUE CHAIN

Nano for food packaging

(In the present)

Nano visions for bottled products
JUNGLE PUNCH!

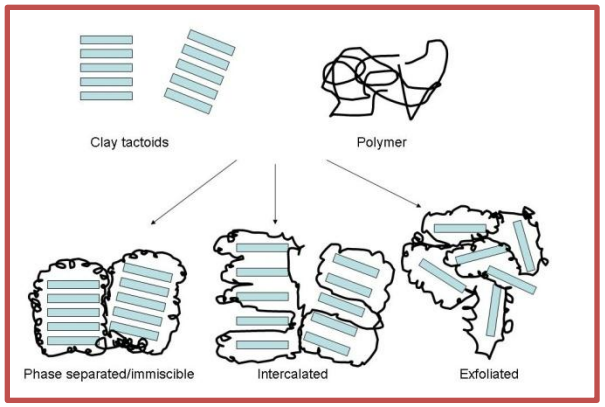
Figure 1 – Nanotechnologies applications in a juice bottle

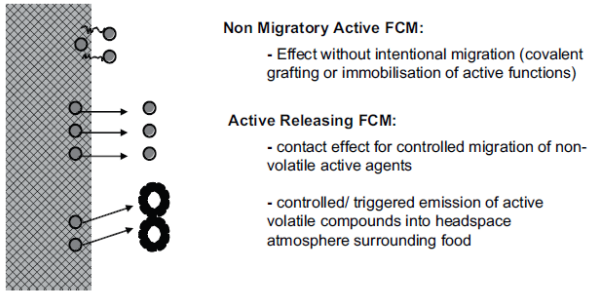
Source: Lux Research reference study, The Nanotech Report, 5th Edition, 2007.

Let's look at this more deeply with a TA Exercise (conducted in 2010 – ObservatoryNANO – Doug Robinson)

Nanocomposites promises

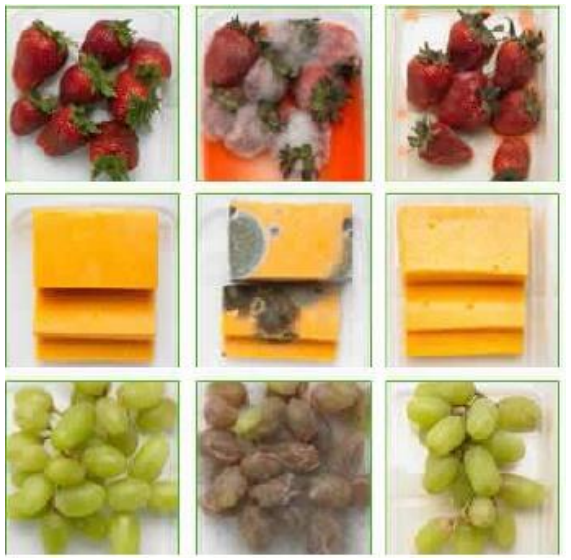
- Nanocomposite contain a polymer plus a nano-additive.
- Mostly nanoclay particulates are used;
- Polymer nanocomposites containing nanoclay particulates are currently leading the food packaging market.
- Nanocomposites market share is rapidly growing (the fastest area of growth in he $40 billion polymer composite market).
- Nanocomposites based on Imperm® found their early application in multi-layer PET beer bottles used by Miller Brewing Co.

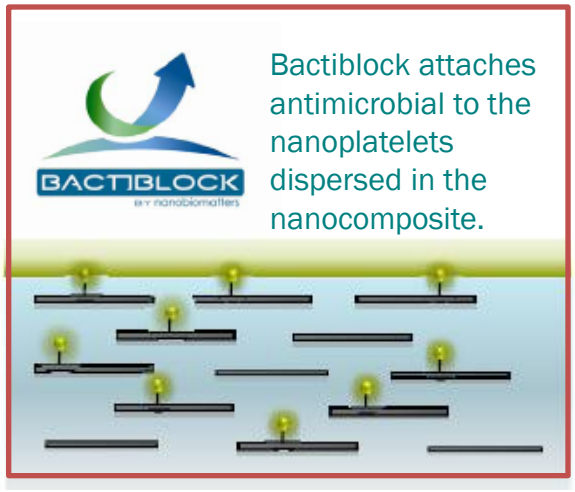




Active antimicrobial packaging

- Antimicrobial active packaging allows improved product quality and safety over an extended period of time.
- EU Regulation 450/2009
- already been introduced in Japan: nano silver, nano wasabi and ethanol
- Examples in Europe include antimicrobial active film which includes a controlled release mechanism.,
- Nanobiomatters (Valencia) is commercializing its bactiblock ®





The Driver for Green Packaging

Packaging waste costs money and costs the environment

Using figures just for the UK:

Approximately 10.5 million tons of packaging enters the UK waste system every year (DEFRA report)

More than half of this is related to food and drink

The cost of the raw materials for this is about 4.5 billion Euros per year

And this cost does not include disposal and recovery costs or wider social and environmental costs such as the accumulation of platicizers in underground water, or the production of dioxins by, for example, PVC and paper based packaging materials

SO LETS GO GREEN?

So we have:
Promising nanotechnology options
AND
Grand societal challenge of packaging waste

Lets look at the value chain linking research and eventual embedment of technology

Emerging Value Chains

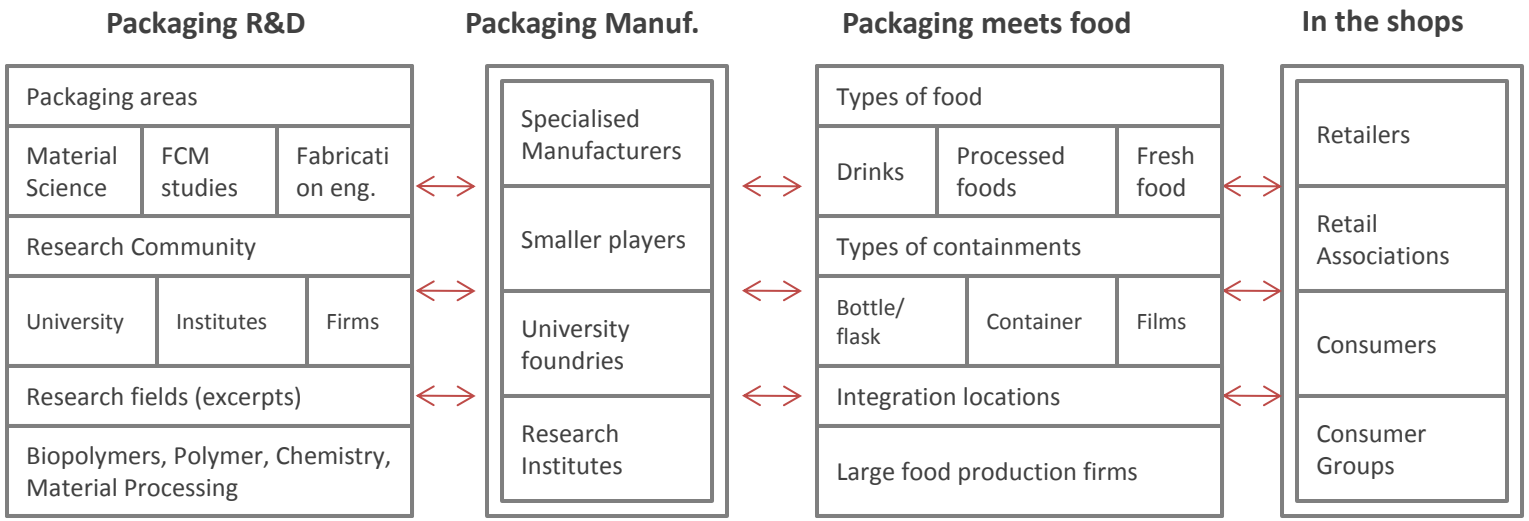
Packaging R&D | **Packaging Manuf.** | **Packaging meets food** | **In the shops**

Packaging areas			Specialised Manufacturers	Types of food			Retailers
Material Science	FCM studies	Fabrication eng.	Smaller players	Drinks	Processed foods	Fresh food	Retail Associations
Research Community			University foundries	Types of containments			Consumers
University	Institutes	Firms	Research Institutes	Bottle/ flask	Container	Films	Consumer Groups
Research fields (excerpts)				Integration locations			
Biopolymers, Polymer, Chemistry, Material Processing				Large food production firms			

Look at the current industrial value chain (here for food packaging)

Adapted from: Douglas Robinson, Lu Huang, Ying Guo & Alan Porter (2013)
Forecasting Innovation Pathways (FIP) for New & Emerging Science & Technologies.

Emerging Value Chains



Adding nanotechnology creates new supply chains in nanomaterials, but shapes the Framing conditions that effect the food packaging value chain (leading to a number of challenges and opportunities)

Adapted from: Douglas Robinson, Lu Huang, Ying Guo & Alan Porter (2013)
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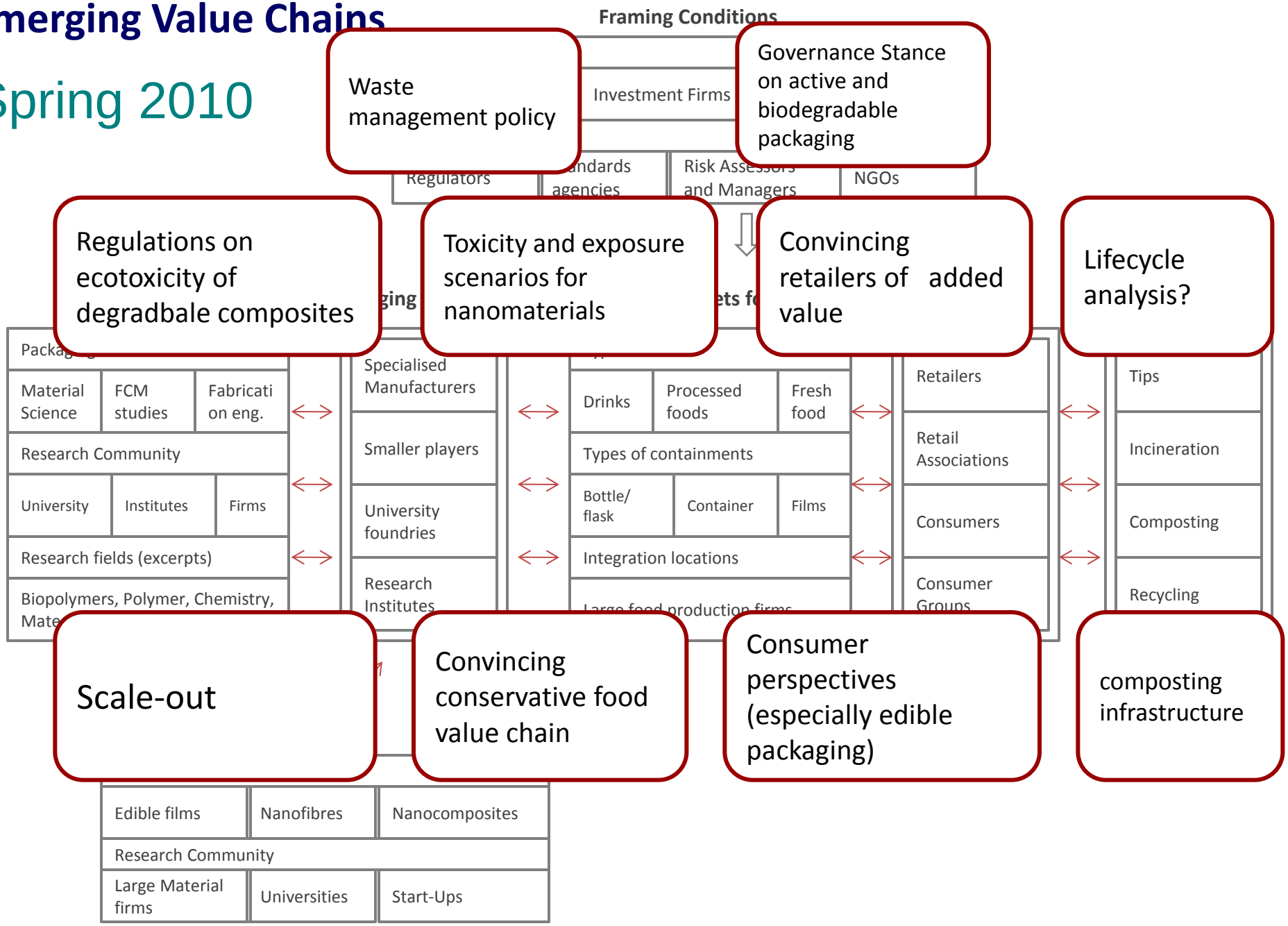
Emerging Value Chains

Spring 2010



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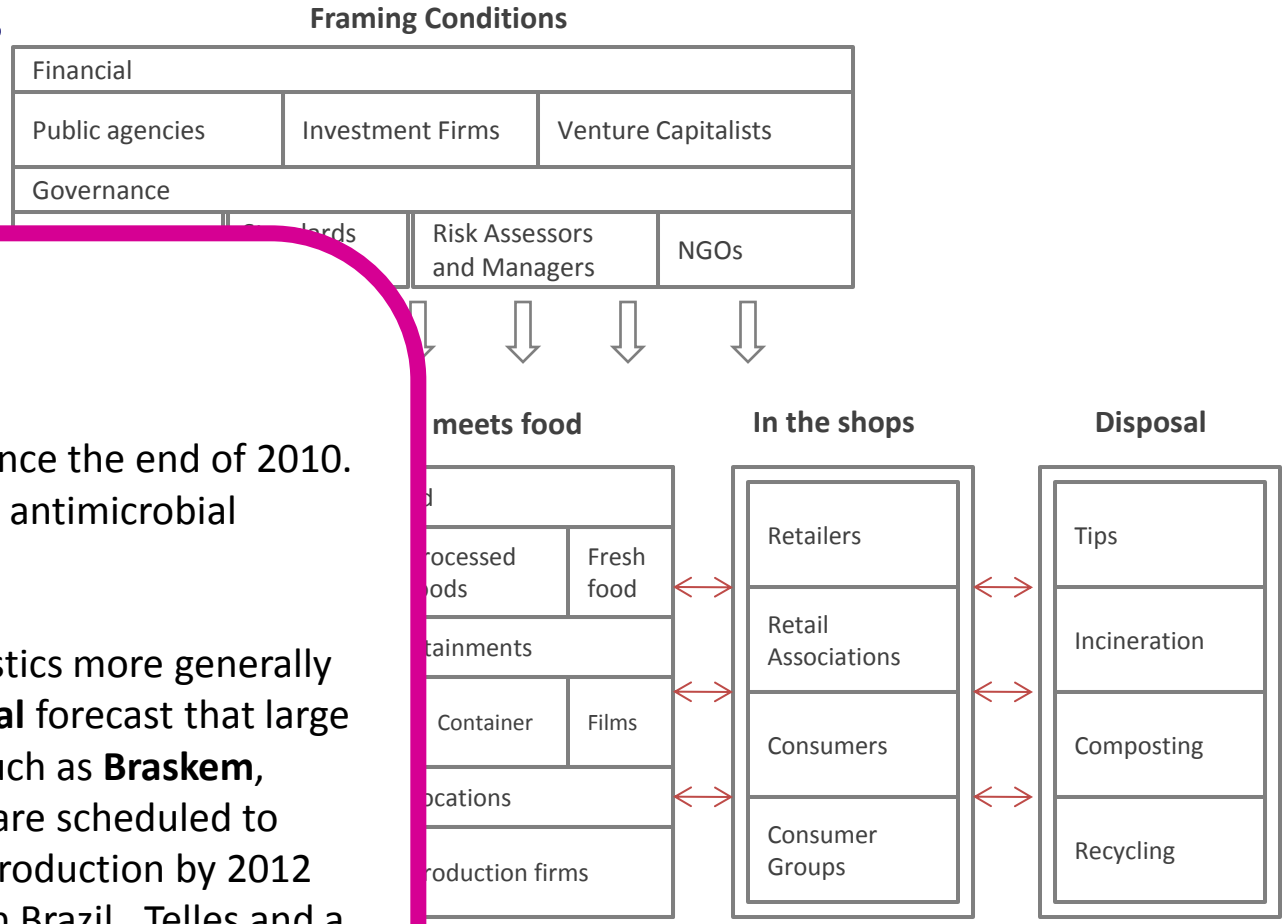
Emerging Value Chains

Jan 2011



Scale-out

Infrastructure is emerging since the end of 2010. **Nanobiomatters** for bio and antimicrobial composite packaging.

In a recent report on bioplastics more generally (Jan 2011) **PIRA International** forecast that large petrochemical companies such as **Braskem**, **Dow Chemicals** and **Solvay** are scheduled to commence bio-derived PE production by 2012 at industrial-scale facilities in Brazil. Telles and a number of Chinese producers are known to be investing too.

Edible films	Nanofibres	Nanocomposites
Research Community		
Large Material firms	Universities	Start-Ups

Adapted from: Douglas Robinson, Lu Huang, Ying Guo & Alan Porter (2010)
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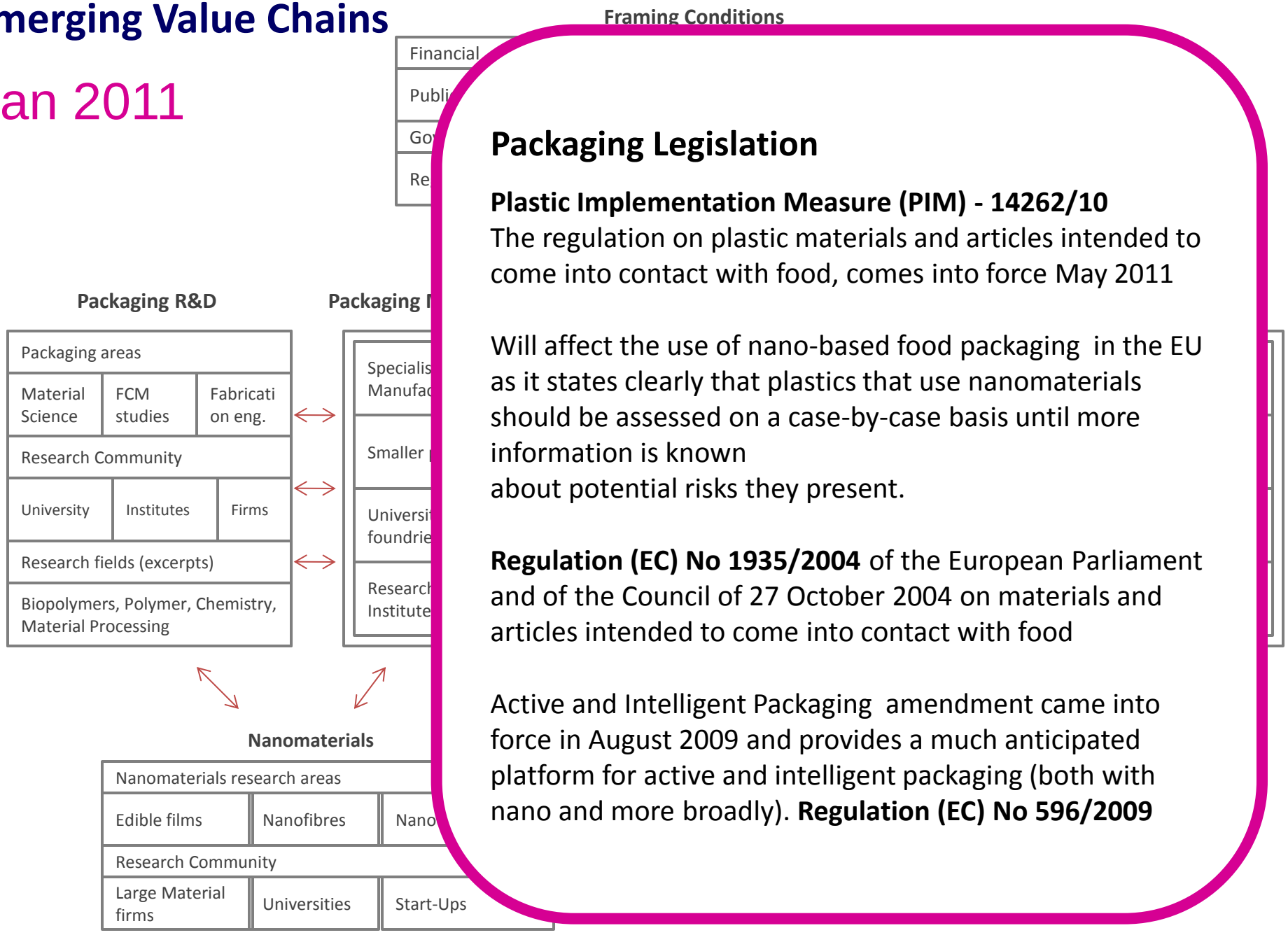
Emerging Value Chains

Jan 2011



Packaging Legislation

Plastic Implementation Measure (PIM) - 14262/10
The regulation on plastic materials and articles intended to come into contact with food, comes into force May 2011

Will affect the use of nano-based food packaging in the EU as it states clearly that plastics that use nanomaterials should be assessed on a case-by-case basis until more information is known
about potential risks they present.

Regulation (EC) No 1935/2004 of the European Parliament and of the Council of 27 October 2004 on materials and articles intended to come into contact with food

Active and Intelligent Packaging amendment came into force in August 2009 and provides a much anticipated platform for active and intelligent packaging (both with nano and more broadly). **Regulation (EC) No 596/2009**

Adapted from: Douglas Robinson, Lu Huang, Ying Guo & Alan Porter (2010)
Forecasting Innovation Pathways (FIP) for New & Emerging Science & Technologies.

In real-time we can explore the developments and the impacts of a nanotechnolgy (here for food packaging)

We can look at how these have co-evolve historically

What about future impacts?

Impacts are co-produced by development and deployment (ebmedment/adoption/rejection).

Therefore: anticipation on future impacts (as well as the means to monitoring them) needs to be based on the co-production!

PART IV

CREATE AND EXPLORE NARRATIVES OF DEVELOPMENT AND IMPACT: *SOCIO-TECHNICAL SCENARIOS*

Socio-Technical Scenarios are stories of how the future may unfold from the present

They are not predictions, they are platforms for exploration with a variety of actors, in interviews and in workshops.

They blend the context and dynamics of the present with controlled speculation (informed fictions)

Socio-technical Scenarios

- Combines value-chains, governance framing conditions and user cultures.
- Structured using theories of technical change, STS and innovation studies.
- Relies on good knowledge of the target domain (to be plausible and credible in workshop situations).
- Focuses on the unfolding of the present into the future
- Incorporates co-evolution, co-production of impacts, dilemmas, openings and lock-ins

PART V

SOME EXAMPLES

Socio-technical scenarios: Example Thread

Patchwork of codes enables innovation journeys in nanomaterials and nano-enabled medicine.

In this scenario there is a fork, where governance lies on the enactors (self-regulated soft law for nano amidst regulation for other sectors)

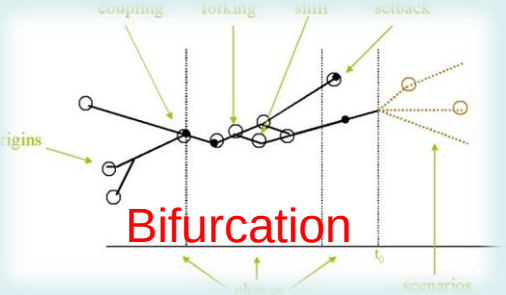
Finland anticipates on large returns and sinks investments into nano focussed on paper production. Other nations look on jealously as such focus is difficult in their own nation.

When event occurs (a worker affected by toxicity) opportunity for GOs and NGOs move in to regulate

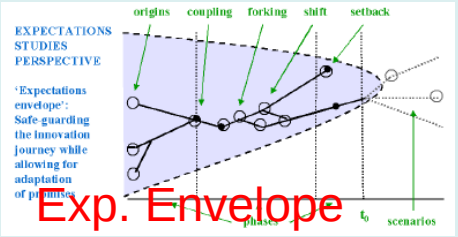
Causes **innovation bottlenecks** as regulation catches up with innovation…deadly consequences for small techno start-ups which currently proliferate in nano.

Emerging irreversibilities through networks and routines (Van Merkerk & Robinson 2006)

Eis enable & constrain

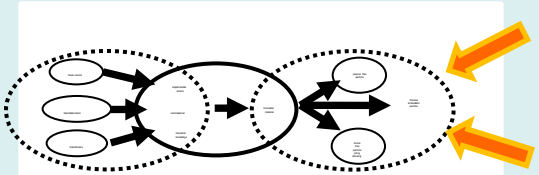


Bifurcation



Exp. Envelope

Triggering event present opportunity for shifts. EIs are brokendown.



Selection/Innovation Tension

Socio-technical scenarios: Example Thread

		Informed by endogenous futures		Path dynamics/perspective
	Innovation Journey "critical event"	Entanglements and Emerging Irreversibilities	Expectations that come to pass in text	Multi-level &/or actor-centric dynamics
1	Fork: some actors agree to codes of conduct, others are suspicious/ambivalent and do not agree to sign up.	Patchwork of codes of conduct and best practices here has meant no overall alignment. Also, there is lock out of alternative approaches. This is not mentioned in scenario but acts as an entrance point for discussion in workshop – picked up by participants or highlighted by [illegible]	From my case research, some large pharma-ceutical industry actors anticipate an opening for litigation and liability due to vagueness of codes. This "product" expectation of undesirable regulatory environment changes [illegible] abstaining.	Meso-level: industry consortia initiate code of conduct. Macro-level: Government initiated voluntary reporting scheme makes little progress. I purposefully reduce emphasis on micro-level activities. EU code for research and not cost, also purposefully
2	Patchwork of codes enables new medical device development (reinforces existing regulation). Lack of regulation for Nanomaterials is not a point of focus.	Current medical device developers aligned in more or less stable innovation chains – no pressure for new relationships. Nanomaterial innovation chains set up with no triggers from regulators or potential consumers/users.	The "Paradigm" expectation of the nano promise helps mobilise resources, but for the time being does not effect the "Search" and "Product" expectations, which remain the same (nothing new for nano).	Multi level alignment remains the same. Business as usual for medical technologies, which are now integrating micro/nano. Nanomaterials remains unfettered and unnoticed by governance arrangements
3	Nano for paper picked up as a key driver for nano investment in Finland	Large sunk investments in nano for paper processing constrains non paper related nano but gives impetus to those inline with the programme – emerging irreversibility in Finnish nano technology trajectories/path.	All three types of expectation are reshaped and become foreceful through the backing of strong government support.	There is multi-level alignment around these goals based on the promise of this type of nano for the Finnish economy. Anticipation at the macro-level (top-down governance mode).
4	Limited attempts at public engagement. Fork occurs: (1) RRI focussing on "Real issues" of HES and (2) Broader speculations on ethics and philosophy of Human enhancement, justice and theology.	Those contributing to Responsible Innovation begins to separate into two communities, one industry dominated focussing on HES, the other public actor based looking at Ethics and Philosophy (academic and political)	Two paradigm expecations are emphasised here. One on improved industrial processes and products (Fork 1) and the other on tranhumanism and broader ethical issues of nano (Fork 2). Discussions consolidate around each path. Those issues lying between these two are not picked up.	Micro and Meso-level focus on HES Macro focus on broader ethical issues. Ad-Hoc or no linkages between Macro and other levels with regards to nano specific responsible innovation.
5	Monitoring Code of Conduct signatory compliance becomes a major point of contention. Lack of watchdogs.	Gradual "Lock out" of governmental organisations (GOs) and NGOs as nano specific governance focuses on codes of conduct (soft law) rather than changes in regulation (hard law).	Some concerns in numerous discussions concerning a number of codes is that self-regulation is fundamentally [illegible]	Meso-level dominance in nanotechnology governance mechanisms. This dominance is observed but is difficult for macro-level actors (GOs and NGOs) to intervene.
6	Nanotechnology booms. Some issues of worker safety raised but has little effect (early signal lost in the noise of the boom)	Industry consortia self impose best practices (patchwork) becomes locked in. NGOs and labour organisations find it difficult to raise issues.	The soft law option prevails and allows nanotechnology to grow rapidly (a paradigm expectation pushed in market reports and used in policy circles – in this scenario by Finland).	Meso-level dominance in nanotechnology governance mechanisms leads to fast growth and large economic returns on nano investments.
7	Platform technologies with applications in multiple sectors begin to emerge.	Enabling nanotechnologies now capable of affecting multiple sectors. Previous actor arrangement and innovation chains under strain as one nanotechnology can be regulated in numerous ways (as a medical devioce, drug or biomaterial for instance)	This increasing complexity issue is a shared expectation and has been described in the IRGC as a driver for adaptive governance.	Micro-level starts giving signals across and between levels that nanotechnologies are becoming more than extensions of existing technology developments, but complicated enabling technologies that can be used in a wide range of sectors.
8	Unclarity in codes and lack of watchdogs mean soft law has little effect	Patchwork of code aligns innovation actors and reduces pressure to go for regulation. So soft law + non-nano-specific hard law. There is growing recognition that regulation of nano is increasingly difficult due to the enabling nature of the technologies – why regulate nano? Better regulate the nano-enabled product?	Anticipation by labour organisations that some form of accountability be made clear	Lock out of NGOs, stabilisation occurs. N macro change and soft law dominates at meso level. Soft law followed selectively at the micro-level
9	Increasing nano complexity coupled with an accident initiates a renewed look at governance arrangements	GOs, NGOs & CSOs (civil society orgs) attempt to change governance arrangements. Is made difficult because of the complex patchwork already in place – no clear entrance point for change (be it path deviation or pathcreation).	Expectation that governments should start the process now (see Principles of Oversight	Macro-level initiated investigations (mainly by government) reveal gaps in legal framework for active nanoparticle based technology platforms.
10	Trigger at micro-level (nanoparticle aggregation in workers liver) creates opportunities for actors at the government level to reshape industry consortia alignments around soft law and create alternative mixes of governance modes.	Lock-In of governance arrangements remains strong until a key event provides impetus for coordinated mobilisation across and between levels. Entanglements already in place start being affected.	Here I include the effect of a path creating event (Garud and Karnoe 2002) where a window of opportunity allows the mobilisation of resources and mindful deviation from a current path.	Macro-level was impotent due to meso-level alignement. However micro-level trigger creates a window of opportunity, which is seized upon by government actors.
11	Lack of nano specific regulation causes setback for medical devices attempts to enter the clinic	Nano-enabled medical devices working on the model that nano deserves no unique form of governance acts a setback as nano becomes specific. Misalignments between technology developers and the new selection environment causes bottlenecks and major hurdles (both financially and organisationally)	Lack of anticipatory action on the part of medical device manufacturers causes regulatory bottleneck in the innovation chain.	New shifts in governance modes across and between levels means delays for some product innovations. Actors within the affected sector attempt to shape regulatory frameworks, but long time frames cause major delays – fatal for a large number of high-tech start-ups.
12	Health Insurers withhold their backing for new nano-enabled medical devices, whilst regulators scramble to catch up. The general public calls for transparency and accountability.	Unanticipated shift in selection environments cause issues in the development side of the innovation chain.	Public outcry as potential (unexplored) risks are identified. Large nano promise burst (product and paradigmexpectation loses forcefulness and protective quality)	Macro-level activities begin to dominate as civil society voices opinions, and health insurers (medical device innovation chain gate keepers) wield their power against the medical device manufacturers due to the regulatory vacuum which soft law filled initially but overtime caused an unsustainable innovation paradigm.

This scenario has **12 critical events**; these **capture shifts in innovation journeys** and their **environments**.

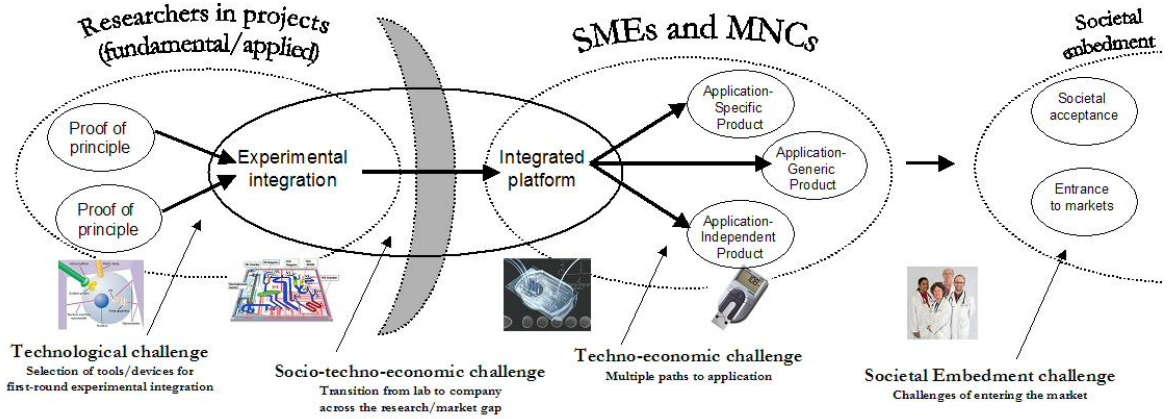
It focuses on the **influence of soft law** (codes of conducts, best practices, standards etc.) on both the **selection environment** and **innovation journeys**.

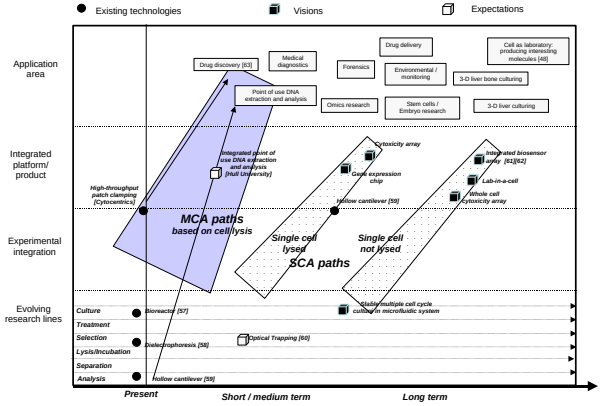
It combines **innovation journeys**, with innovation/ selection-environment **dynamics**, **paths** in terms of evolving paradigms and actor strategies, and **anticipatory coordination**.

Explore in Scenarios in workshops
Cell based Lab-on-a-chip from lab to markets

Douglas Robinson, Amsterdam (NL),

- **Focus:** Bridging Societal aspects with innovation through prospecting innovation journeys.
- Took a technology producer perspective and described innovation chain via their perspective.
- Used techno-centric socio-technical scenarios in order to broaden the innovation chain perspective. Scenarios where informed by path dynamics and emerging irreversibilities
  - *see Robinson and Propp (below) & van Merkerk and Robinson TA&SM 2006*
- Workshop brought start-ups and researchers together in a future-oriented multi-path mapping exercise (1-day long workshop)
- Workshop focused on composition of possible actor-networks and issues that are relevant - Identified 4 main paths.
- Some expected bottlenecks and broader issues identified





Figures – (Top) Technology developer perspective on innovation chain (Bottom Left) Douglas in Action during workshop (Bottom Right) One version of multi-path map.

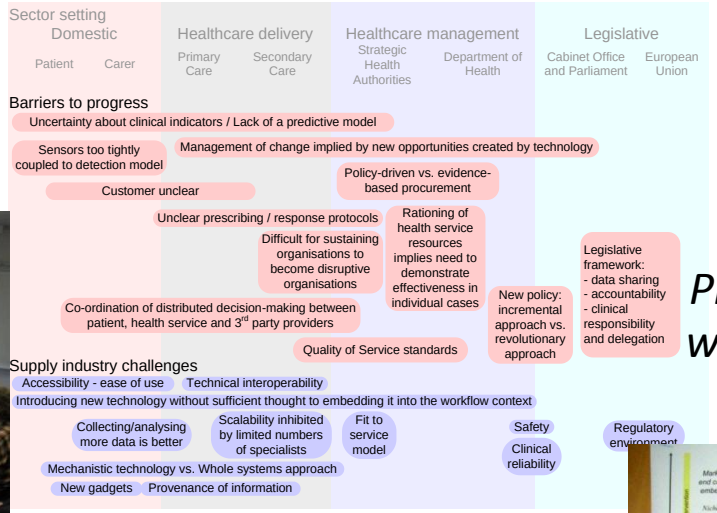
See article **Robinson & Propp, Technology Forecasting and Social Change, online April 2008: doi:10.1016/j.techfore.2008.02.002**

From scenario discussion and further interaction flesh out key elements that will shape impact pathways

Smart Health: Telemonitoring innovations for the UK

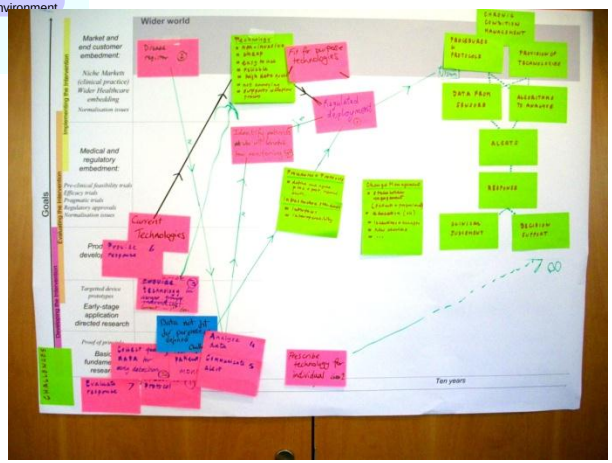
Douglas Robinson, Cardiff (UK),

Discuss Scenarios and experience and perspectives of important actors

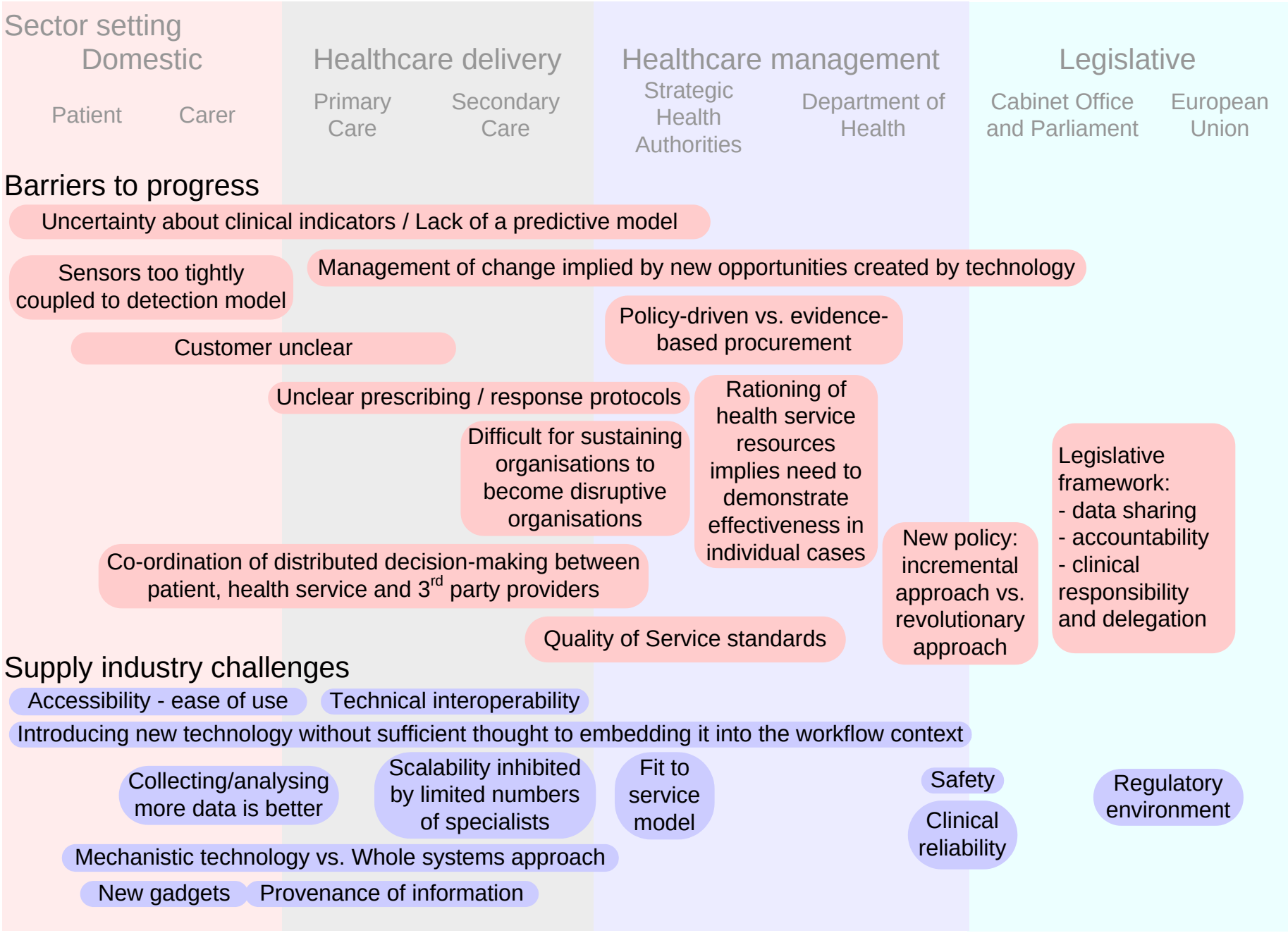


Identify key issues for different actors and how they interact

Plot impact pathways along with development pathways



See article **Robinson et al 2013 (forthcoming)**


Sector setting
Domestic
Patient
Carer
Healthcare delivery
Primary Care
Secondary Care
Healthcare management
Strategic Health Authorities
Department of Health
Legislative
Cabinet Office and Parliament
European Union
Barriers to progress
Uncertainty about clinical indicators / Lack of a predictive model
Sensors too tightly coupled to detection model
Management of change implied by new opportunities created by technology
Policy-driven vs. evidence-based procurement
Customer unclear
Unclear prescribing / response protocols
Rationing of health service resources implies need to demonstrate effectiveness in individual cases
Difficult for sustaining organisations to become disruptive organisations
Legislative framework:
- data sharing
- accountability
- clinical responsibility and delegation
Co-ordination of distributed decision-making between patient, health service and 3rd party providers
New policy: incremental approach vs. revolutionary approach
Quality of Service standards
Supply industry challenges
Accessibility - ease of use
Technical interoperability
Introducing new technology without sufficient thought to embedding it into the workflow context
Collecting/analysing more data is better
Scalability inhibited by limited numbers of specialists
Fit to service model
Safety
Clinical reliability
Regulatory environment
Mechanistic technology vs. Whole systems approach
New gadgets
Provenance of information

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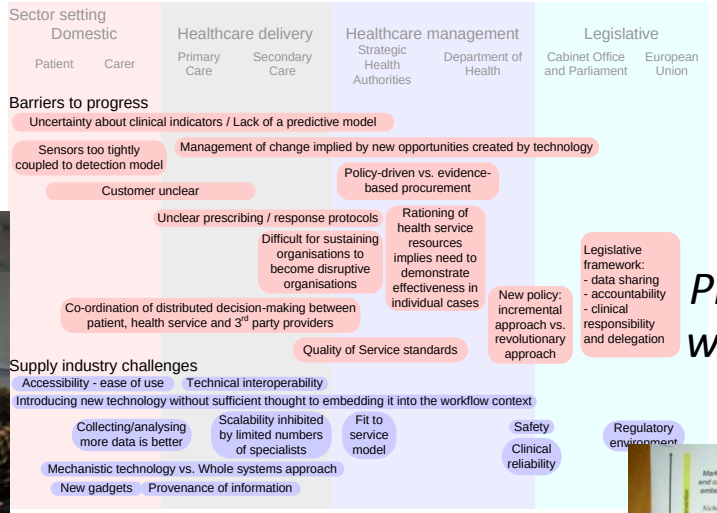
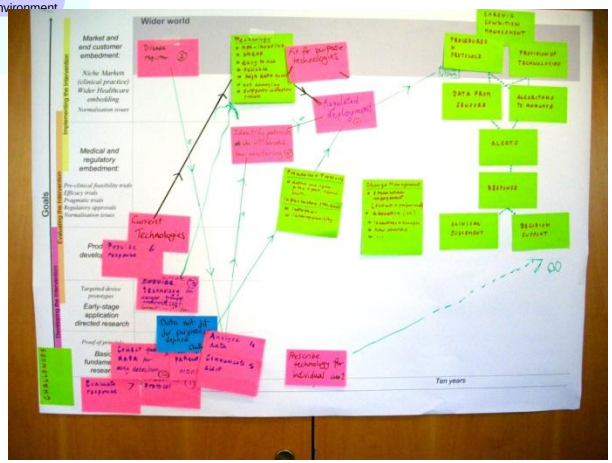
Douglas Robinson, Cardiff (UK),

Discuss Scenarios and experience and perspectives of important actors



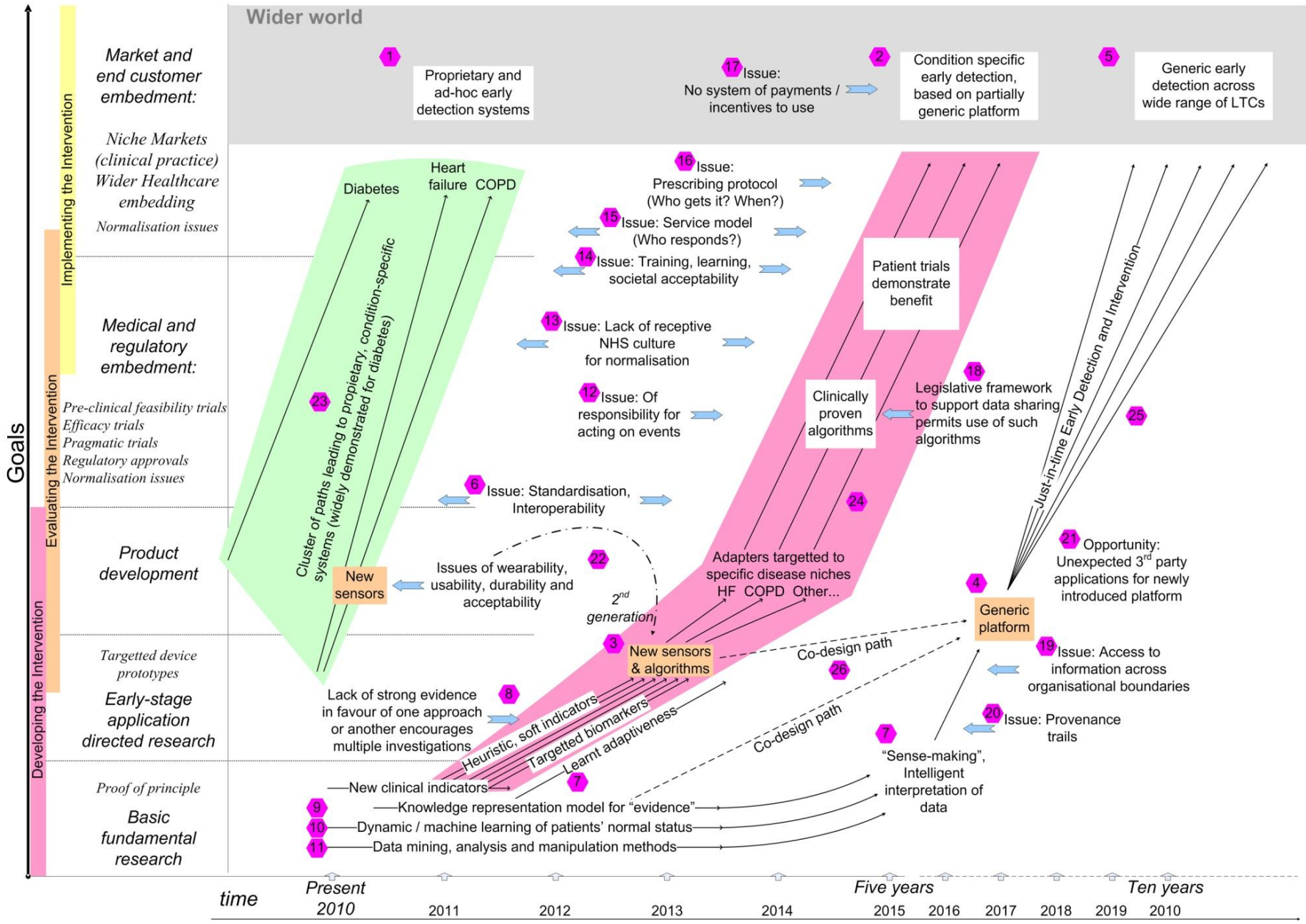
Identify key issues for different actors and how they interact

Plot impact pathways along with development pathways



See article **Robinson et al 2013 (forthcoming)**

Innovation and embedment pathways



PART VI

WRAPPING UP

In summary

The technology context and innovation context matters

- For nanotechnology, Impact pathways are varied:
  - Not only because nano enables innovation in a variety of ways and in a variety of sectors, but also
  - Impacts are co-produced and thus the way they will play out is dependent on this process

TA of the present and Anticipatory TA

- One can gauge impacts in the present by focusing on value-chains
- One can anticipate on impact pathways using insights from STS/innov. Studies with a focus on co-evolution of and co-production of impacts (We have suggested scenarios/workshops though there are other ways)

Returning to the challenge of indicators of impact:

- Exploring particular (families) of impact pathways allows on one to create bespoke indicators of impact – elicited through the FLA/TA process

An opportunity for FLA/TA combinations!!