

μ-Sapient

**Synergetic Process Integration for
Efficient Micro and Nano
Manufacture**



**MICRO AND NANO MANUFACTURING
FIRST STAGE ROADMAPPING
Deliverable 1.1**

FINAL REPORT

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15 June 2006

Revision: Draft

Start date of Project: 01 March 2006 Duration: 36 months

Project funded by the European Commission within the Sixth Framework Programme (2002-2006)		
Dissemination level		
PU	Public	
PP	Restricted to other programme participants (including the Commission Service)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	X
CO	Confidential, only for members of the consortium (excluding the Commission Services)	

1. Document Info

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1.2. Document History

Document version #	Date	Change
V0.1	10/06/06	Outline
V1.0	15/06/06	Re-formatted draft version

1.3. Document Data

Keywords	
Delivery date	15 June 2006

1.4. Distribution List

Date	Issue	Recipients

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2. Executive Summary

This document reports the outcomes from a twelve-week programme, as a precursor to the main body of μ-SAPIENT Workpackage 1 (WP1).

μ-SAPIENT WP1 comprises a set of activities aimed at developing a long term EU vision regarding micro- and nano- technologies (MNT) by performing sector and industry specific studies on MNT manufacturing technologies, manufacturing strategies, benchmarking and market analyses.

The precursor First Stage Roadmapping study reported in this document had the following objectives:

- To provide an early input to the EC for consideration in formulating the work programme for FP7
- In conjunction with partner organisations, to collate, generate and test the hierarchy and topics which will underpin the main roadmapping activities for the μ-SAPIENT project
- To ascertain the scale of data collection required in order to gain reliable information during the remainder of the μ-SAPIENT project
- To engage with other organisations and industry to seed the networking and information dissemination activities of the μ-SAPIENT project

The twelve-week study comprised a two-day inaugural workshop, followed by a period of development ahead of three facilitated data collection workshops at which 30 organisations and 35 participants from 9 European countries contributed:

- 105 views of how 14 MNT technologies will impact 14 market sectors
- 86 views regarding potential products using MNT across the 14 market sectors, and their technological content
- 126 proposals for projects, 62 regarding research into MNT equipment and 64 concerning research into MNT process technologies, all categorised within 23 technical areas and with an assessment of which market sectors they will support

All inputs were mapped against a year-by-year timeline stretching from 2006 to 2016 and beyond. In all, the 300+ entries provided some 15,000 data points, plus over 1,000 text descriptions, together providing a rich and detailed picture within a structured database which may be usefully analysed in many different ways.

A final dissemination workshop presented the results and prompted valuable discussion regarding the study's observations.

2.1. Contents of the report

This report describes the study in the context of the μ-SAPIENT project as a whole, details the methodology behind the study, summarises in graphical form the primary outcomes of the study, and tables initial observations and recommendations drawn from analysis of the information gathered.

3. μ-SAPIENT objectives

μ-SAPIENT aims to create a focused and sustainable European-wide infrastructure for the co-ordination of MNT research and dissemination activities, linking relevant national and international projects, organisations and initiatives to support critical EU market sectors by:

- Carrying out a critical analysis of emerging Micro and Nano Technologies (MNT) that result from many complementary EC, national and industrially funded Research and Development (R&D) projects.
- Identifying gaps in emerging MNT that prevent effective integration and up-scaling, thus assisting national and EC funding bodies in defining the priorities of their future R&D programmes
- Creating a forum for co-ordinating the efforts of many complementary R&D projects in ERA and in this way to ensure that technology and application challenges are addressed concurrently

A continuously updateable European MNT Roadmap - an MNT research plan backed by a business case for Europe - is a necessary underpinning feature of the project

3.1. μ-SAPIENT Work Description – Overview

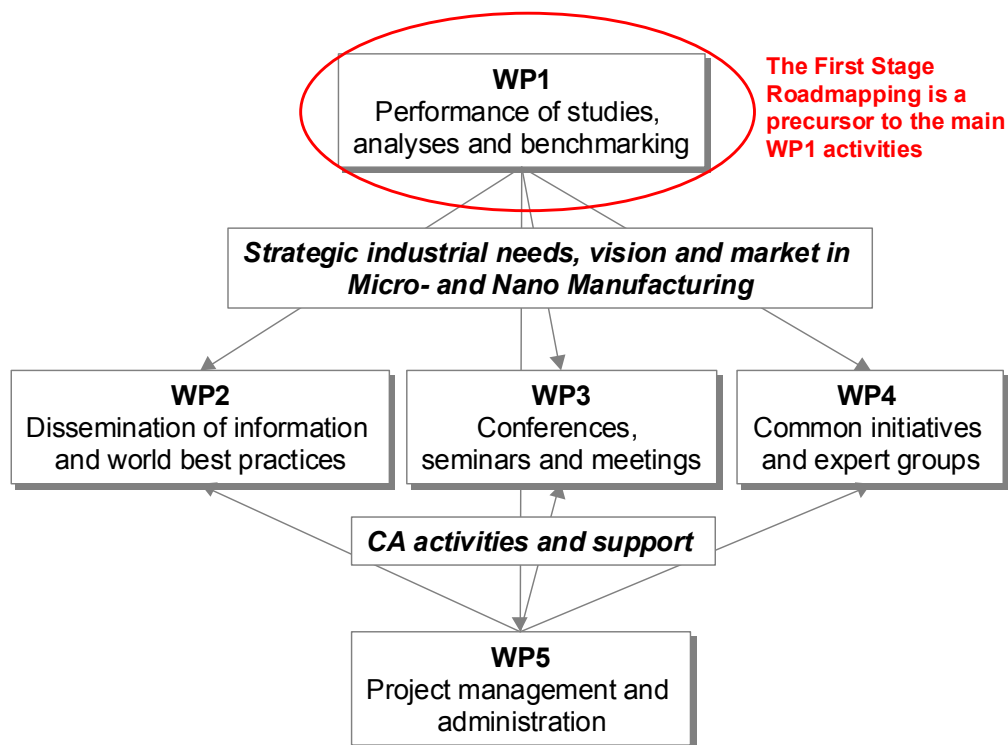


Figure 1: μ-SAPIENT Work Description – Overview

Overall, μ-SAPIENT provides support and coordination for performing a set of studies, surveys and benchmarking exercises by linking the related activities from different R&D projects and national and international initiatives.

The work will specifically focus on providing first-hand information to industry and support for R&D by producing a coherent long term vision for MNT manufacturing in Europe. New disruptive technologies with potential for changing the way different industries operate will be specifically monitored and their potential integration with existing or developing solutions will be monitored and analysed.

Specific benchmarking studies will be used to identify technology leaders and to set clear targets to achieve a higher level of maturity in currently developed MNT manufacturing technologies, whilst also providing the basis for accelerated adoption of the most promising disruptive technologies in the field by encouraging their synergistic integration.

The results of the studies and benchmarking activities will be used to provide the basis for setting a European wide community of best practice in MNT manufacture.

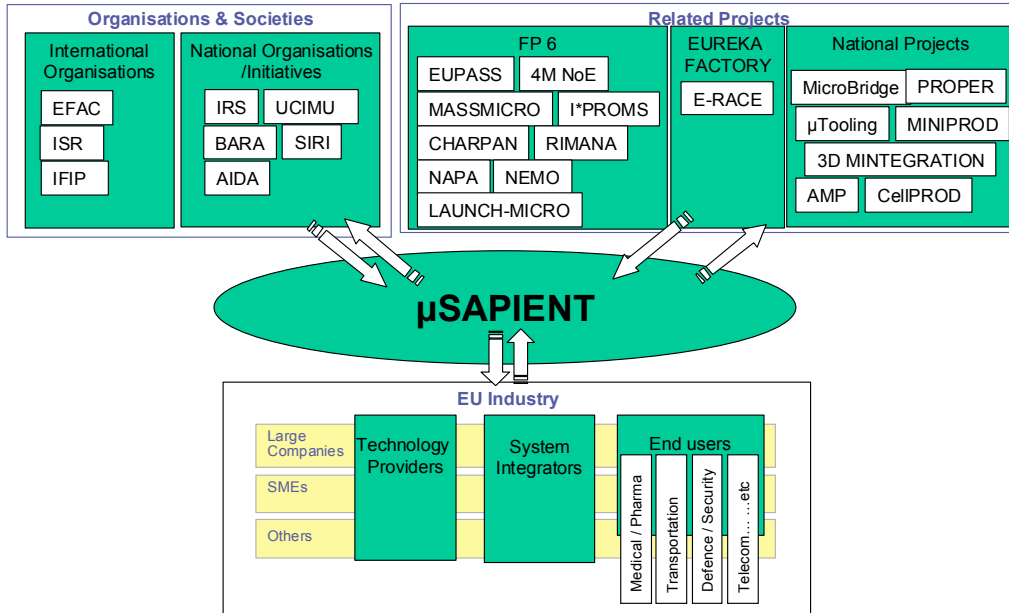


Figure 2: µ-SAPIENT Coordination strategy

3.2. Roadmapping timeline

Roadmapping will underpin the µ-SAPIENT programme for its duration. The First Stage roadmapping was executed early in the programme so as to collate, generate and test the hierarchy and topics for the main roadmapping activities.

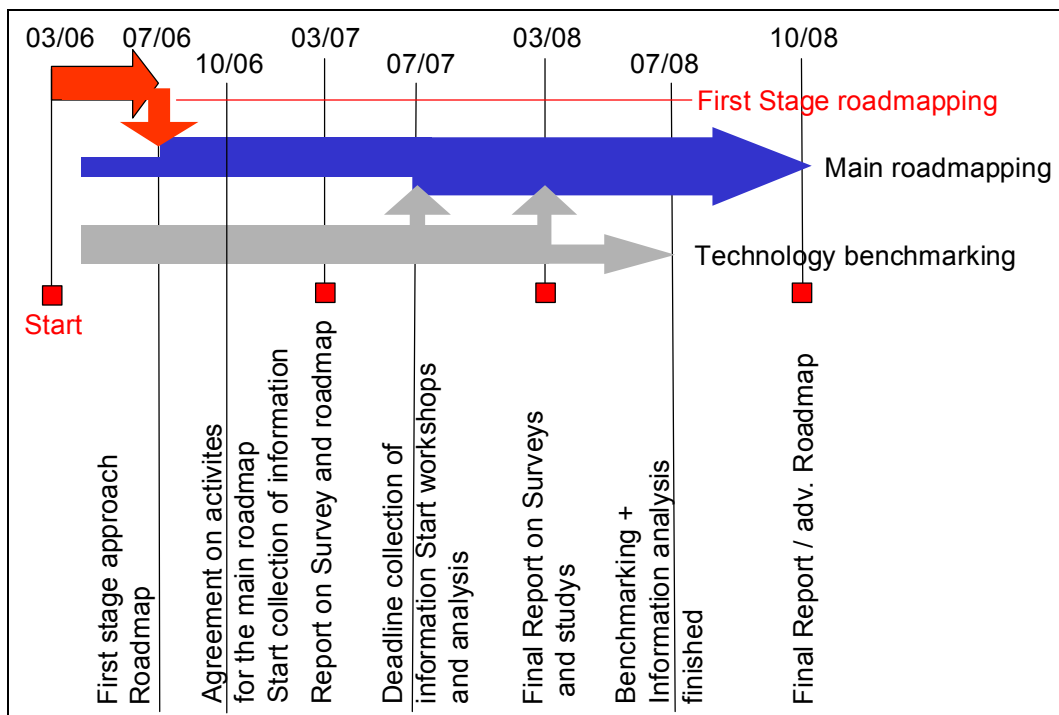


Figure 3: Roadmapping timeline

4. Methodology

A technology roadmap is a diagrammatic or textual representation of a future vision that describes technological capabilities, product requirements and timescales.

4.1. Initial consultation with stakeholders

One of the unique features of the μ-SAPIENT approach is the coordination of roadmapping activities between a number of major international and national projects as well as leading industrial partners in Europe.

Accordingly a two-day inaugural workshop was held on 8 and 9 March 2006 to discuss and agree the methodology for the First Stage roadmapping, and to ensure that the chosen path would:

- Allow a smooth transition to the longer-term roadmapping exercise
- Be compatible with the roadmapping activities of the partner organisations

4.2. Identifying the roadmapping tool and approach

Several roadmapping tools were identified and analysed. It was proposed that for the longer-term roadmapping a final selection will be made between the GMS and Geneva Strategist roadmapping tools.

For the First Stage roadmapping a flexible approach was adopted that would allow the rapid refinement that would be required during the abrupt early phase of the twelve-week programme. The approach was based upon:

- An Excel spreadsheet format that could be easily communicated throughout the stakeholder community
- Information capture through consistent input templates
- Emphasis put on traceable quantitative data that can stand analysis
- A series of three facilitated data collection workshops held at Eindhoven, Karlsruhe and Stansted
- Following analysis, summary information presented in graphical formats that encourage the recognising of patterns
- A final dissemination workshop at Schipol, inviting comment and discussion

3.3 The chosen hierarchy

Justifying an investment - plant, people, a research project, or even a whole research programme - should rest heavily upon a plan which puts forward a compelling economic argument within a described wider context which will make the investment an attractive and successful proposition.

The First Stage roadmapping work within μ-SAPIENT approached this justification by:

- Summarising the issues and timescales regarding the introduction and exploitation of MNT into different, quantified, market sectors
- Testing these issues through the suggesting of products benefiting or enabled by MNT, with estimates of their sales values and timing for introduction

- Assessing the MNT technologies that will predominate in each market sector
- Identifying and categorising the research that must be done to underpin economic development through MNT, with an estimate of timescales, costs and emphasis

The resulting comprehensive picture comprised:

- A top-level view of how and when MNT will penetrate and impact market sectors important to the EU
- Predictions of product developments - enhancements or entirely new products - that may be enabled by MNT
- Suggestions regarding the production equipment that will require development to make the products of the future become a reality
- Forecasts of the design and manufacture process technology that will need to be developed to underpin future products and markets

At a more detailed level, the hierarchy expanded to:

Market Predictions	Agriculture/Fisheries/Forestry Automotive/Transportation Clothing/Textiles Communications Computers/Business Construction Consumer/Entertainment	Energy/Water/Chemicals Food and Drink Medical/Pharmaceuticals Military/Aerospace Pollution control Security Other
Product Forecasts	Bio/Genetic Gas/chemical sensing Micro-acoustic Micro-electromechanical Micro-electronic Micro-fluidic Micro-magnetic	Micro-optic Micro-RF/microwave Nano-machines Nano-particles Nano-patterns Nano-surfaces Other
Production Equipment	Actuators and drives Biorobotics Cells Control and Vision Design & Simulation Energy beams High precision machine tools High precision linear stages Fixtures, Grippers, Feeders Imaging Micro factory	Moulds Nanofactory Nanorobotics Nanosensors Nanotooling Sensors System Integration Test,inspection,characterisation Tooling Other
Process Technology	Casting Etching Focused Ion Beam technologies Laser technology, additive Laser technology, subtractive Lithography Materials / Smart materials Metrology/Inspection Microfabrication Micro-growth Microforming	Micromachining Micro-surface processing Nano materials Nanocoating processes Nanoimprinting Nanoindentation/nanostructuring Nanointegration Packaging/Integration Printing Self-assembly Other

4.3. Data collection

Data was collected at three facilitated workshops. Input Templates were distributed in paper form for each level in the hierarchy, with mandatory fields indicated mainly as square tick-boxes (multiple selections) or round buttons (single selections).

Each input template also provided narrative fields for short explanations and discussion, space for document references or URLs to support the input and to provide background references for the subsequent more detailed μ-SAPIENT roadmapping.

This very structured approach of individual contributions eliminated the persuasion, lobbying and swaying of opinion that can produce bias in a workshop environment

The input templates were provided in the form of pre-printed A3-sized sheets, colour coded to aid in the rapid analysis of responses and in an overall format customised for each level of hierarchy.

The figure shows four overlapping input templates for data collection. The top template is for 'MARKET PREDICTIONS', the second for 'PRODUCT FORECASTS', the third for 'EQUIPMENT RESEARCH', and the bottom for 'PROCESS TECHNOLOGY RESEARCH'. Each template includes sections for 'ORIGIN OF INFORMATION', 'CURRENT WORK', 'TECHNOLOGY APPLICATION', and 'MARKET SECTORS'. The 'PROCESS TECHNOLOGY RESEARCH' template has a detailed 'PRIMARY CATEGORY' list with radio buttons and a 'PROJECTIONS' timeline at the bottom.

Figure 4: Input templates

4.4. Real-time data analysis

Immediate graphic feedback during each data workshop was a significant factor in motivating the delegates to provide rich research quantities of information. In particular, the timeline information built up an engaging picture of the take up of MNT in markets and products, and thereby the necessary requirements for research

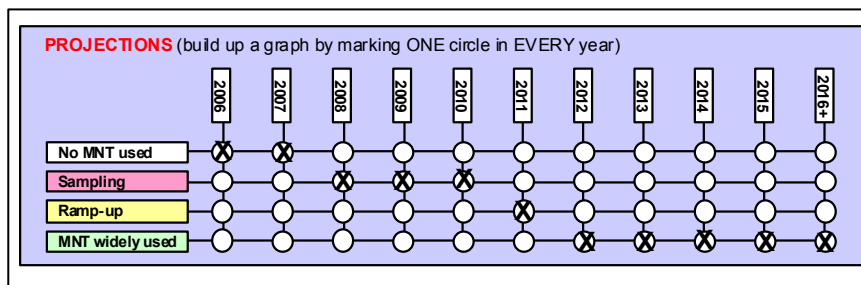


Figure 5: Timeline information panel

To the bottom-right of each template a timeline information panel allowed contributors to forecast stages of take-up for MNT.

Using coloured pens, the workshop facilitators were able to quickly encode this information on the bottom edge of each sheet as it was submitted:

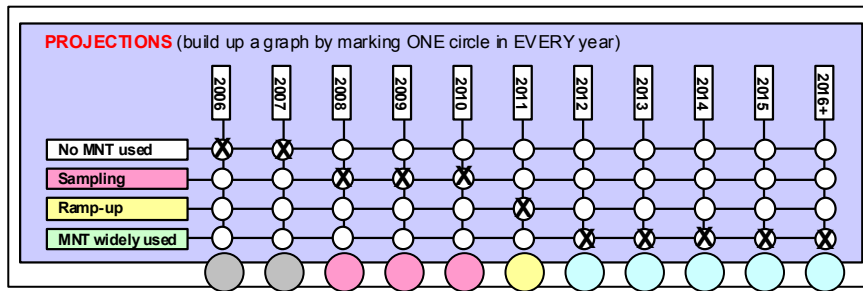


Figure 6: Timeline information panel - coded

Completed input template sheets were, along with their colour encoding, displayed in an overlapping fashion, from which it was immediately apparent to contributors that patterns and characteristics were emerging from the data submitted.

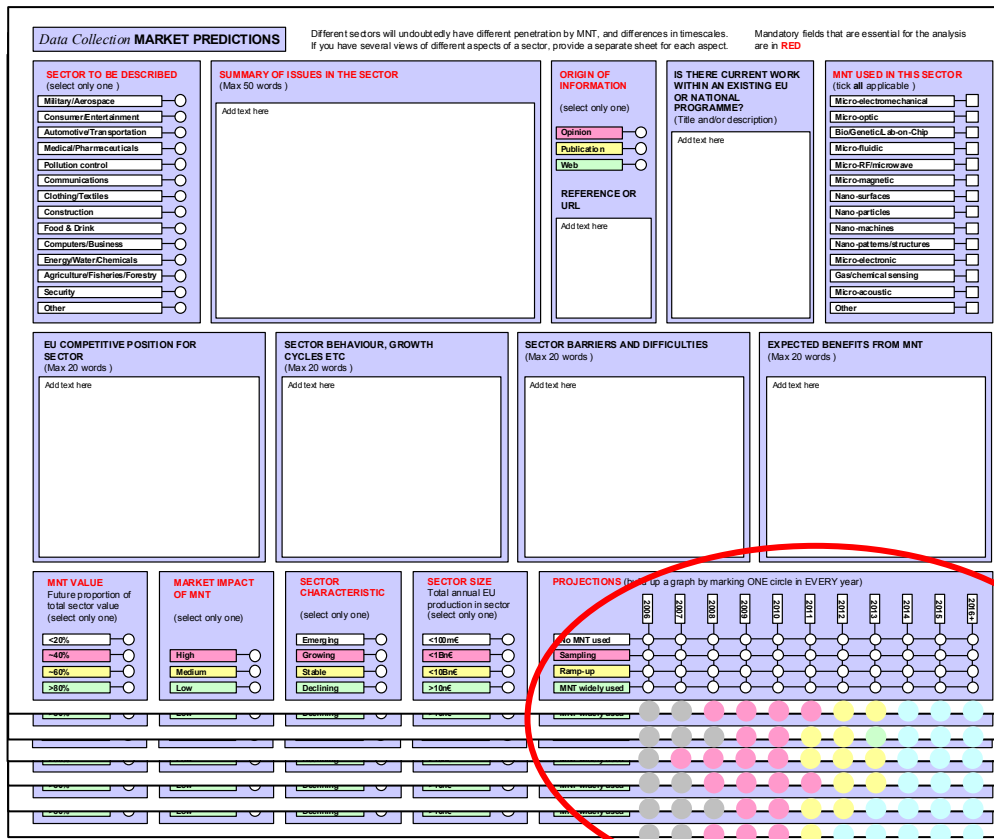


Figure 7: Stacked input templates

4.5. Subsequent data analysis

Following the three data collection workshops, the submitted input templates were transcribed into excel spreadsheet files. As the files were processed, in addition to the text fields, some fields were automatically colour-coded, allowing the very fast analysis that was needed to complete the project within the 12-week timeframe.

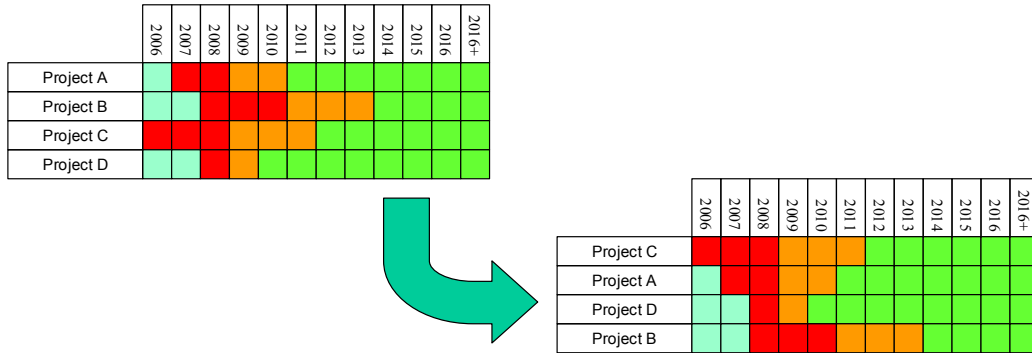


Figure 8: An illustration of one method of analysis

In practice the cells to be sorted also contain text information, which allows the analysis to be automated, but under the eye of the analyst.

The technique lends itself to subsequent visual presentation and discussion, as will be seen in the following sections of this report.

Furthermore, the “definition” of the resulting patterns can give confidence of the validity of the sample size and the consistency of the data. As an example:

(Projected market introduction of MNT)

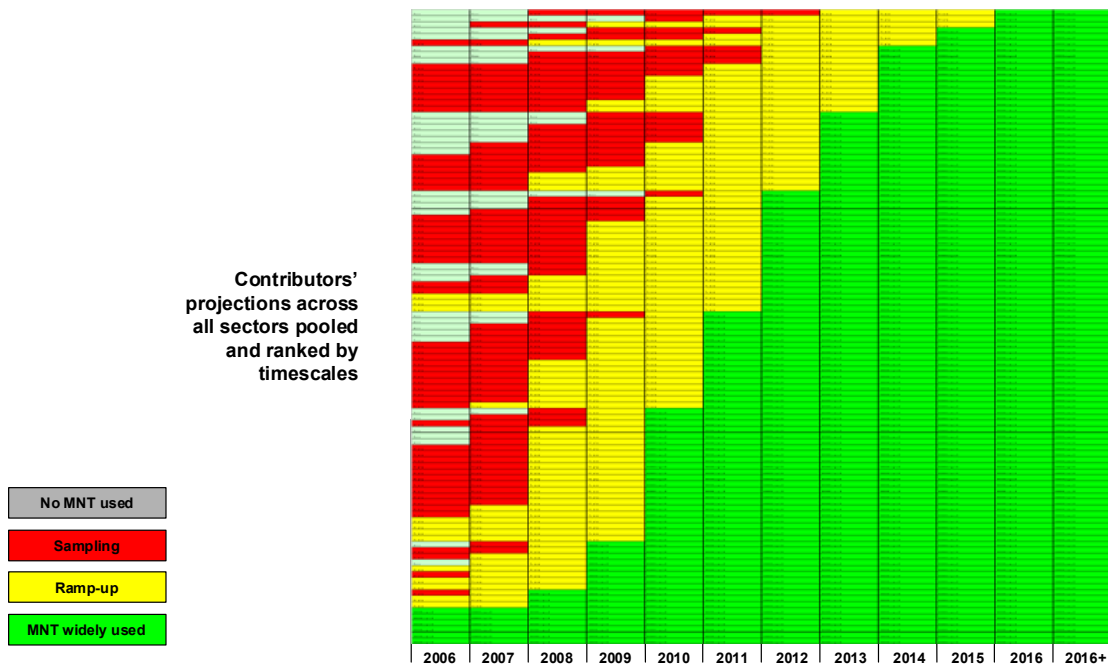


Figure 9: An example of timeline sorting

The above chart shows the progressive introduction of MNT into the market as distilled and ranked from 105 expert opinions. It shows a major move towards wide exploitation (green) starting in 2010; sampling periods (red) of typically 2 to 4 years, and ramp-up to production (yellow) taking of the order of 2 years.

- The well-characterised patterns in this diagram give good confidence that the underlying data gives a picture that would be unlikely to be better defined if the sample size were increased.

5. Market predictions

Contributors put forward 105 views regarding 14 Market sectors. The input templates used at the workshop sought:

- Coarse estimates of the market value of EU production in each sector and the proportion of this value represented by MNT
- Forecasts of the uptake of MNT in each sector over the period 2006 to 2016+
- An estimation of the MNT technologies that will predominate in each sector

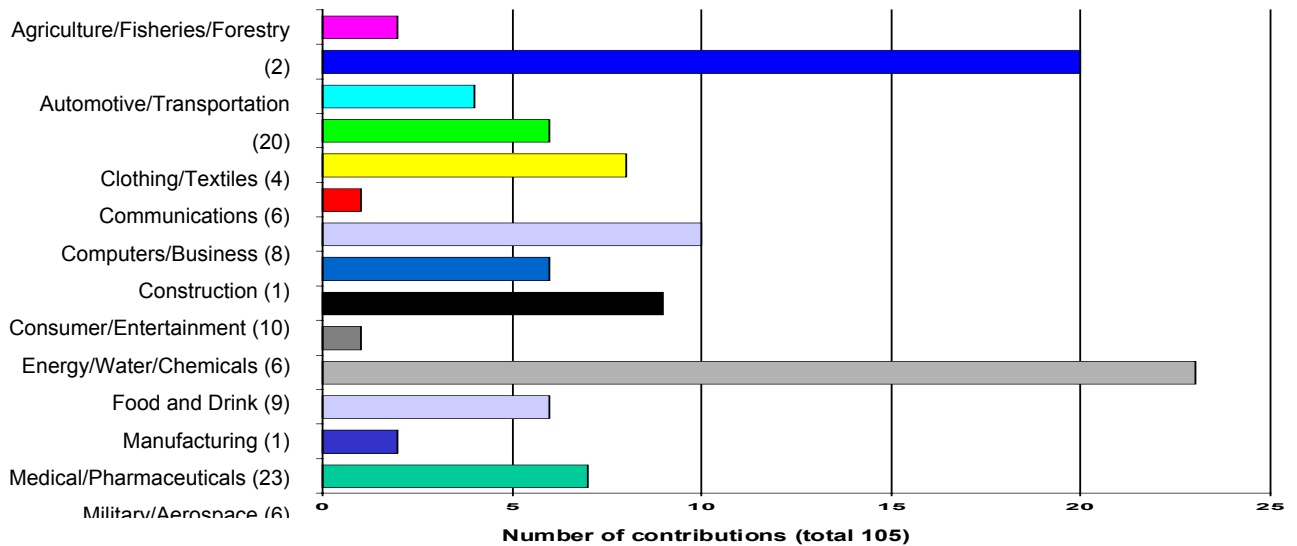


Figure 10: Market sectors commented upon

Observation 1:

Medical/Pharmaceuticals, Automotive/ Transportation and Consumer /Entertainment were front-running topics throughout the study

Recommendation 1:

Agriculture/Fisheries/Forestry, Construction, Manufacturing and Pollution Control drew too few responses for reliable data. The future comprehensive study needs to poll a larger (probably 5x larger) population to gain a dependable picture for these sectors

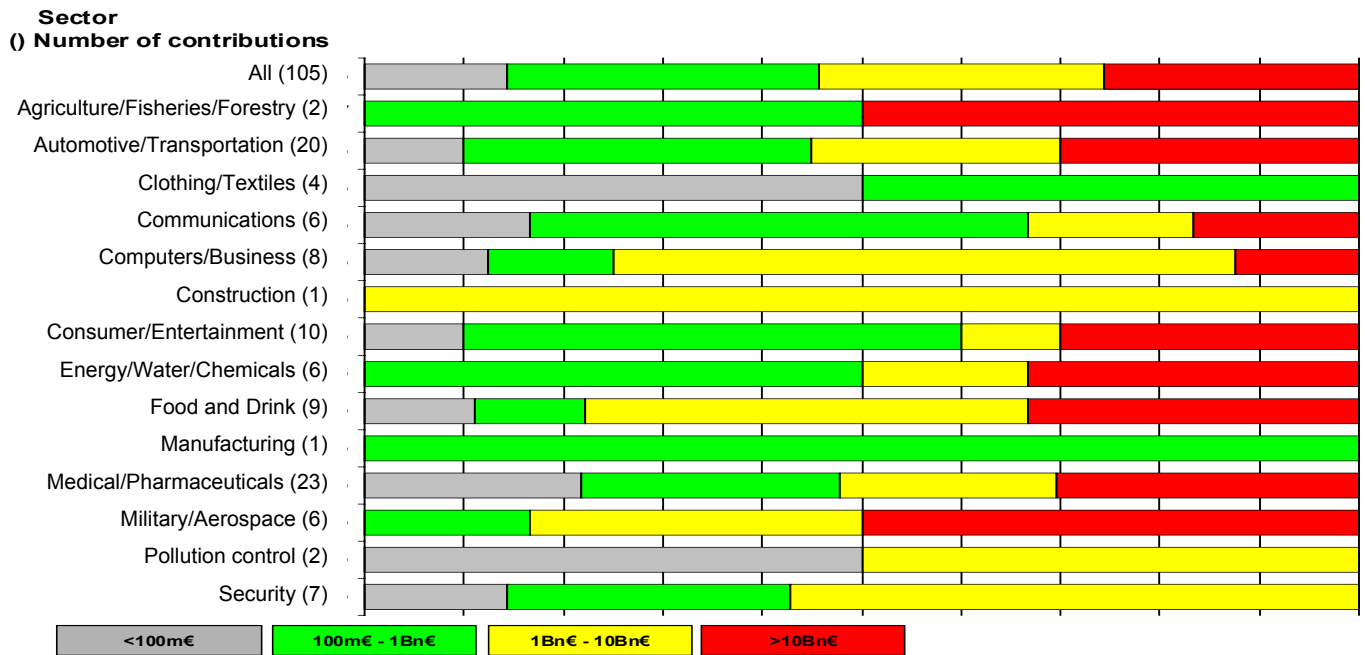


Figure 11: Views of sector sizes

Observation 2:

For the sectors described by an adequate number of people (ie., excluding Agriculture/Fisheries/Forestry, Construction, Manufacturing and Pollution Control) there is a scatter of opinion about sector sizes, possibly through respondents describing different aspects .

Recommendation 2:

Future roadmapping needs to investigate and delineate different aspects of each market sector, and understand the insertion of MNT into different levels within supply chains



Figure 12: Estimated MNT value as a proportion of total sector value

Observation 3:

For the sectors described by an adequate number of people, most predictions were for MNT value to be <40% of the total sector value

Recommendation 3:

Perceptions of MNT value as a proportion of total sector value are probably too high. This further indicates that future study needs to understand the insertion of MNT into supply chains

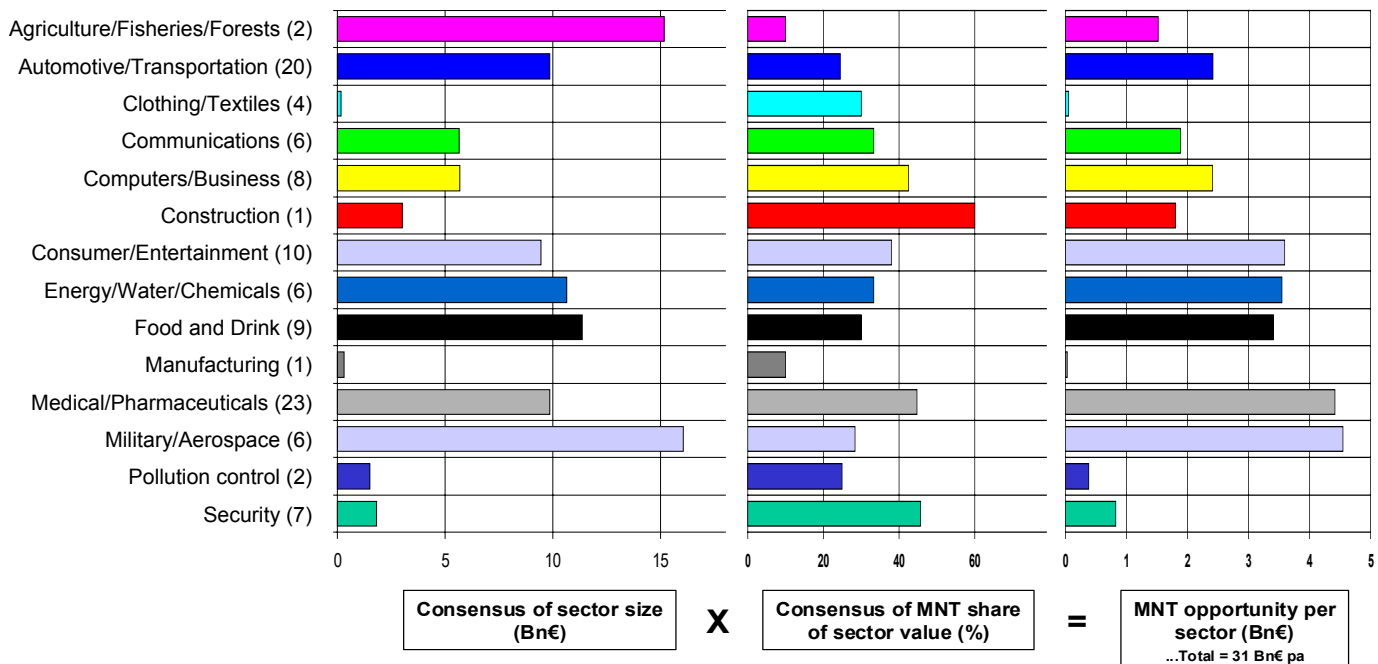


Figure 13: Comparison of the MNT opportunity per sector

Observation 4:

Figure 13 should be viewed with some caution. Firstly there is the caveat to exclude the data for Agriculture/Fisheries/Forestry, Construction, Manufacturing and Pollution Control, as there was insufficient response for the figures to be reliable, and secondly there are the discrepancies in views of sector size, and possibly an over-enthusiasm for the percentage value of introduced MNT.

Nevertheless, the MNT opportunity appears very significant in:

- Automotive/Transportation
- Communications
- Computers/Business
- Consumer/Entertainment
- Energy/Water/Chemicals
- Food and Drink
- Medical/Pharmaceuticals
- Military/Aerospace
- Security

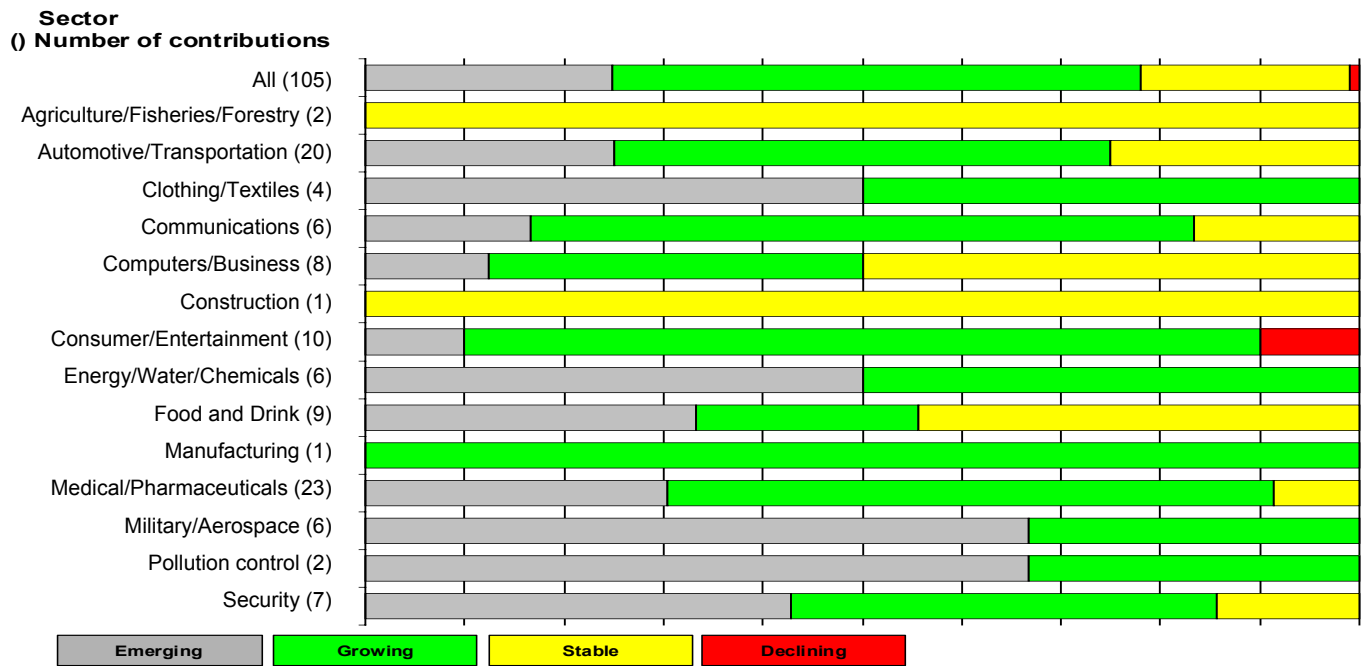


Figure 14: Sector characteristics

Observation 5:

Excluding the data for Agriculture/Fisheries/Forestry, Construction, Manufacturing and Pollution Control, as there was insufficient response for the figures to be reliable, a large proportion of correspondents describe the sectors as “emerging” or “growing”. A smaller proportion cites “stability”, and there was only one perception of “decline”.

Recommendation 4:

Future roadmapping needs to poll practitioners in each sector, who are more in touch with the characteristics of each sector.

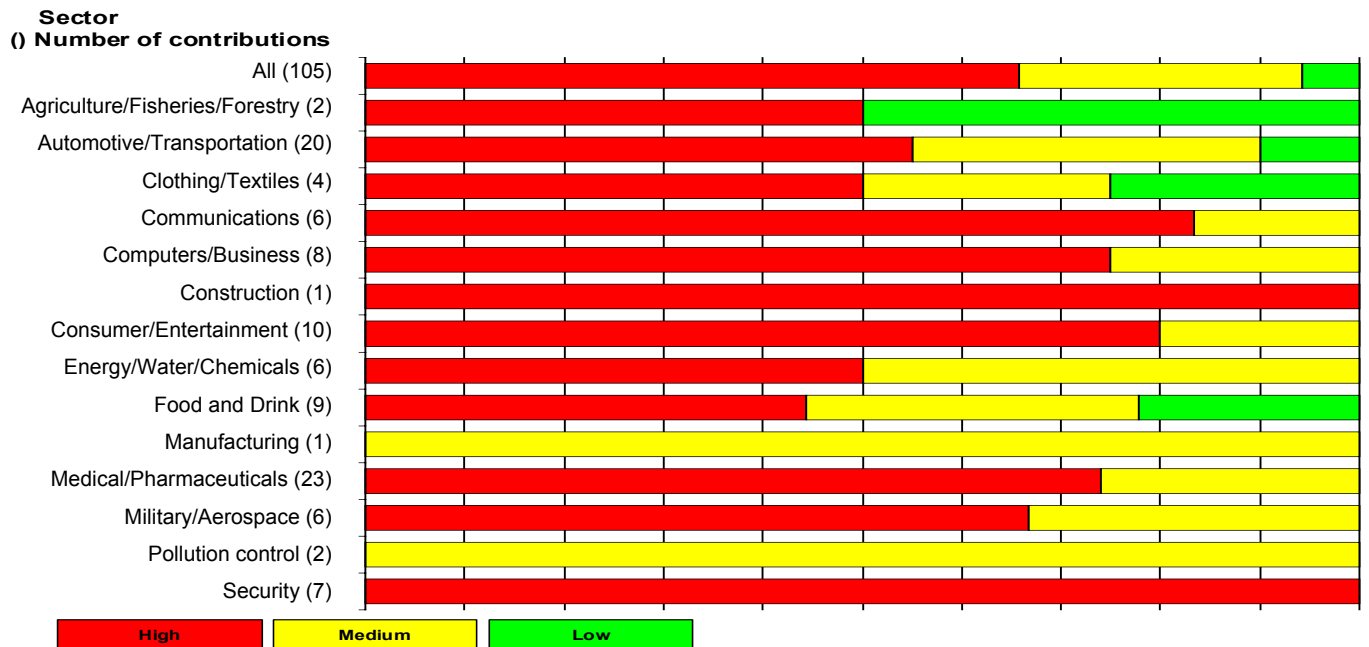


Figure 15: Market impact of MNT per sector

Observation 6:

Excluding the data for Agriculture/Fisheries/Forestry, Construction, Manufacturing and Pollution Control, as there was insufficient response for the figures to be reliable, a large proportion of correspondents describe the impact of MNT to be either “High” or “Medium”.

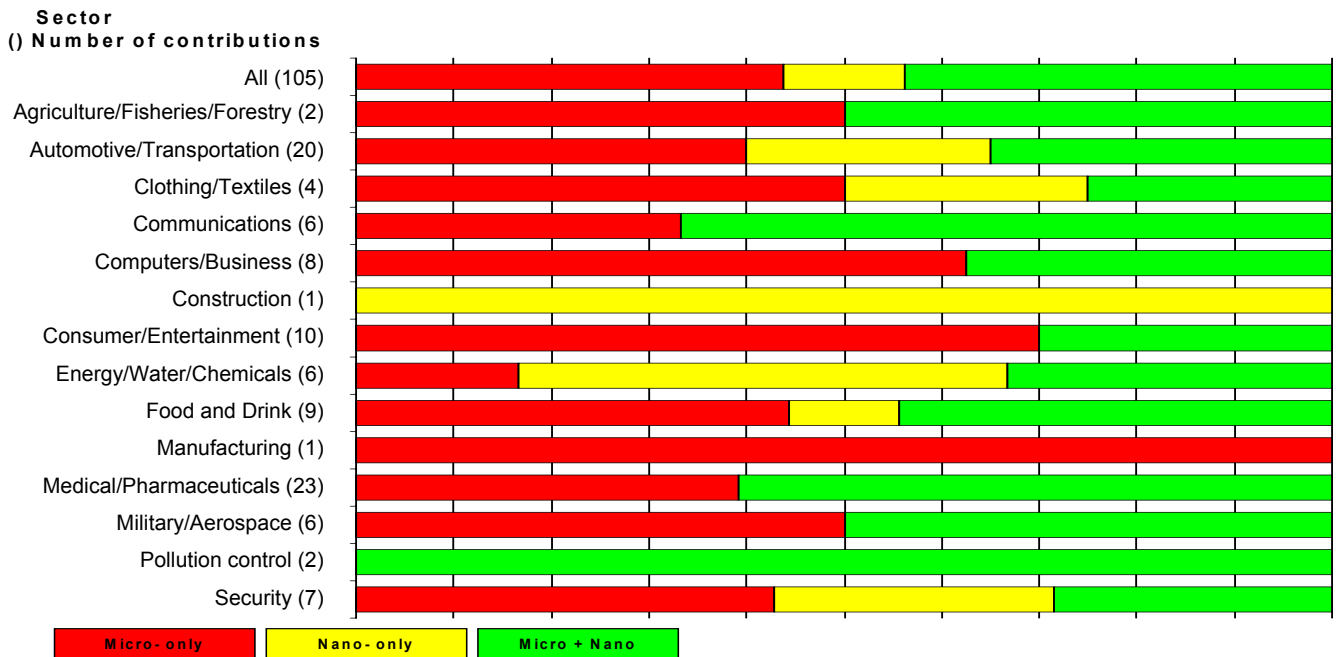


Figure 16: Comparison of uptake: Micro only / Nano only / Micro + Nano

Observation 7:

Excluding the data for Agriculture/Fisheries/Forestry, Construction, Manufacturing and Pollution Control, as there was insufficient response for the figures to be reliable, few respondents forecasted uptake of nanotechnology in its own right

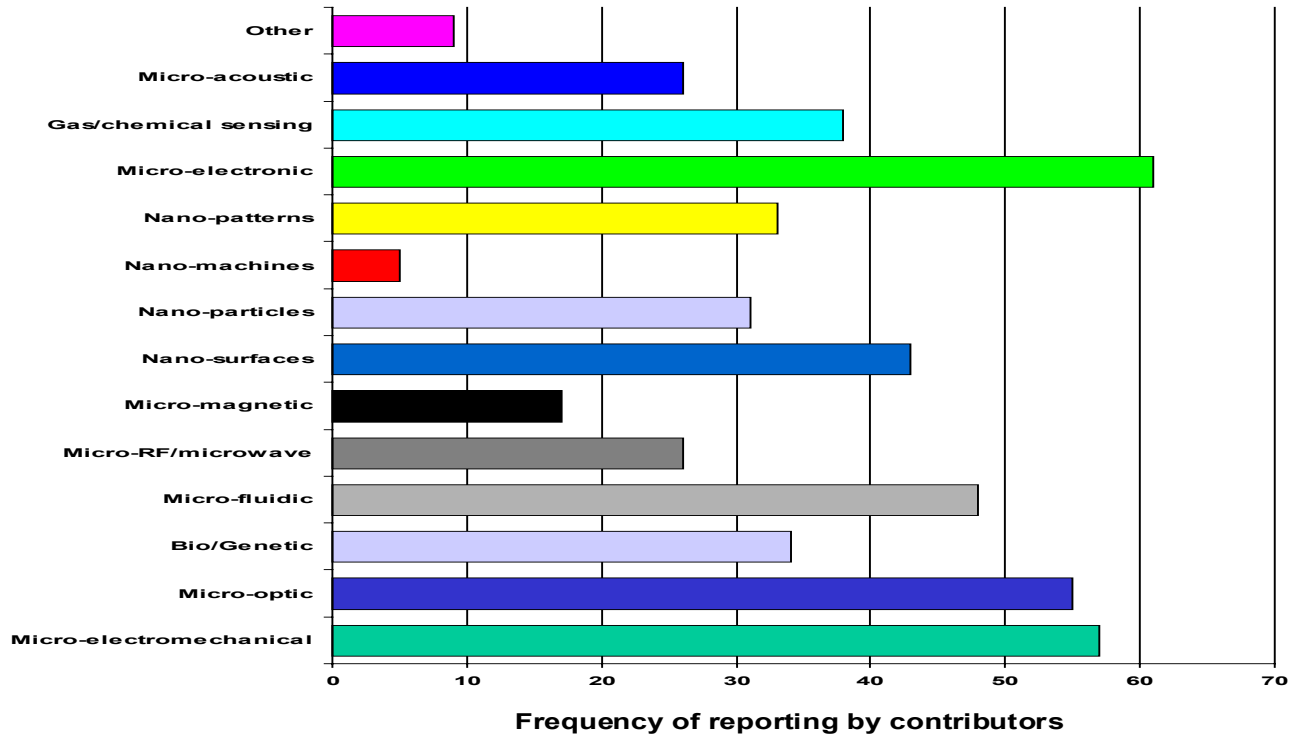


Figure 17: Projected market uptake of MNT categories

Observation 8:

The popularity of the front-running technologies is not surprising. Nanomachines are probably seen to be far in the future. Magnetics and RF/Microwave are important subjects, but perhaps reside in the minds of specialists.

Recommendation 5:

Future roadmapping needs to identify expert contributors regarding Magnetics and RF/Microwave

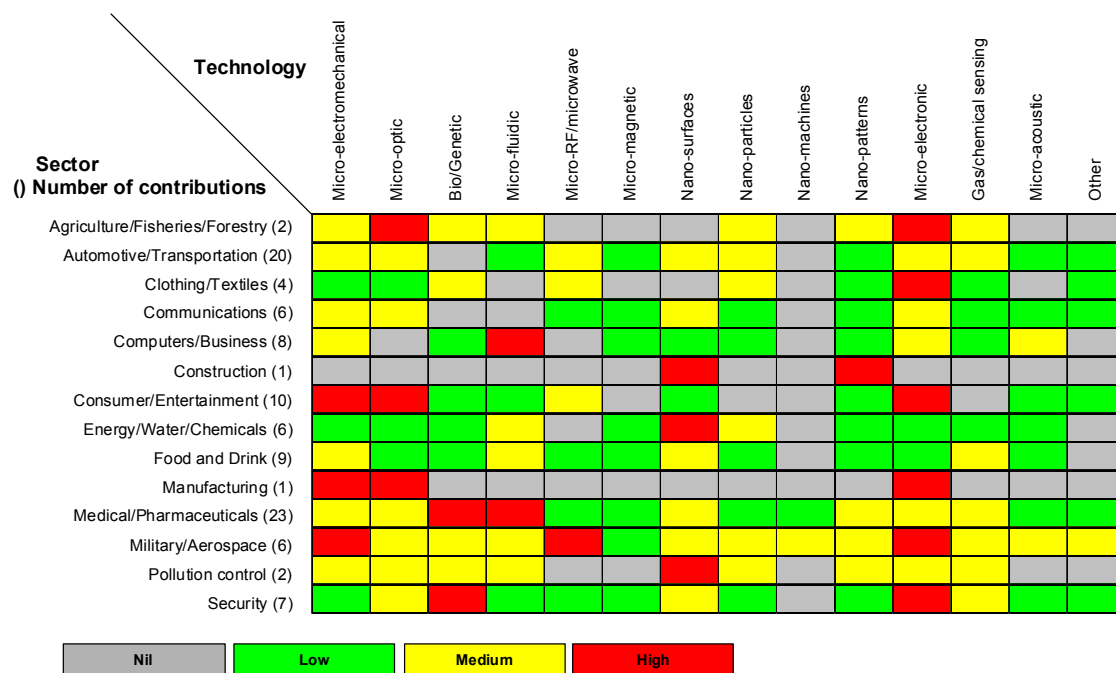


Figure 18: Projected use of MNT per sector (unsorted)

The preceding Figure 18 plots the projected use of MNT technologies against market sectors, categorised from "Nil" to "High" according to the relative frequency with which the technologies were cited by correspondents reporting each sector.

In its unsorted form Figure 18 reveals little, but sorting rows and columns to group the highest use of MNT technologies results in Figure 19, in which after sorting, a notional mask is placed over rows and columns containing 3 or more "Nil" uses of MNT

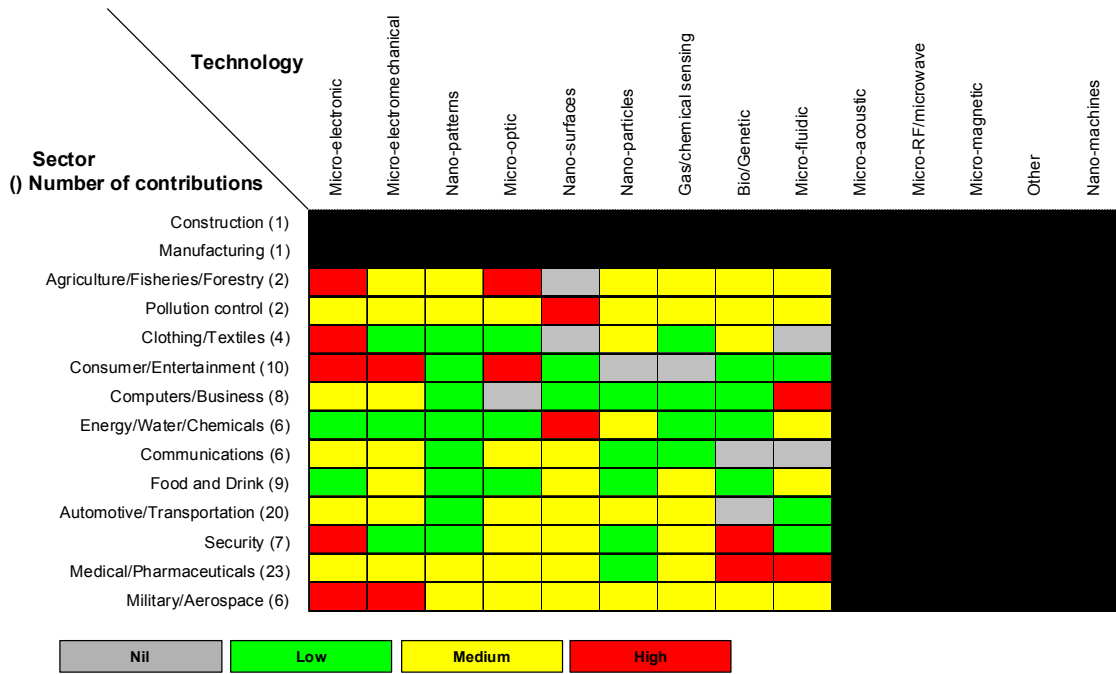


Figure 19: Projected use of MNT per sector (sorted)

Observation 9:

Construction and Manufacturing appear to be scant users of MNT, being reported in any case by only single correspondents. Micro-acoustic, RF/Microwave, Micro-magnetic and Nanomachines show as less popular technologies.

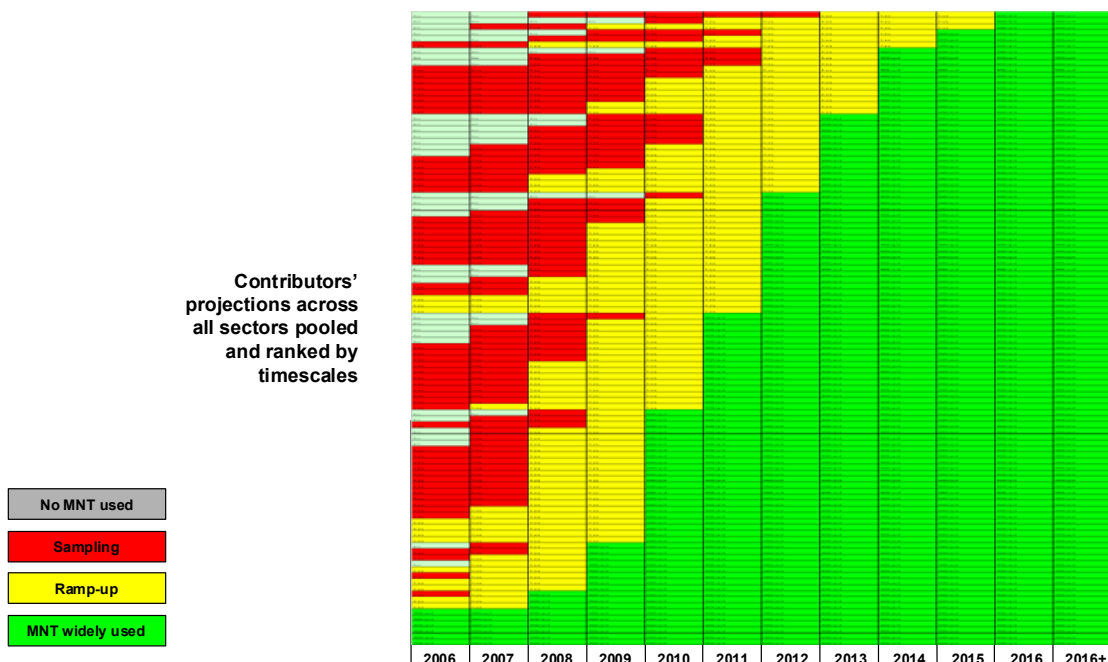


Figure 20: Projected market introduction of MNT

The preceding Figure 20 shows the progressive introduction of MNT into the market as distilled and ranked from 105 expert opinions. It shows a major move towards wide exploitation (green) starting in 2010; sampling periods (red) of typically 2 to 4 years, and ramp-up to production (yellow) taking of the order of 2 years.

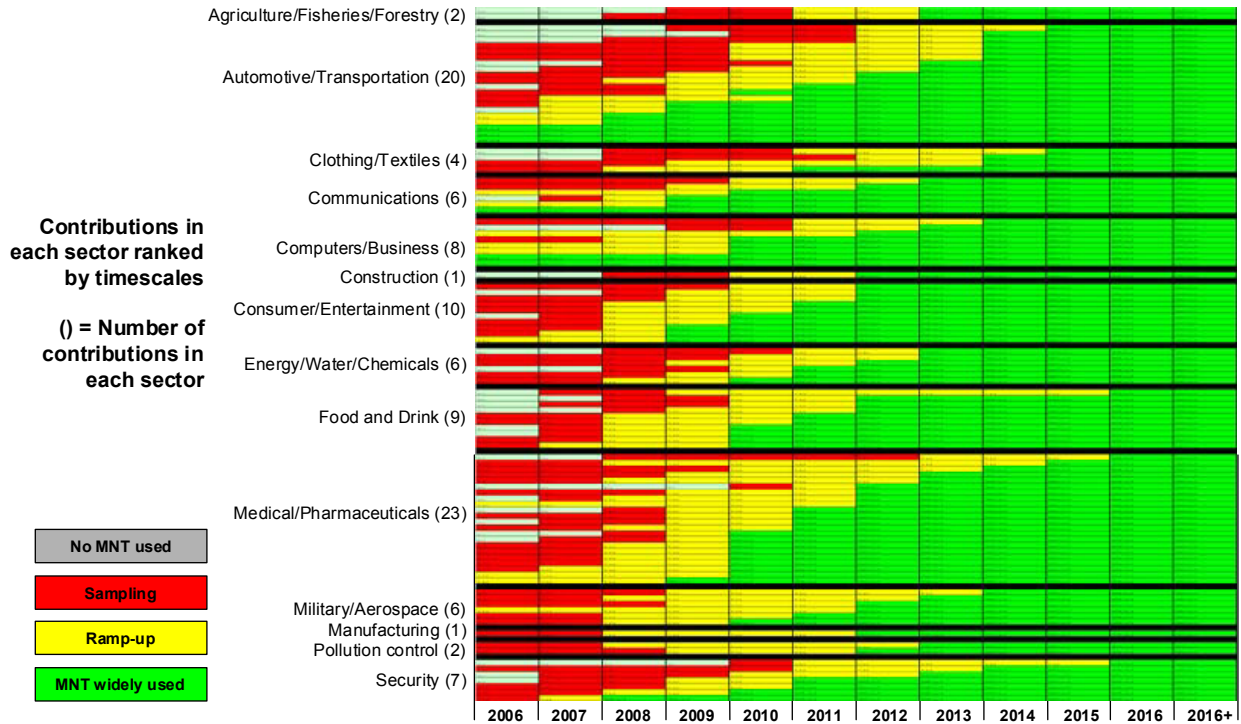


Figure 21: Projected market introduction of MNT per sector

Observation 10:

The Automotive/Transportation, Communications and Computers / Business sectors are clearly seen to lead in the adoption of MNT.

The Energy/Water/Chemicals and Food & Drink sectors display conservatism, whilst the Medical/Pharmaceuticals and Military/ Aerospace sectors are retarded by issues of standards and qualifications.

Security should be seen as an interesting emerging opportunity for MNT

6. Product forecasts

Contributors put forward 86 views regarding potential products using MNT across 14 market sectors. The input templates sought:

- Suggestions for product developments - enhancements or entirely new products - that may be enabled by MNT
- Coarse estimates of the market value of EU production for each product and the proportion of this value represented by MNT
- Forecasts of the uptake of each product over the period 2006 to 2016+
- A description of the MNT technologies that will be used in each product
- A view of the market sector or sectors in which each product will be sold

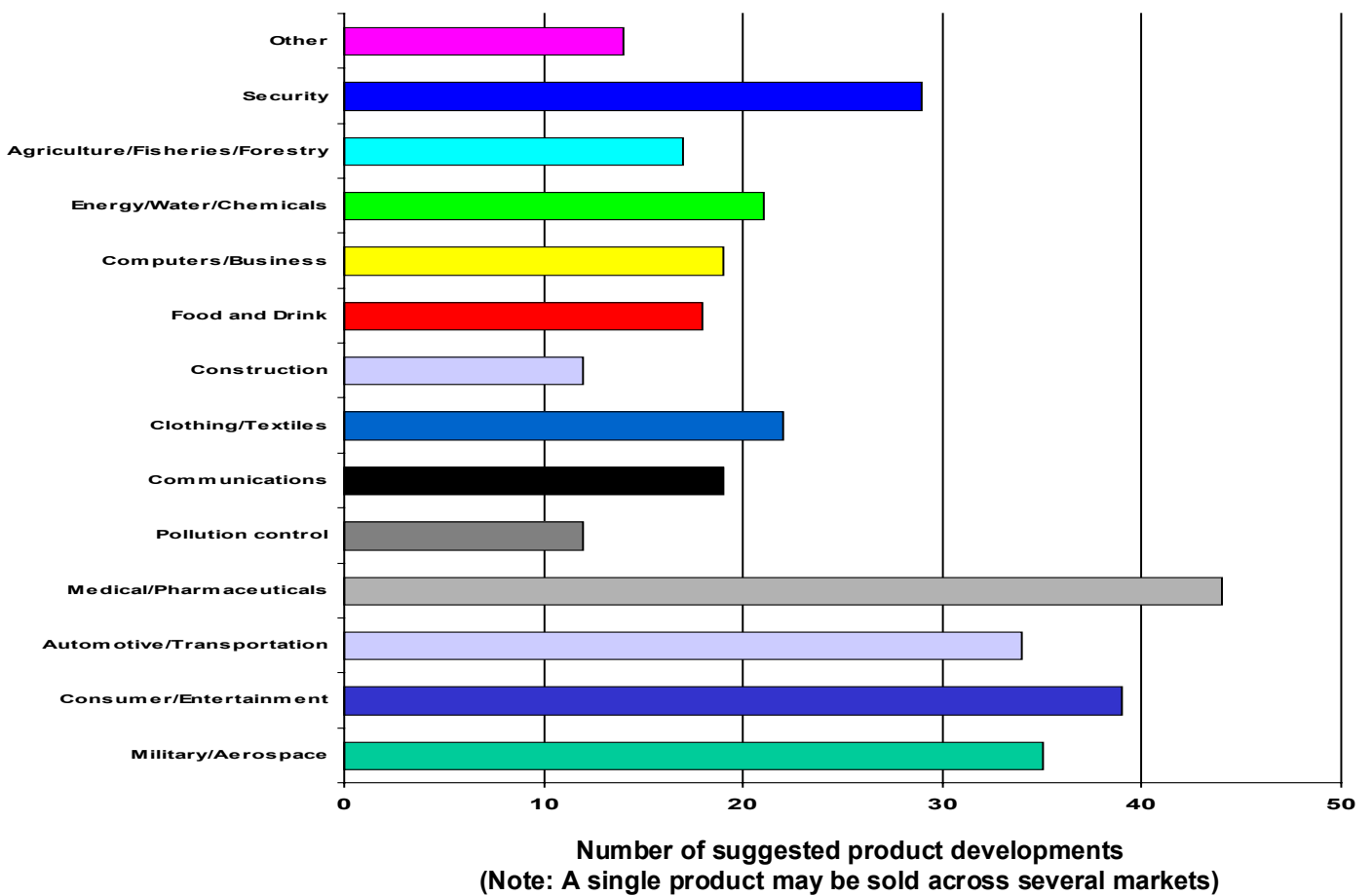


Figure 22: Product suggestions: Target markets

Observation 11:

Medical/Pharmaceuticals, Automotive/ Transportation and Consumer /Entertainment are front-running topics throughout the study, but for product introduction these sectors are joined by military/aerospace and security

Recommendation 6:

The five sectors: Medical/Pharmaceuticals, Automotive/ Transportation, Consumer/Entertainment, Military/aerospace and Security, plus perhaps Communications, are candidates for special interest groups and focused workshops involving sector practitioners as the µ-SAPIENT programme progresses

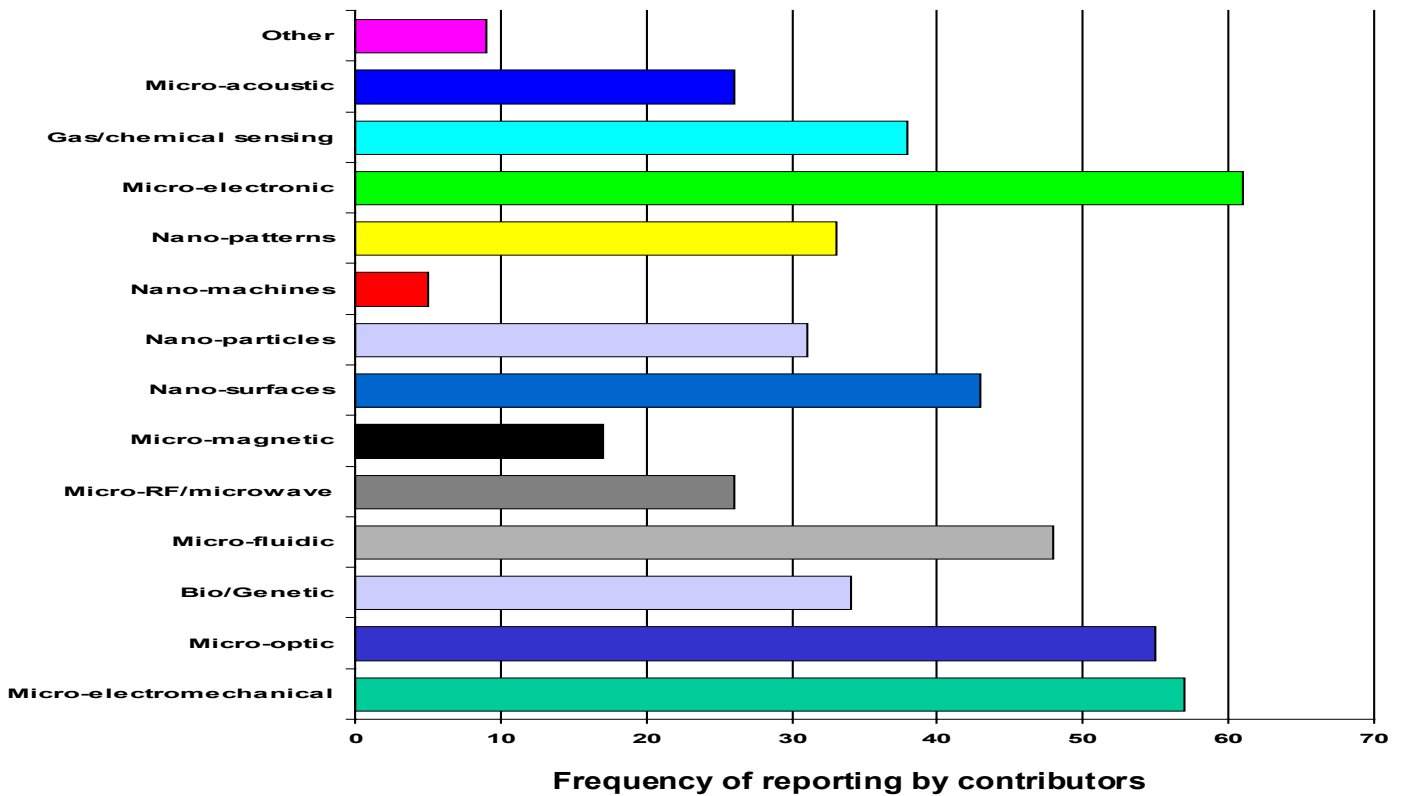


Figure 23: Product suggestions: technology content

Observations and recommendations for Figure 23 are in line with those for Figure 17:

Observation 8:

The popularity of the front-running technologies is not surprising. Nanomachines are probably seen to be far in the future. Magnetics and RF/Microwave are important subjects, but perhaps reside in the minds of specialists.

Recommendation 5:

Future roadmapping needs to identify expert contributors regarding Magnetics and RF/Microwave

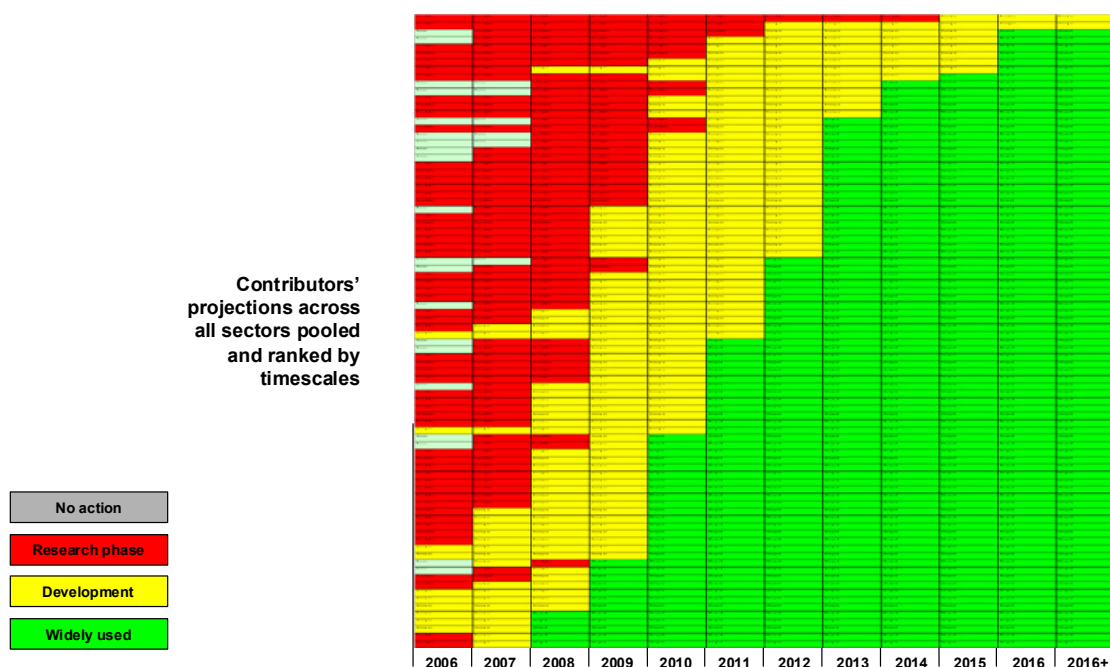


Figure 24: Projected introduction of new products using MNT

The preceding Figure 24 shows the progressive introduction of products using MNT as distilled and ranked from 86 expert opinions. It shows a major move towards wide use (green) starting in 2010 and jumping again in 2012; research phases (red) of typically 2 to 4 years, and development (yellow) of generally 3 years.

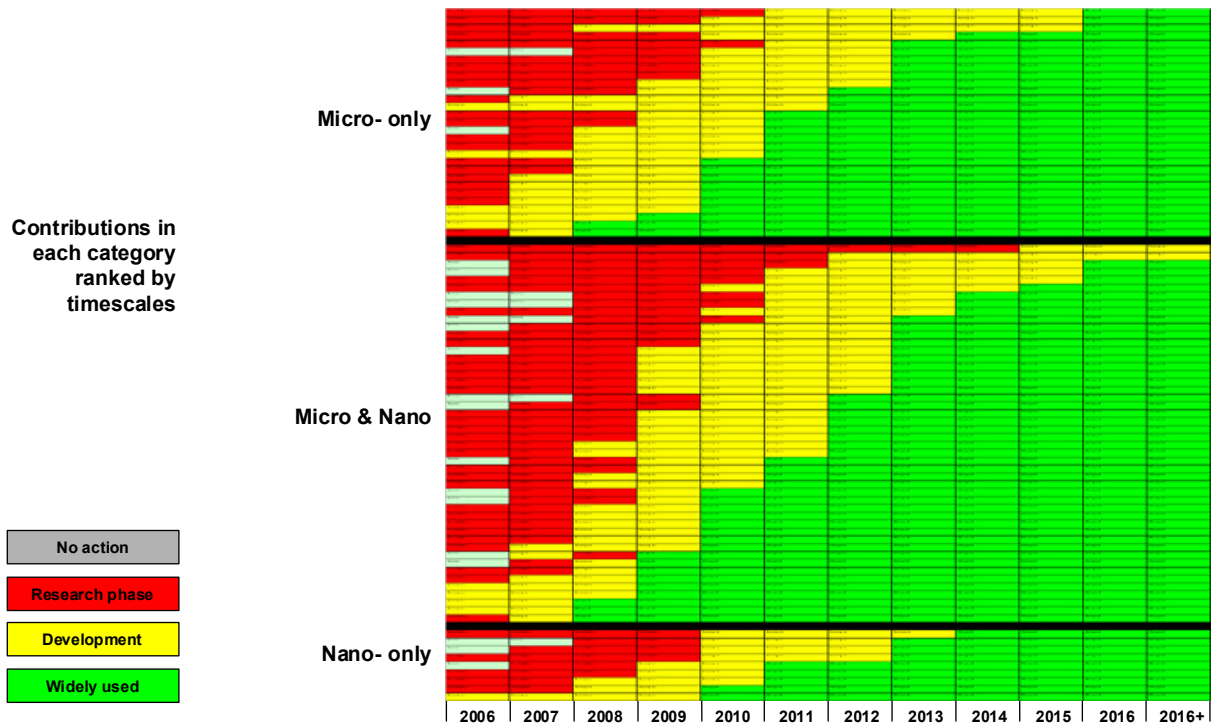


Figure 25: Projected introduction of new products using: Micro- only /Micro + Nano / Nano- only

Observation 12:

There are fewer forecasts of the introduction of products purely dependent upon nanotechnology, and the timescale is some 2 years retarded compared with products using fuller categories of MNT

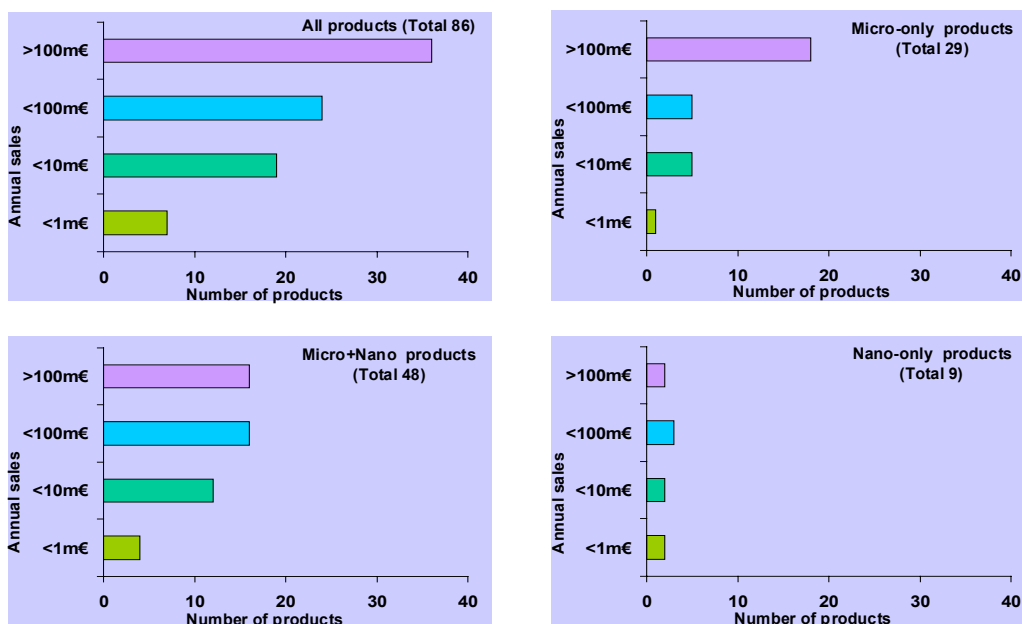


Figure 26: Projected sales value of Micro+Nano, Micro- only and Nano- only products

Observation 13:

Products combining Micro- and Nano- technologies have good sales prospects

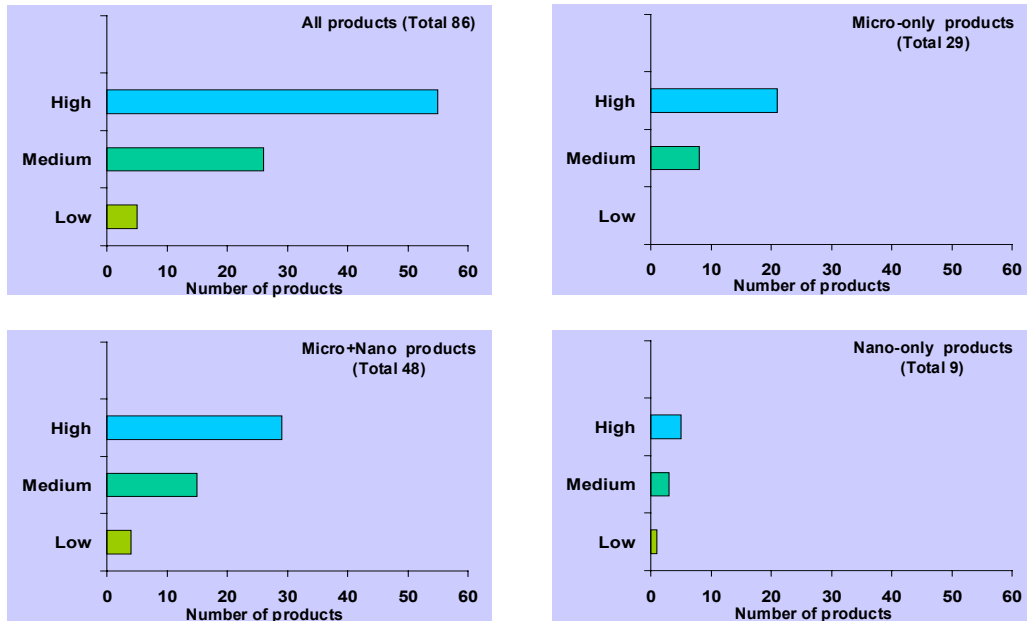


Figure 27: New products using MNT - predicted market impact

Observation 14:

Products using MNT are predicted to mainly have high market impact

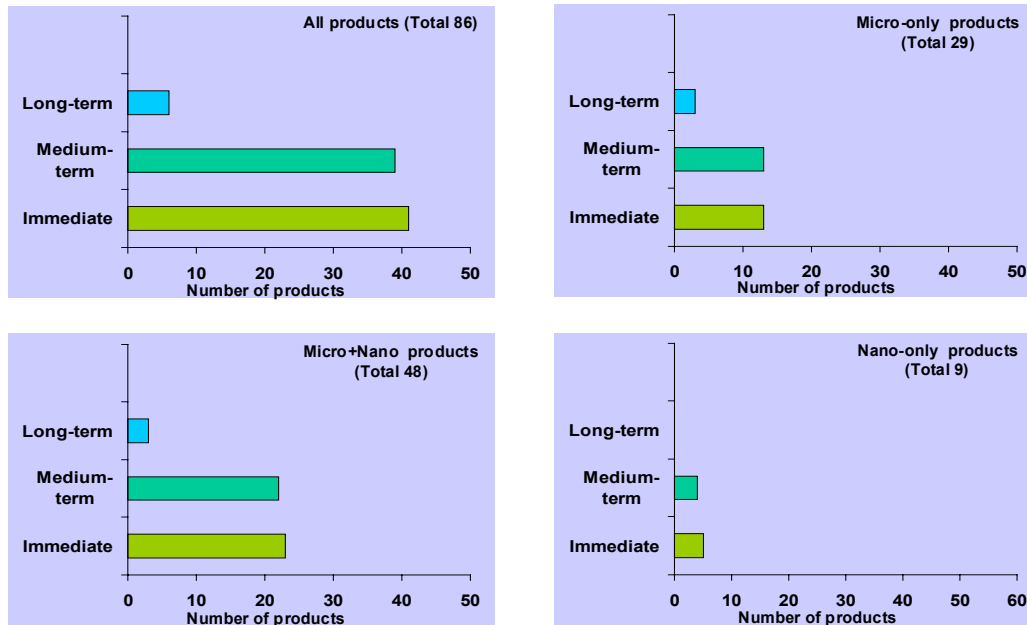


Figure 28: New products using MNT - urgency for introduction

Observation 15:

Products using MNT are predicted to be needed in the short-to-medium term.

This bias of timing, which seems at odds with the timescales indicated in Figure 24, could stem from the views of companies who would be unlikely to contemplate product introduction plans not leading to wide exploitation in advance of 4 years.

Recommendation 7:

µ-SAPIENT needs to counsel industrialists and researchers alike on the practicalities of MNT product introduction, to avoid the pitfalls of over-optimistic planning

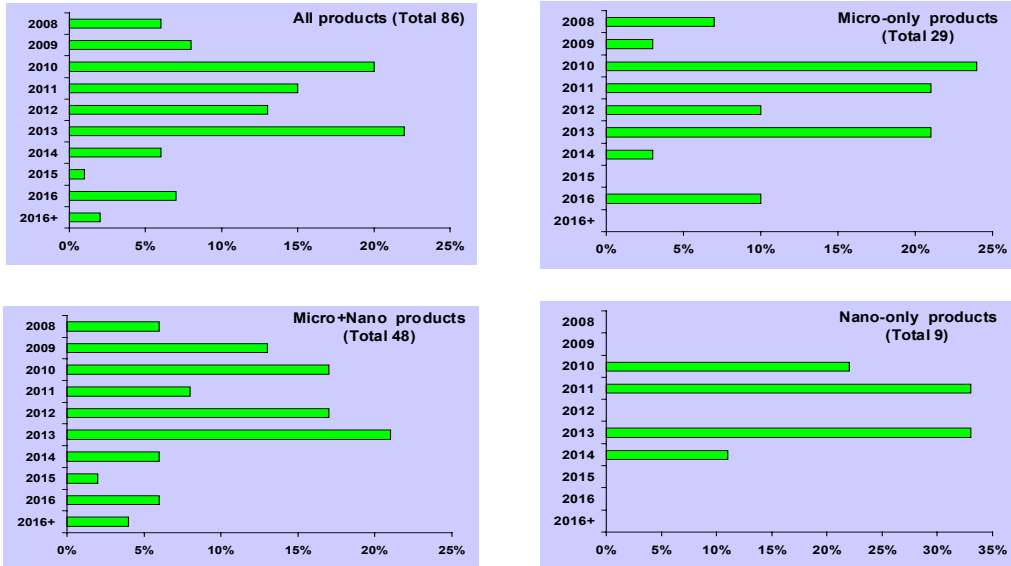


Figure 29: New products - distribution of estimated time to market

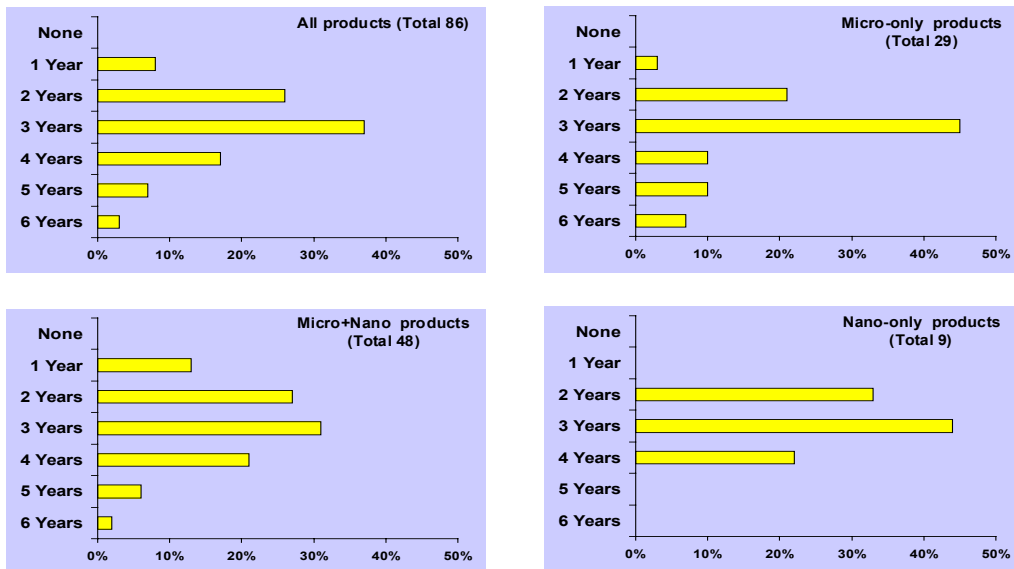


Figure 30: New products - distribution of estimated duration for development phases

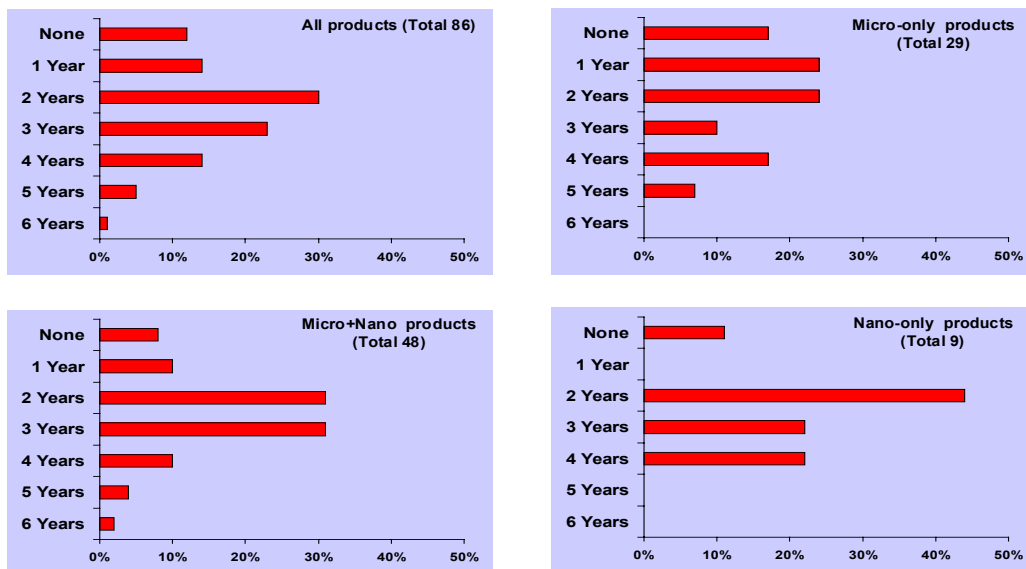


Figure 31: New products - distribution of estimated duration for research phases

7. Research potential

Contributors put forward 126 project proposals, 62 regarding research into MNT equipment and 64 concerning research into MNT process technologies. The input templates sought:

- Suggestions for projects to develop MNT production assembly and test equipment
- The technologies that will be applied as a result of the research and the market sectors that will be supported
- An idea of the budget required for the topic, and the research phasing over the period 2006 to 2016+
- Whether each suggested research project is “necessary”, “enabling” or “speculative”, whether it is short, medium or long term, and to gauge the level of its market impact
- Coarse estimates of the market value of EU production for each product and the proportion of this value represented by MNT

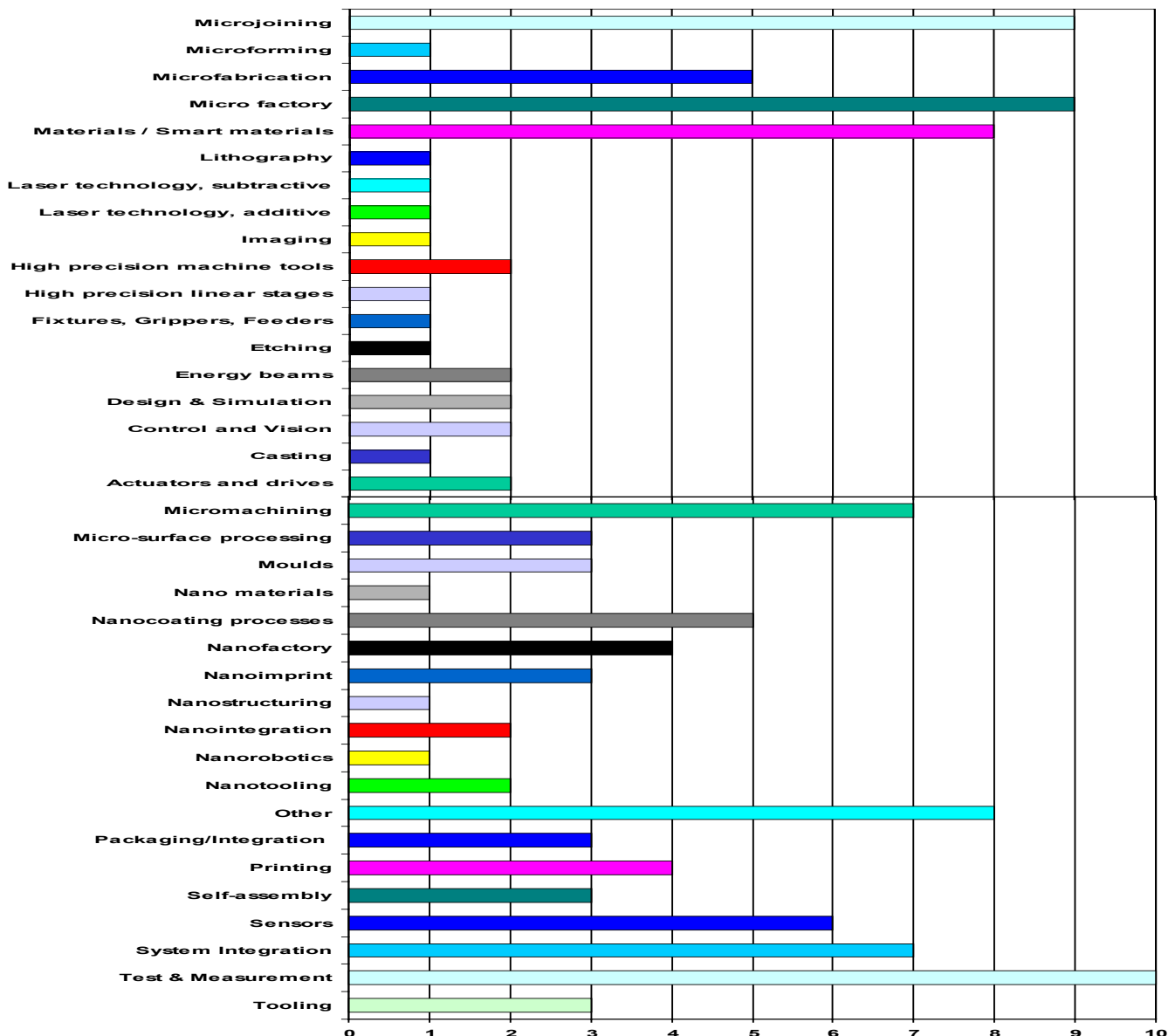


Figure 32: Sample research projects: Frequency of primary topics from 126 suggested projects

Observation 16:

Except for the widely-defined topics, primary interests appear to be spread very evenly.

The most popular candidates for research were shown as:
 Microjoining
 Microfabrication
 Microfactory
 Materials/Smart Materials
 Micromachining
 Nanocoating
 Sensors
 System Integration
 Test & Measurement

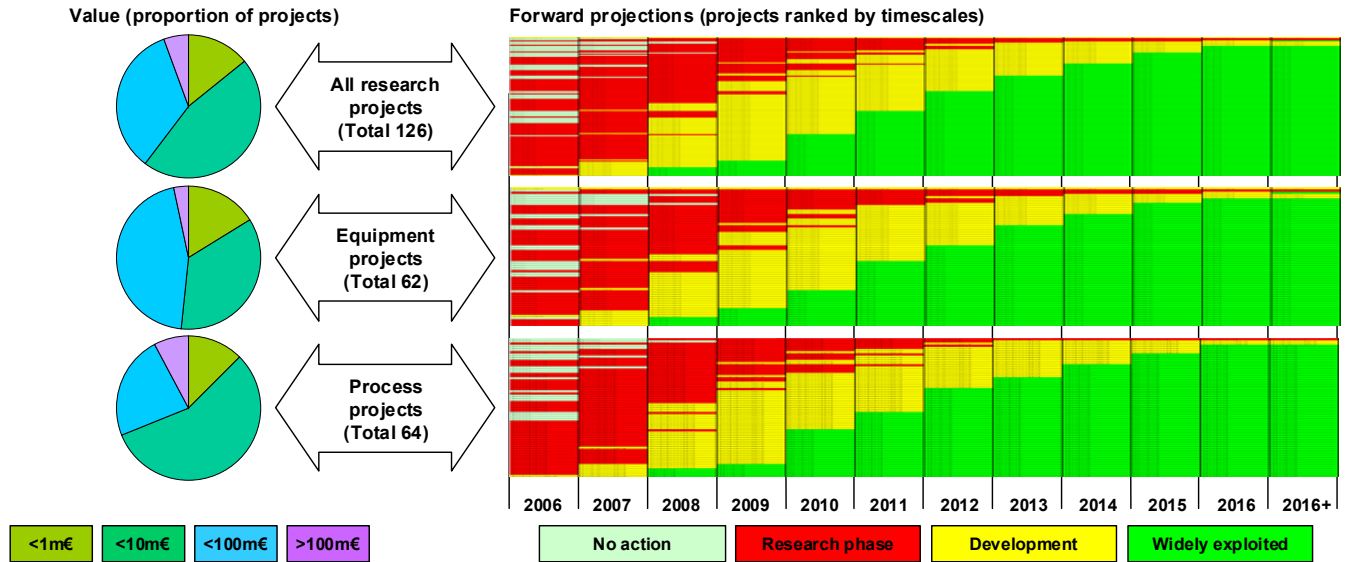


Figure 33: Research projects - cost and time comparison of Equipment vs Process project proposals

Observation 17:

Equipment projects slightly lead process projects in time, expectedly?

Observation 18:

On balance, equipment projects cost slightly more than the average for all projects, process projects slightly less.

Observation 19:

In the main, the cost and time characteristics of equipment and process development projects are broadly similar

- At the outset of, and during, the First Stage roadmapping programme there was some doubt that process research can be truly independent from equipment research
- The analysis of questionnaires showed that the cost and time characteristics of both process and equipment research are broadly similar
- Moreover, the suggested primary research topics were spread fairly evenly across process and equipment research proposals
- Accordingly, for the remainder of the analysis, process and equipment research were combined as a single data set

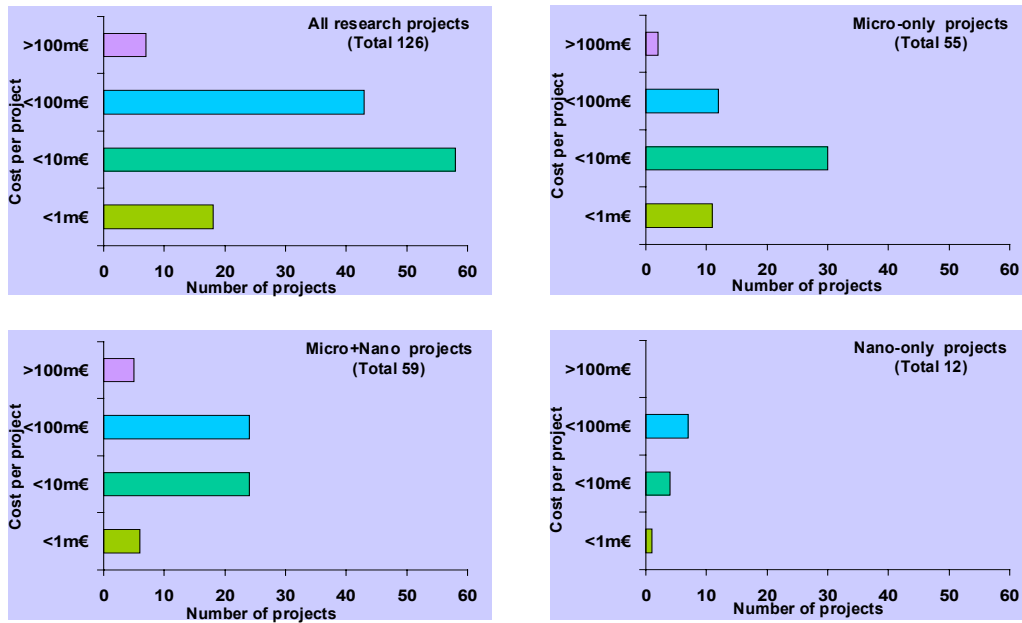


Figure 34: Research projects - cost distribution of Micro+Nano, Micro- only and Nano- only proposals

Observation 20:

Project scale was suggested to be predominantly in the range 1m€ - 100m€

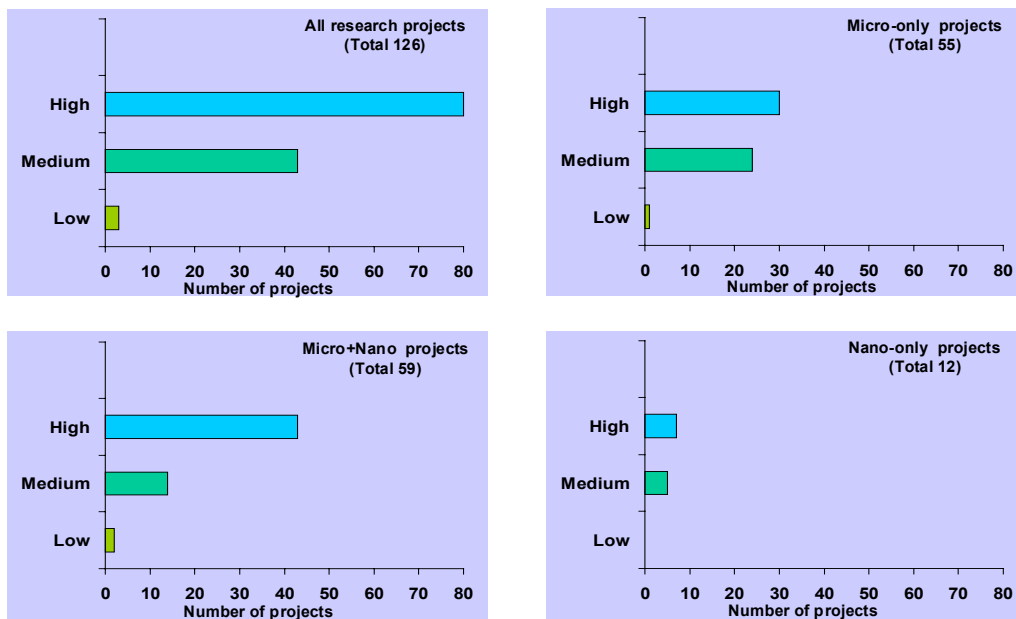


Figure 35: Research projects - predicted market impact

Observation 21:

Market impact is consistent with that predicted in Figure 27, which concerns the market impact foreseen for new products based upon MNT

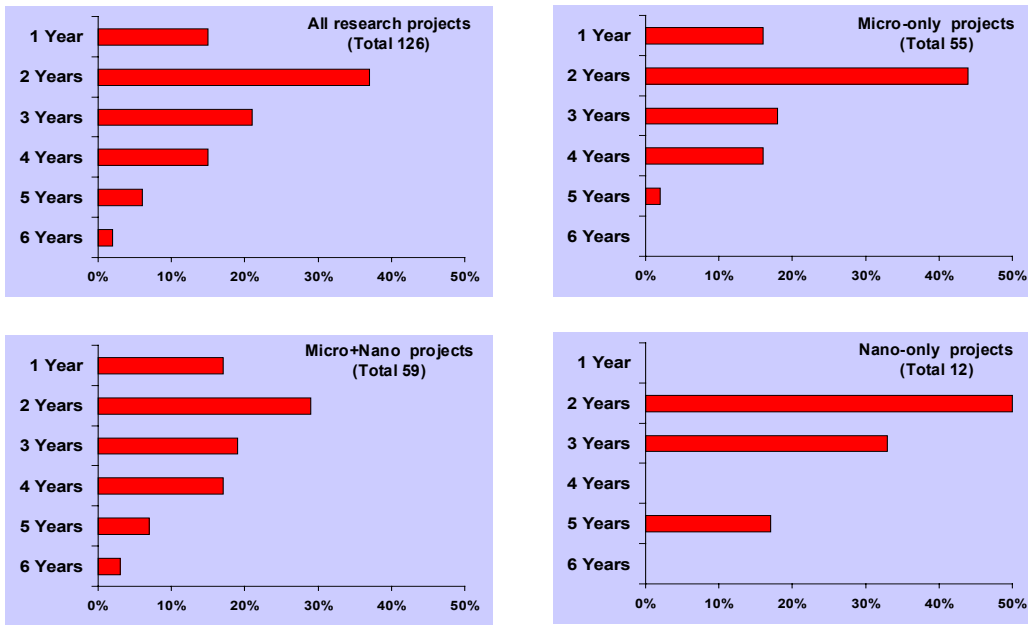


Figure 36: Research projects - distribution of estimated duration

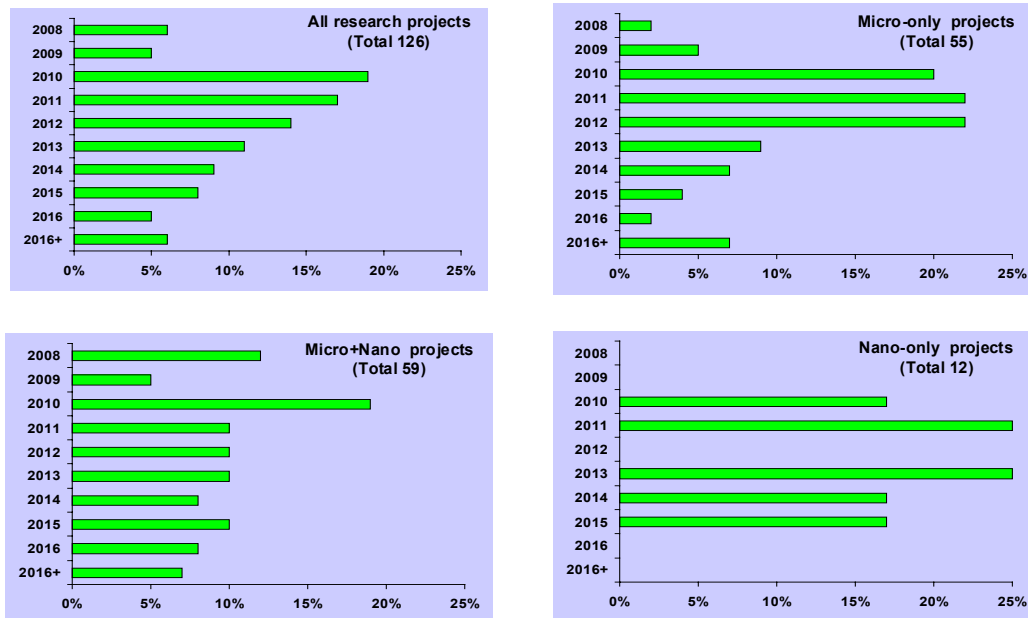


Figure 37: Research projects - distribution of estimated time to market

Observation 22:

The low number of responses putting forward nano- only research projects has lead to patchy data. It does however seem reasonable, by comparing the data to the whole MNT population, that nano- only research projects will follow the duration distribution (mainly 2 to 3 years) for MNT projects as a whole, and that the time to market will lag MNT as a whole by about 2 years

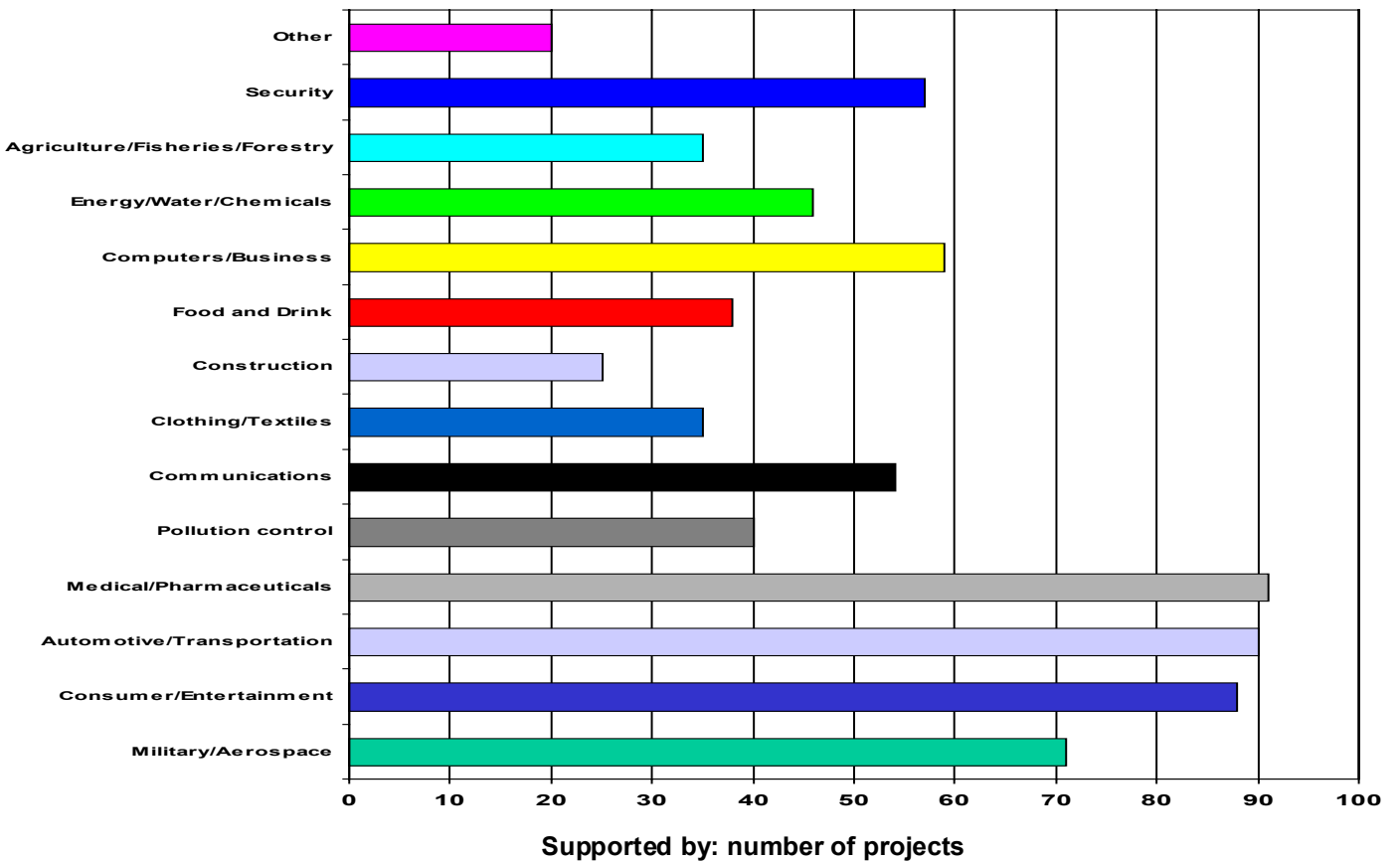


Figure 38: Research projects - market sectors supported

The sector support profile research matches that for product development as illustrated in

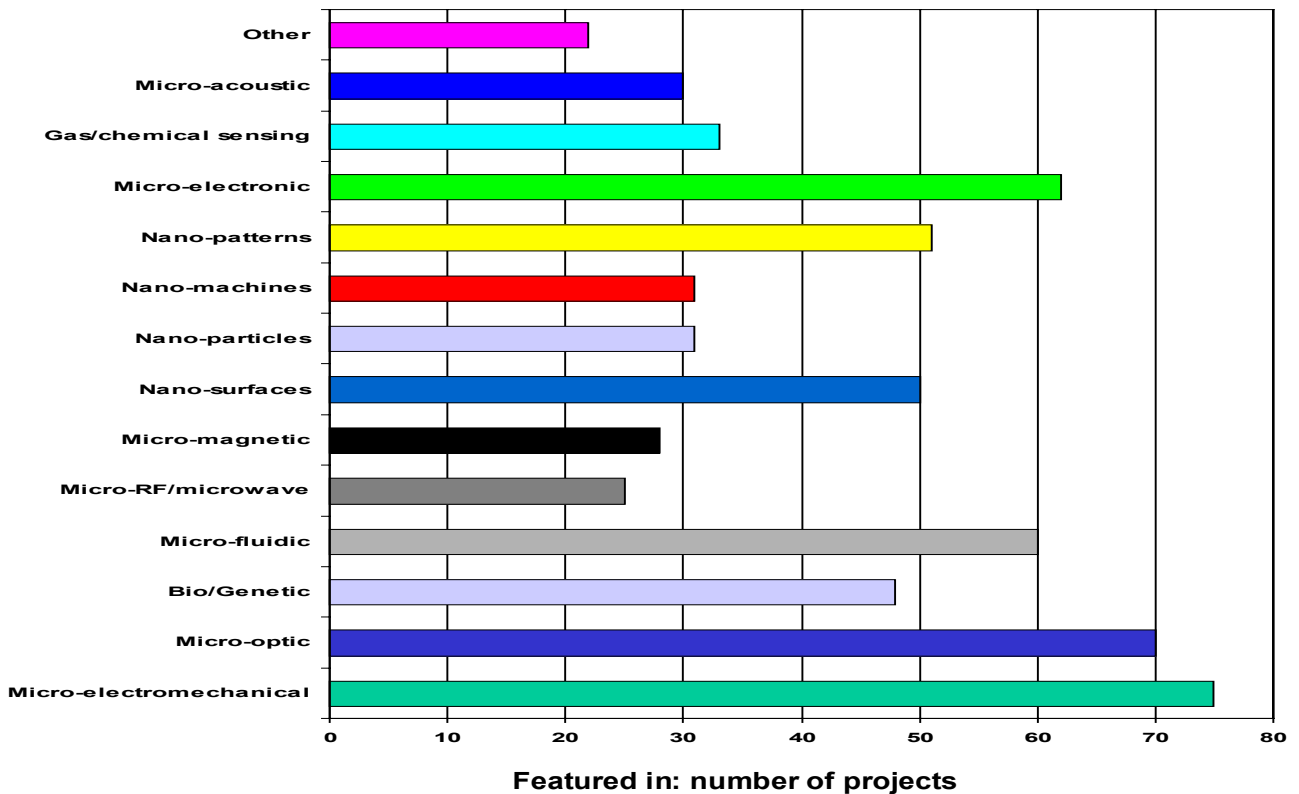


Figure 22. This underlines the prior observation and recommendation:

Figure 39: Research projects - technology content

The profile of technologies supported by research projects is very similar to the technology content expected in new products depicted in Figure 23:

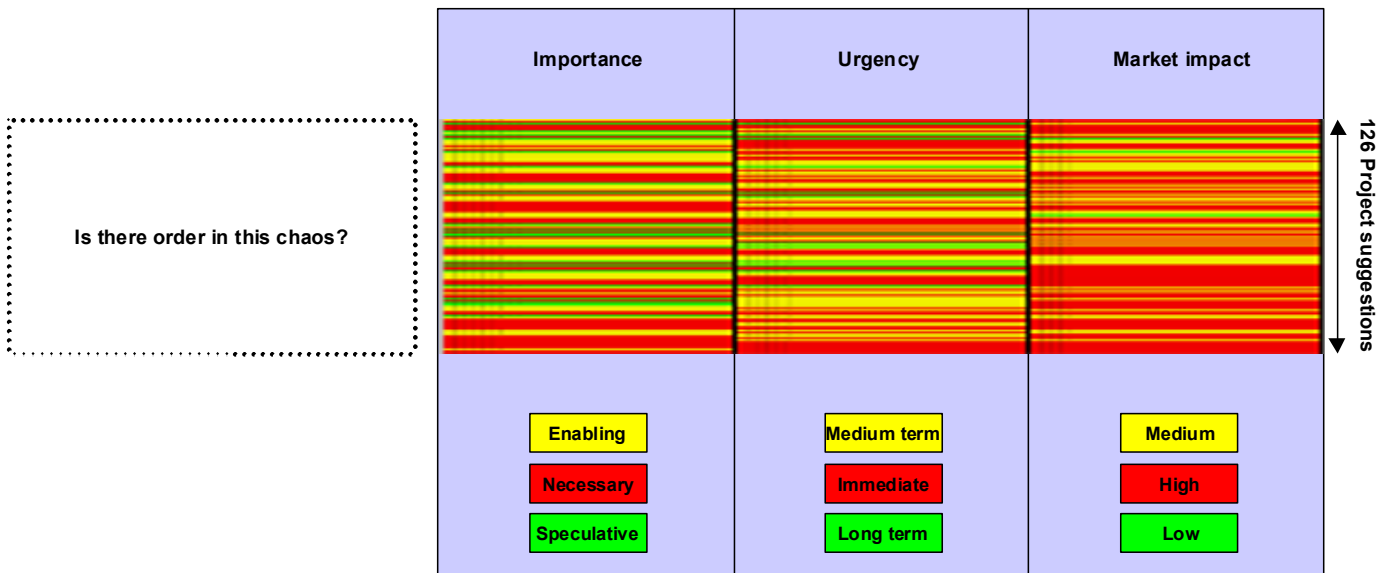
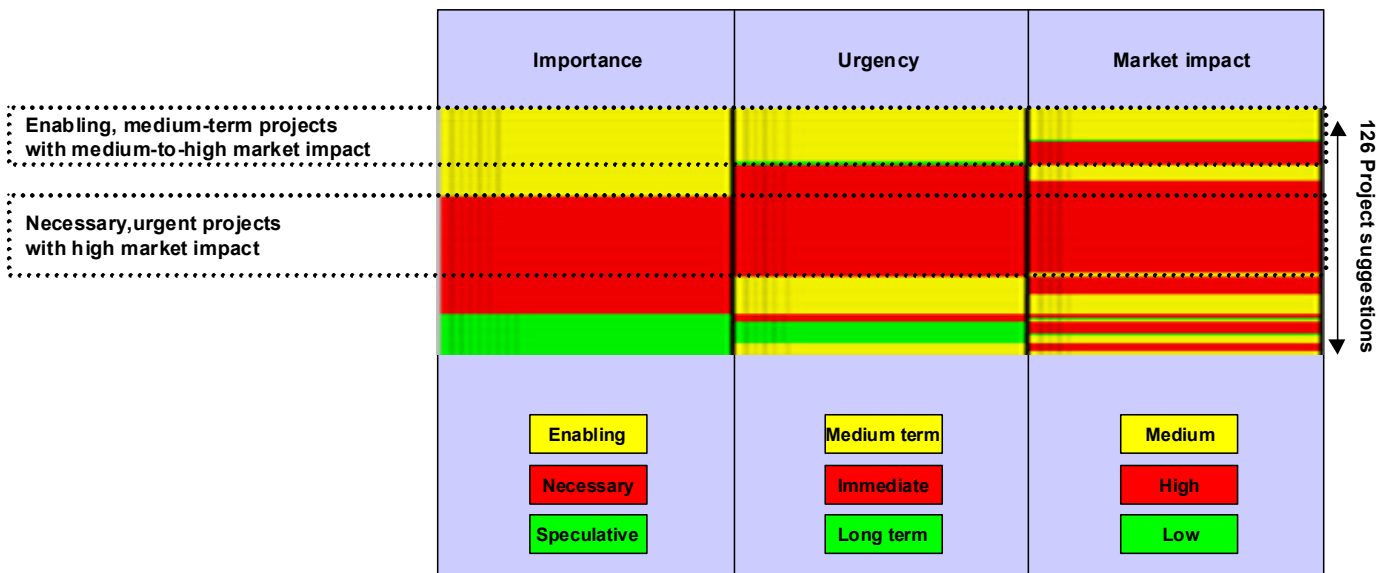


Figure 40: Research projects - importance, urgency and market impact

After sorting:



Observation 23:

The majority of research projects proposed can be split into two classes:

1. Necessary, urgent projects with high market impact
2. Enabling, medium-term projects with medium-to-high market impact

7.1. Primary and Secondary themes

A comparison of the number of projects suggested in each Primary Category of research against estimated Cost reveals an underlying opinion of which are the major research themes.

This is not to say that categories which attracted few suggested projects should not be supported, but rather that there were fewer research opportunities seen in those areas by the workshop contributors

Primary Category	<1m€	<10m€	<100m€	>100m€
Microjoining	Improved micro joining techniques Micro joining of small parts	Interconnections Micro / nano dispensing Adhesive application technology Lead free micro/nano soldering Micro assembly snap-in	Micro/Nano Fusion as applied to assembly / joining	Glues: Material Composites for Interfaces
Sensors	Optical laser control system	Sensors monitoring functional modes Electric fluidic die to substrate bonder	Low cost sensor	Fluidic Connection
Nanocoating processes		Structured Coatings Coating technology	High added value coating Hybrid process system (plasma / wet process) Roll to roll surface treatment.	Hybrid process
Materials / Smart materials	Chip to Substrate connection Optical plastic surviving soldering process	Smart Cap Smart Textiles Aspheric glass moulds surviving 800K to 1M shots Smart Materials for Self Heating PZT Deposition		Smart materials tailored to function
Self-assembly	Cheap Operators and maintenance	Design for replication		Self assembly of a electroactive nanomaterial

Figure 41: Major research themes (1)

- Large and small projects were suggested within these categories of research

Primary Category	<1m€	<10m€	<100m€	>100m€
Microjoining	Improved micro joining techniques Micro joining of small parts	Interconnections Micro / nano dispensing Adhesive application technology Lead free micro/nano soldering Micro assembly snap-in	Micro/Nano Fusion as applied to assembly / joining	Glues: Material Composites for Interfaces
Sensors	Optical laser control system	Sensors monitoring functional modes Electric fluidic die to substrate bonder	Low cost sensor	Fluidic Connection
Nanocoating processes		Structured Coatings Coating technology	High added value coating Hybrid process system (plasma / wet process) Roll to roll surface treatment.	Hybrid process
Materials / Smart materials	Chip to Substrate connection Optical plastic surviving soldering process	Smart Cap Smart Textiles Aspheric glass moulds surviving 800K to 1M shots Smart Materials for Self Heating PZT Deposition		Smart materials tailored to function
Self-assembly	Cheap Operators and maintenance	Design for replication		Self assembly of a electroactive nanomaterial

Figure 42: Major research themes (2)

- Generally smaller projects were suggested within these categories of research

Primary Category	<1m€	<10m€	<100m€	>100m€
Micro-surface processing		New cleaning technologies for surfaces	Develop an MNT Diagnostic Instrument Simulation for Interface Chemistry	
Nanoimprint		Nano Imprint lithography for Quantum dots Nanostructures on large areas	Micro fluidics in Printing	
Nanotooling		Modularisation of automation	Nano plasma texturing surface equipment	
Packaging/Integration		Very high integration density electrical connections Assembling	Assembly and packaging of highly miniaturised sensor systems.	
Tooling		Ultra short pulse laser Dispensing systems for small volumes	Wafer independent shaping and assembly	
Printing	Electronics Printing on ceramics	High Accuracy printing for Reel to Reel production Submicron Printing High precision printing		
Control and Vision	Nano Assembly	Quality control of particle contamination.		

Figure 43: Secondary research themes

- There were no very large projects suggested within these categories of research, and fewer proposed research ideas in each category

7.2. Other research themes

These categories did not attract a spread of project ideas. Perhaps they should be clustered into larger sub groups?

- Actuators and drives
- Casting
- Design & Simulation
- Energy beams
- Etching
- Fixtures, Grippers, Feeders
- High precision linear stages
- High precision machine tools
- Imaging
- Laser technology, additive
- Laser technology, subtractive
- Lithography
- Microfabrication
- Microforming
- Nano materials
- Nanoindentation / nanostructuring
- Nanointegration
- Nanorobotics
- System Integration

7.3. Time ranking of research themes

Early - (Highest incidences occur in "Immediate" category)	Later - (Highest incidences occur in "Medium term" + "Long term" categories)
Actuators and drives	Casting
Control and Vision	Design & Simulation
Etching	Energy beams
High precision linear stages	Fixtures, Grippers, Feeders
High precision machine tools	Laser technology, additive
Imaging	Laser technology, subtractive
Lithography	Materials / Smart materials
Microfabrication	Micro factory
Microforming	Microjoining
Micromachining	Micro-surface processing
Moulds	Nano materials
Nanofactory	Nanocoating processes
Nanorobotics	Nanoimprint
Nanotooling	Nanoindentation/nanostructuring
Sensors	Nanointegration
System Integration	Packaging/Integration

Test, inspection, characterisation	Printing
Tooling	Self-assembly

8. Observations and recommendations

This section is prefaced by a fascinating collation of opinion drawn from the sum of the contributions:

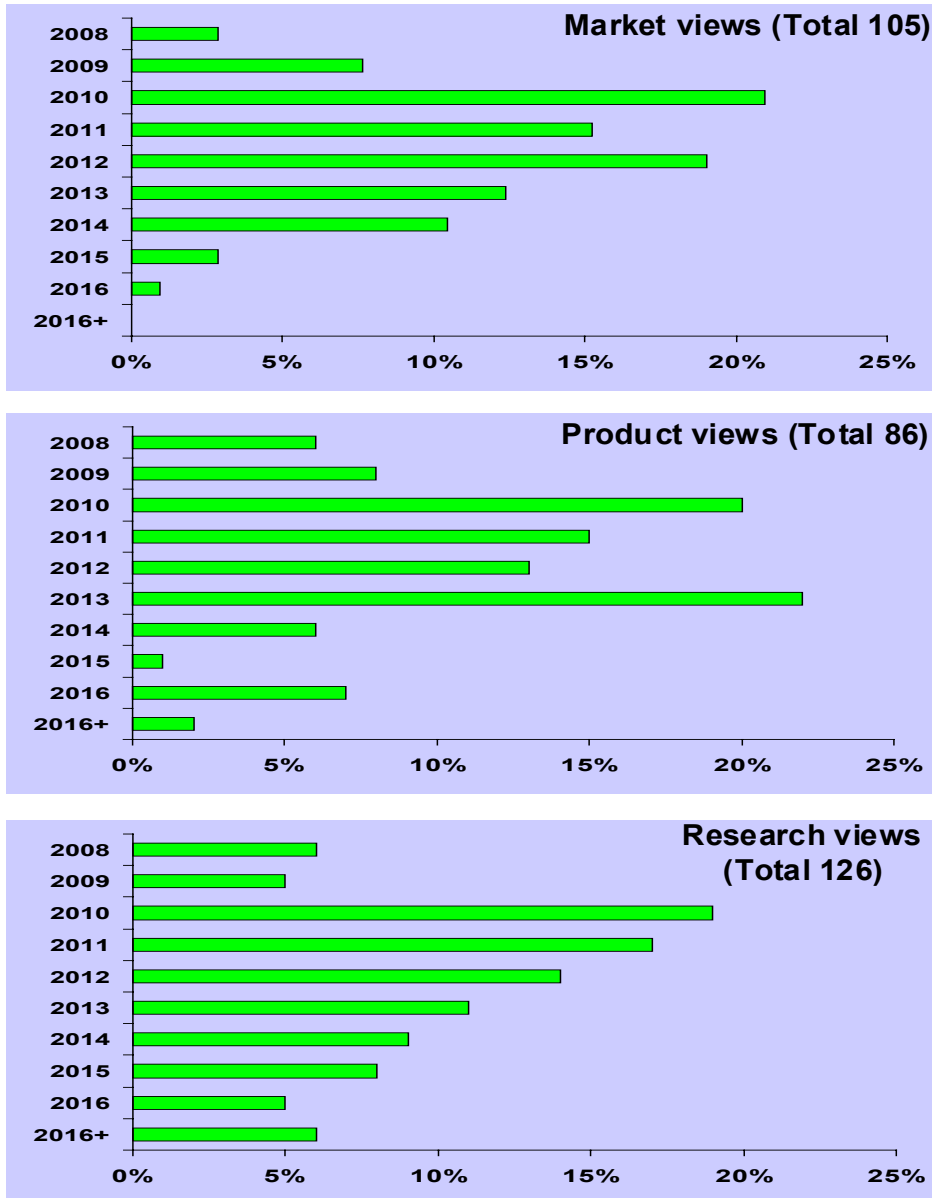


Figure 44: MNT - Distribution of estimated time to exploitation

It is interesting that:

- The "MNT into Market" leadtime appears in advance of the "MNT into Products" leadtime

Furthermore

- The "MNT into Product" leadtime appears in advance of the "Exploitation of MNT Research" leadtime

The probable explanation for this is that MNT is progressing into markets *now*, bouyed in by existing products using MNT. Moreover, the peak in Product introductions in 2010 is most likely a result of research and development programmes already in progress.

The second wave of products very evident in 2013 is the evidence of the exploitation of the research peak coming to fruition in 2010. *Investment is needed now to ensure that that research peak happens.*

8.1. Collated Observations

23 observations were noted during the First Stage roadmapping study and the analysis of contributions

	Observation	Relevance
1. (page 10)	Medical/Pharmaceuticals, Automotive/ Transportation and Consumer /Entertainment were front-running topics throughout the study	Potential for prioritisation / maximise effectiveness
2. (page 11)	For the sectors described by an adequate number of people (ie., excluding Agriculture/Fisheries/Forestry, Construction, Manufacturing and Pollution Control) there is a scatter of opinion about sector sizes, possibly through respondents describing different aspects	In future need to better understand respondents' perceptions of sectors and supply chains
3. (page 11)	For the sectors described by an adequate number of people, most predictions were for MNT value to be <40% of the total sector value	Perception probably too high – position in supply chain may be relevant
4. (page 12)	The MNT opportunity appears very significant in: Automotive/Transportation Communications Computers/Business Consumer/Entertainment Energy/Water/Chemicals Food and Drink Medical/Pharmaceuticals Military/Aerospace Security	Potential for prioritisation / maximise effectiveness
5. (page 12)	A large proportion of correspondents .describe the sectors as "emerging" or "growing". A smaller proportion cites "stability", and there was only one perception of "decline". Optimism?	Future roadmapping needs to poll practitioners in each sector, who are more in touch with the characteristics of each sector
6. (page 13)	A large proportion of correspondents describe the impact of MNT to be either "High" or "Medium".	Be wary of enthusiastic optimism
7. (page 13)	Few respondents forecasted uptake of nanotechnology in its own right	Consider carefully the balance and background of contributors
8. (page 14 and page 18)	The popularity of the front-running technologies is not surprising. Nanomachines are probably seen to be far in the future. Magnetics and RF/Microwave are important subjects, but perhaps reside in the minds of specialists.	Be sure to poll specialists
9. (page 15)	Construction and Manufacturing appear to be scant users of MNT, being reported in any case by only single correspondents. Micro-acoustic, RF/Microwave, Micro-magnetic and Nanomachines show as less popular technologies.	Consider carefully the balance and background of contributors
10. (page 16)	The Automotive/Transportation, Communications and Computers / Business.sectors are clearly seen to lead in the adoption of MNT. The Energy/Water/Chemicals and Food & Drink sectors display conservatism, whilst the Medical/Pharmaceuticals and Military/ Aerospace sectors	Potential for prioritisation / timeline planning to maximise effectiveness

	are retarded by issues of standards and qualifications. Security should be seen as an interesting emerging opportunity for MNT											
	Observation	Relevance										
11. (page 17)	Medical/Pharmaceuticals, Automotive/ Transportation and Consumer /Entertainment are front-running topics throughout the study, but for product introduction these sectors are joined by military/aerospace and security.	Candidates for special interest groups and focused workshops involving sector practitioners as the µ-SAPIENT programme progresses										
12. (page 19)	There are fewer forecasts of the introduction of products purely dependent upon nanotechnology, and the timescale is some 2 years retarded compared with products using fuller categories of MNT	Prioritisation										
13. (page 19)	Products combining Micro- and Nano- technologies have good sales prospects	Prioritisation										
14. (page 20)	Products using MNT are predicted to mainly have high market impact	Logic for funding and investment										
15. (page 20)	Products using MNT are predicted to be needed in the short-to-medium term	Prioritisation										
16. (page 22)	Except for the widely-defined topics, primary research interests appear to be spread very evenly The most popular candidates for research were shown as: <table style="width: 100%; border: none;"> <tr> <td style="width: 50%;">Microjoining</td> <td style="width: 50%;">Nanocoating</td> </tr> <tr> <td>Microfabrication</td> <td>Sensors</td> </tr> <tr> <td>Microfactory</td> <td>System Integration</td> </tr> <tr> <td>Materials/Smart Materials</td> <td>Test & Measurement</td> </tr> <tr> <td>Micromachining</td> <td></td> </tr> </table>	Microjoining	Nanocoating	Microfabrication	Sensors	Microfactory	System Integration	Materials/Smart Materials	Test & Measurement	Micromachining		Prioritisation
Microjoining	Nanocoating											
Microfabrication	Sensors											
Microfactory	System Integration											
Materials/Smart Materials	Test & Measurement											
Micromachining												
17. (page 23)	Equipment projects slightly lead process projects in time, expectedly?	Prioritisation										
18. (page 23)	On balance, equipment projects cost slightly more than the average for all projects, process projects slightly less.	Prioritisation										
19. (page 23)	In the main, the cost and time characteristics of equipment and process development projects are broadly similar.	Can be analysed together										
20. (page 24)	Project scale was suggested to be predominantly in the range 1m€ - 100m€	Planning information for FP7										
21. (page 24)	Market impact for exploitation of research is consistent with that predicted for the market impact of new products based upon MNT	Corroboration										
22. (page 25)	The low number of responses putting forward nano- only research projects has lead to patchy data. It does however seem reasonable, by comparing the data to the whole MNT population, that nano- only research projects will follow the duration distribution (mainly 2 to 3 years) for MNT projects as a whole, and that the time to market will lag MNT as a whole by about 2 years	Prioritisation and planning										
23. (page 27)	The majority of research projects proposed can be split into two classes: <ol style="list-style-type: none"> 1. Necessary,urgent projects with high market impact 2. Enabling, medium-term projects with medium-to-high market impact 	Prioritisation and planning										

8.2. Collated recommendations

7 recommendations for the furtherance of the ongoing µ-SAPIENT programme are collated here from the body of the report:

Recommendation for the ongoing µ-SAPIENT programme	
1. (page 10)	Agriculture/Fisheries/Forestry, Construction, Manufacturing and Pollution Control drew too few responses for reliable data. The future comprehensive study needs to poll a larger (probably 5x larger) population to gain a dependable picture for these sectors
2. (page 11)	Future roadmapping needs to investigate and delineate different aspects of each market sector, and understand the insertion of MNT into different levels within supply chains
3. (page 11)	Perceptions of MNT value as a proportion of total sector value are probably too high. This further indicates that future study needs to understand the insertion of MNT into supply chains
4. (page 12)	Future roadmapping needs to poll practitioners in each sector, who are more in touch with the characteristics of each sector.
5. (page 14 and page 18)	Future roadmapping needs to identify expert contributors regarding Magnetics and RF/Microwave
6. (page 17)	The five sectors: Medical/Pharmaceuticals, Automotive/ Transportation, Consumer/Entertainment, Military/aerospace and Security, plus perhaps Communications, are candidates for special interest groups and focused workshops involving sector practitioners as the µ-SAPIENT programme progresses
7. (page 20)	µ-SAPIENT needs to counsel industrialists and researchers alike on the practicalities of MNT product introduction, to avoid the pitfalls of over-optimistic planning

9. Précis information for the European Commission

For convenience, some salient illustrations from the body of the report are collated here to inform:

- Overall market-driven timescales for MNT research
- The distribution of the cost, duration and prioritisation of research projects
- Views of the resulting economic outcome

9.1. Market-driven timescales

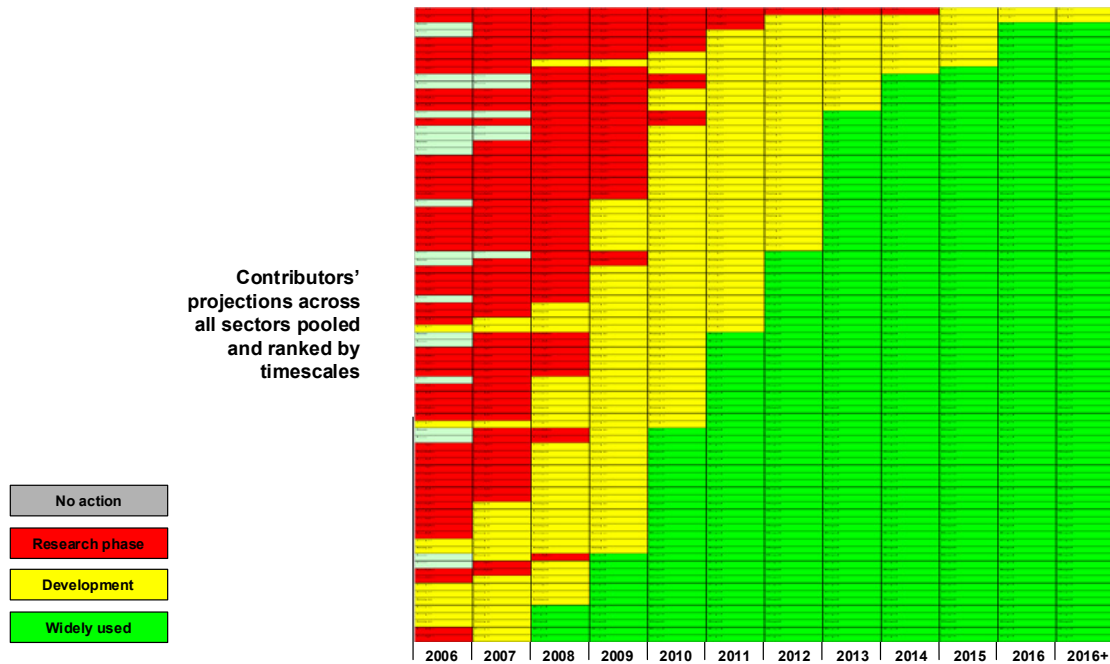


Figure 24 (p18): Projected introduction of new products using MNT

Figure 24 shows the progressive introduction of products using MNT as distilled and ranked from 86 expert opinions. It shows a major move towards wide use (green) starting in 2010 and jumping again in 2012; research phases (red) of typically 2 to 4 years, and development (yellow) of generally 3 years.

9.2. Distribution of the cost, duration and prioritisation of research projects

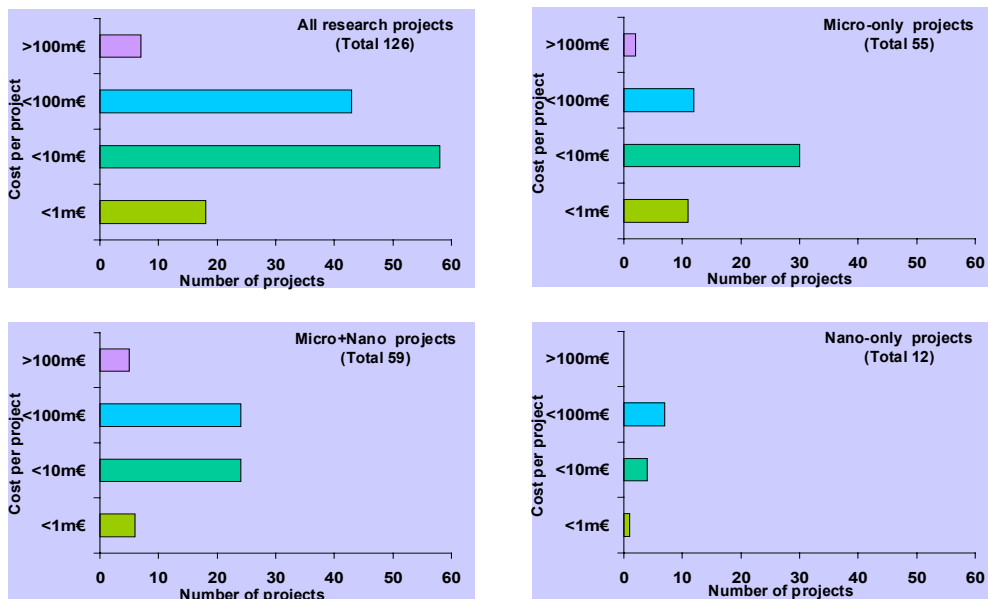


Figure 34 (p24): Research projects - cost distribution

The majority of research project ideas gathered from the industrial experts that participated in the µSapient workshops saw projects to have a value of €1-100million with very few projects exceeding €100million.

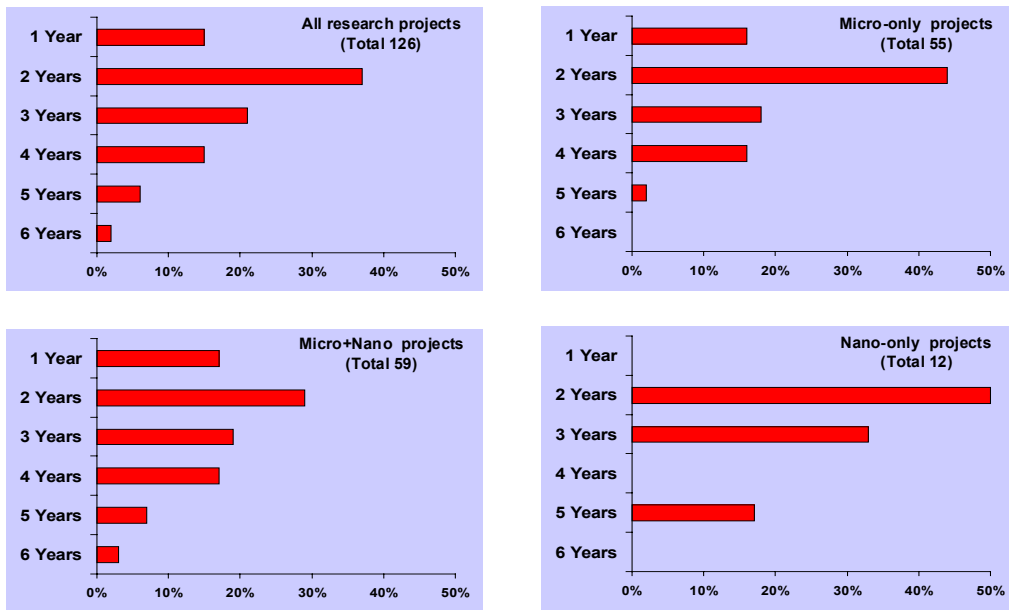


Figure 36 (p25): Research projects - distribution of estimated duration

Further to this most projects were considered to take two to four years for completion, with the majority estimated to be completed within 2 years.

Time ranking of research themes (p29)

Early - (Highest incidences occur in "Immediate" category)	Later - (Highest incidences occur in "Medium term" + "Long term" categories)
Actuators and drives	Casting
Control and Vision	Design & Simulation
Etching	Energy beams
High precision linear stages	Fixtures, Grippers, Feeders
High precision machine tools	Laser technology, additive
Imaging	Laser technology, subtractive
Lithography	Materials / Smart materials
Microfabrication	Micro factory
Microforming	Microjoining
Micromachining	Micro-surface processing
Moulds	Nano materials
Nanofactory	Nanocoating processes
Nanorobotics	Nanoimprint
Nanotooling	Nanoindentation/nanostructuring
Sensors	Nanointegration
System Integration	Packaging/Integration
Test, inspection, characterisation	Printing
Tooling	Self-assembly

A time ranking of research themes has also been conducted as per the list above. The categories that require immediate attention are centred around the development of core technologies that can subsequently enable future development.

9.3. Potential economic outcomes

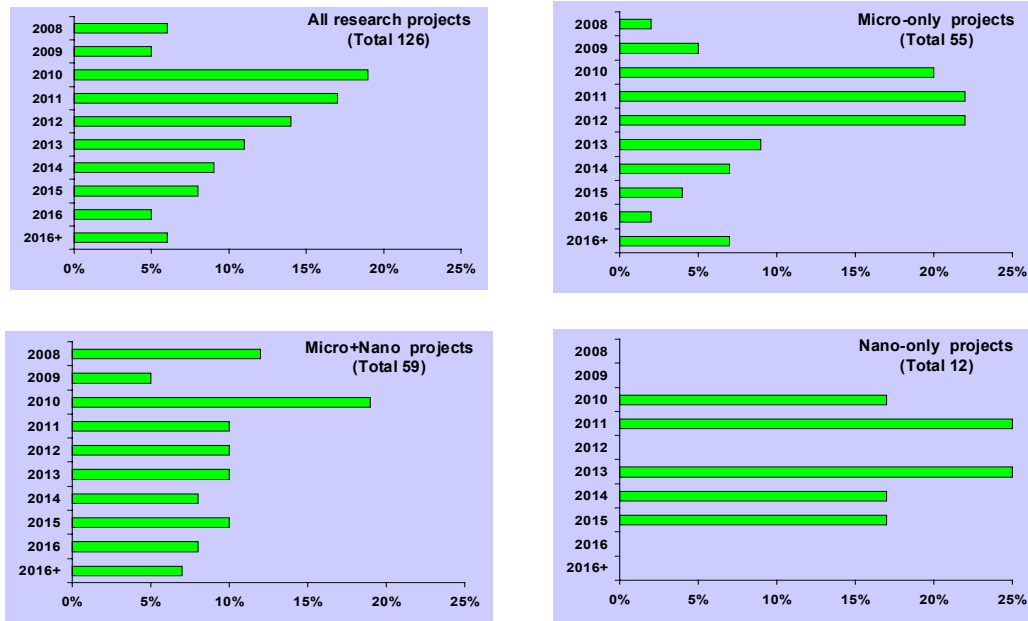


Figure 37 (p25): Research projects - distribution of estimated time to market

Analysis of the data shows that whilst most micro + nano products will enter the market in 2010, micro only projects are not thought to really peak until 2011, whereas nano-only projects will (mostly) reach market after 2013.

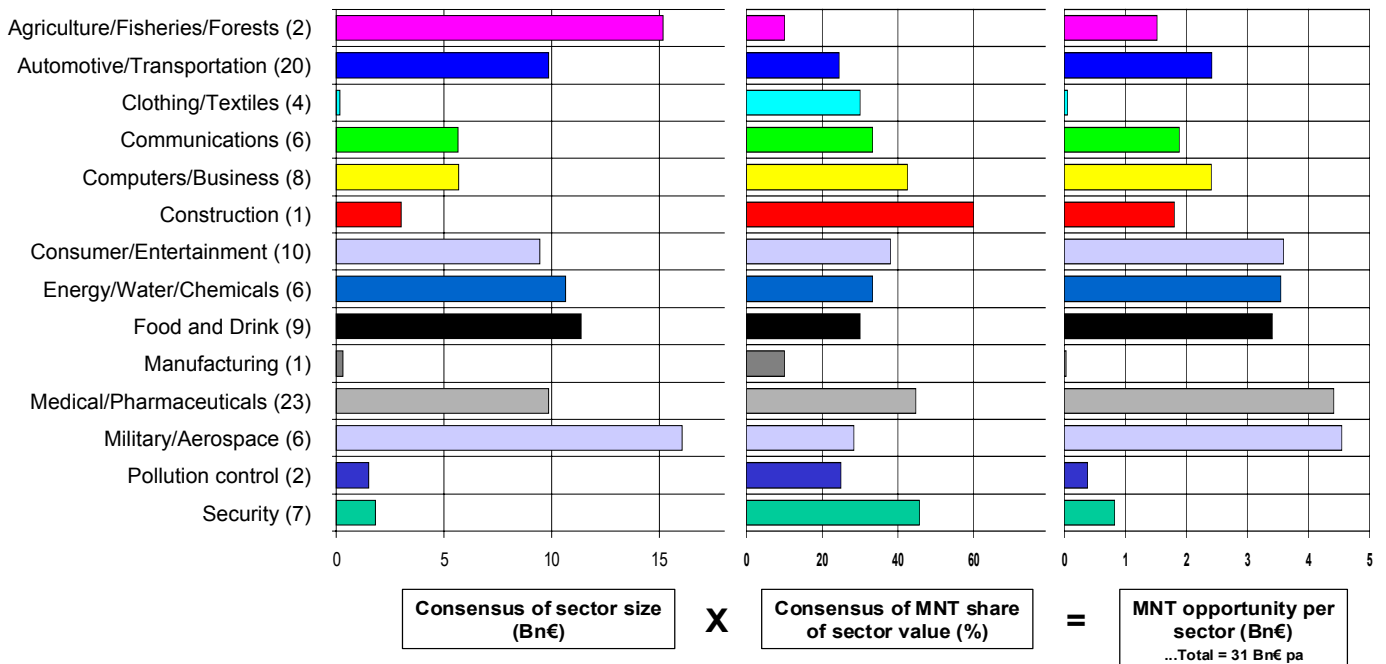


Figure 13 (p11): Comparison of the MNT opportunity per sector

If we consider that the MNT opportunity per market sector is a product of the sector size and the share of market value, the four markets that present the largest opportunities are consumer/entertainment, energy/water/chemicals, medical/pharmaceutical and military/space.

9.4. Initial Project Ideas

A total of 126 proposals for projects, 62 regarding research into MNT equipment and 64 concerning research into MNT process technologies were gathered through the µSapient roadmapping workshops. A selection of these is presented in figure 45 as examples of potential projects with an indication of possible budget and start time.

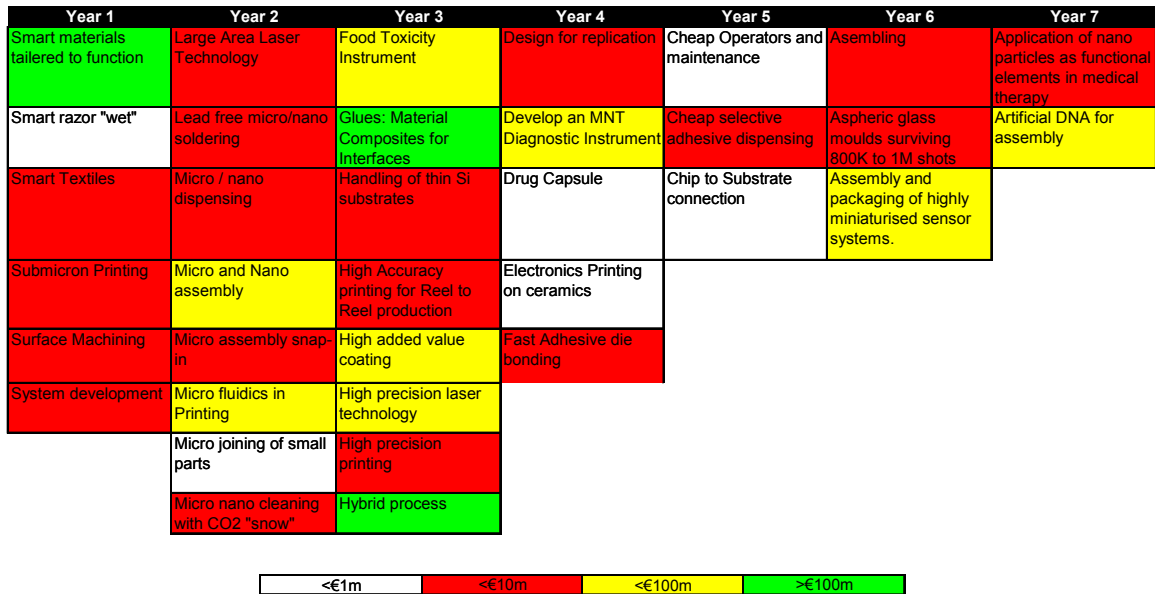


Figure 45: Potential Project Ideas with Budget Indication over a Seven Year Time Span

Most of the projects fall within the under €10million bracket with the main ideas being in the micro and micro-nano domain in the short term. Nano projects are seen to be further down the line as a focus for the future, whilst micro and micro-nano are the focus of current needs from the industrial views gathered in this roadmapping exercise.

10. Conclusion

Following a number of data gathering workshops 30 organisations and 35 participants from 9 European countries contributed:

- 105 views of how 14 MNT technologies will impact 14 market sectors
- 86 views regarding potential products using MNT across the 14 market sectors, and their technological content
- 126 proposals for projects, 62 regarding research into MNT equipment and 64 concerning research into MNT process technologies, all categorised within 23 technical areas and with an assessment of which market sectors they will support

All inputs were mapped against a year-by-year timeline stretching from 2006 to 2016 and beyond. In all, the 300+ entries provided some 15,000 data points, plus over 1,000 text descriptions forming a rich and detailed picture within a structured database which may be usefully analysed in many different ways.

From analysis of the consequent data points several project ideas were presented as examples of potential projects with a preliminary indication of budget. Most of the projects fall within the under €10million bracket with the main ideas being in the micro and micro-nano domain in the short term. Nano projects are seen to be further down the line as a focus for the future, whilst micro and micro-nano technology are the focus of current needs from the industrial views gathered in this roadmapping exercise.

Appendix 1 List of contributing organisations and their affiliations

Company	Country	
Festo	Germany	Technology Provider
Philips HTP	The Netherlands	Large End User
Philips ATP	The Netherlands	Large End User
Robert Bosch GmbH	Germany	Technology Provider
TNO	The Netherlands	Public Research Organisation
OCE	The Netherlands	Large End User
IMS	The Netherlands	
MA3 Solutions	The Netherlands	SME
Lionix BV	The Netherlands	Technology Provider
BE Semiconductor Industries N.V	The Netherlands	Technology Provider
CSEM	Switzerland	Private Research Organisation
Microcoat	Germany	Technology Provider
Sensitec	France	Technology Provider
SNECMA	France	Large End User
ARCELOR	France	Technology Provider
TQC	UK	SME
Battenfeld	UK	Technology Provider
IDEKO	Spain	Public Research Organisation
Crown Biosystems	UK	SME
Rolls Royce	UK	Large End User
SMHA	Switzerland	Large End User
Beckhoff	Germany	SME
Flexlink	Sweden	Large Equipment Supplier
IEF Werner	Germany	Technology Provider
Feintool	Switzerland	Technology Provider
Lagniel	France	Technology Provider
Anter Ltd	Greece	SME
2M engineering	The Netherlands	SME
IVAM	Germany	Trade Association
ACI-group	Germany	Technology Provider
KTH	Sweden	University
CEA	France	Large End User
Hermia Technology Centre	Finland	Private Research Organisation