NRM
nanoroadmap project

Nanoroadmap Conferences

Present Forecast at 2015 of Nanotechnology Application in:
Materials, Health and Medical Systems, Energy

Project co-founded by the EC in the Sixth Framework Programme (FP6 - Thematic Priority 3)

Present Forecasts at 2015 of Nanotechnology Application in: Materials, Health and Medical Systems, Energy

Padova, November 10, 2005

NANOTECHNOLOGY AND THE NANOROADMAP PROJECT

Elvio Mantovani

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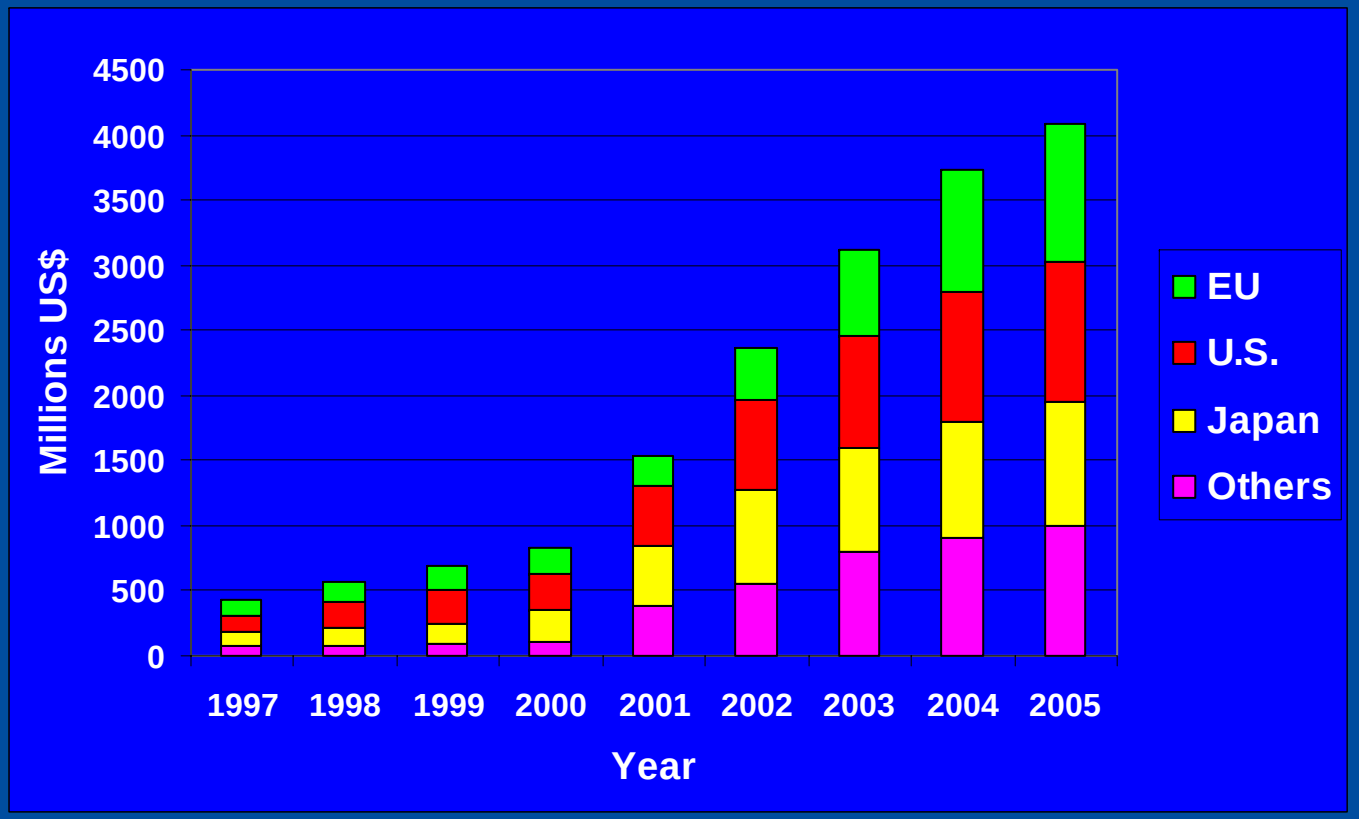
Associazione italiana per la ricerca industriale

ESTIMATE of PUBLIC FUNDING for R&D in NANOSCENCE and NANOTECHNOLOGY WORLDWIDE (1997 – 2005) (US$ million)



Origin: Roco NSF 2005

Others include: Australia, China, Eastern Europe, FSU, South Korea, Singapore, Taiwan and other countries with nanotechnology R&D.

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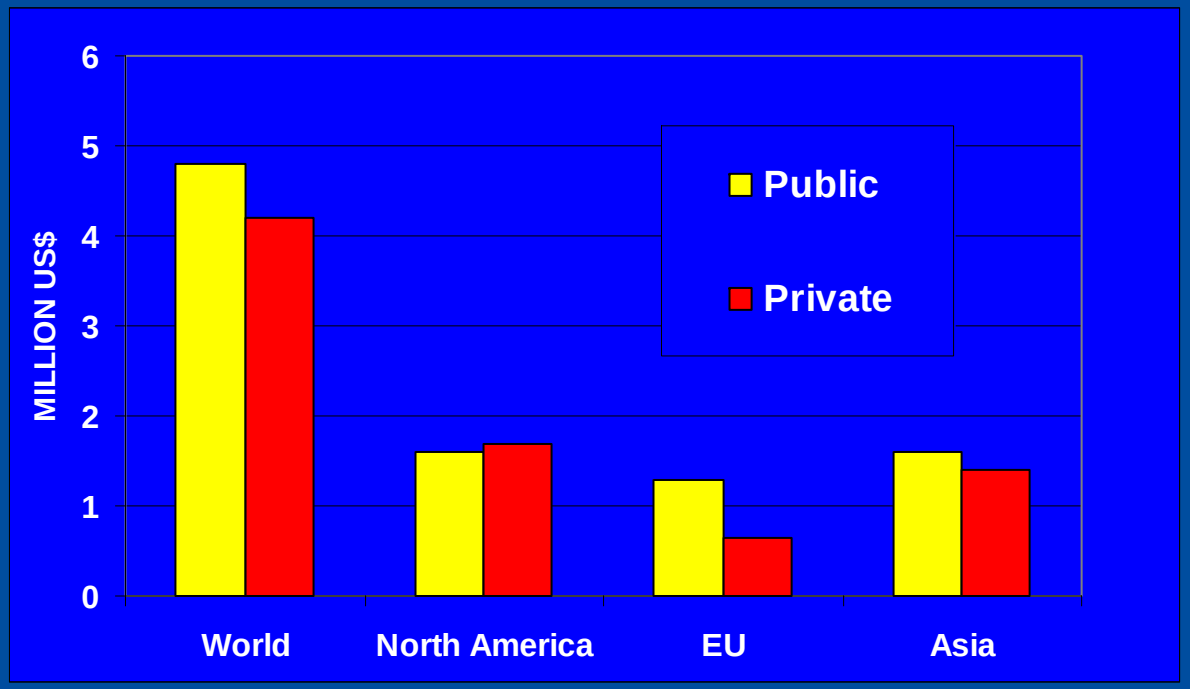
Private and Public Expenditures in 2004



Origin: Lux Research & NSF (public includes national, regional and state funding)

Nanotechnology Application

The sectors which will gain most from nanotechnology are:

- **MATERIALS & MANUFACTURING**
- **MEDICAL AND PHARMACEUTICAL APPLICATIONS**
- **ELECTRONICS**

AROUND 70% OF THE NANO-RELATED MARKET WILL BE SIZED BY THESE SECTORS.

R&D Challenges

- UNDERSTING AND CONTROLLING NANOSCALE PHENOMENA AND PROCESSES
- NANOSTRUCTURES HANDLINGS&MASS PRODUCTION
- INTEGRATE TOP-DOWN AND BOTTOM-UP APPROACHES
- INTERFACE OF LARGE SYSTEMS WITH NANOSYSTEMS

The Nanoroadmap Project

www.nanoroadmap.it

info@nanoroadmap.it

OBJECTIVE

- **PREPARATION OF ROAD MAPS (AT 10 YEARS) FOR THE APPLICATION OF NANOTECHNOLOGY IN THREE SECTORS:**
  - **MATERIALS**
  - **HEALTH AND MEDICAL SYSTEMS**
  - **ENERGY**

DURATION

- **JANUARY 2004-DECEMBER 2005**

The Partners

NRM nanoroadmap project

AIRI/Nanotec IT / (Italy)

Technology Centre (Czech Republic)

IoN (UK)

VTT (Finland)

W&W (Spain & The Netherlands)

MATIMOP- (Israel)

Yole Dèveloppement (France)

VDI/VDE-IT (Germany)

The Project Timeline

JANUARY 2004

START OF THE PROJECT

ASSESSMENT OF THE SITUATION

PREPARATION OF 3 SECTORAL REPORTS

NOVEMBER 2004

ROME NRM INTERNATIONAL CONFERENCE

PRESENTATION OF 3 SECTORAL REPORTS

SELECTION OF THE 12 TOPICS TO BE ROADMAPPED

DEC 2004 – NOV 2005

ROADMAP ELABORATION

NOVEMBER 2005

NRM CONFERENCES

ROADMAPS PRESENTATION

DECEMBER 2005

END OF THE PROJECT

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Countries surveyed

Australia	France	Korea	Slovakia
Austria	Germany	Latvia	Slovenia
Belgium	Greece	Lithuania	Spain
Canada	Hungary	Netherlands	Sweden
China	India	Norway	Switzerland
Czech Republic	Ireland	Poland	Taiwan
Denmark	Israel	Portugal	UK
Estonia	Italy	Russia	USA
Finland	Japan	Singapore	

PUBLIC EXPENDITURES TO SUPPORT R&D IN NANOTECHNOLOGY WITHIN THE 35 COUNTRIES SUEVEYED RESULTED TO BE IN 2003 AROUND US$ 3.1 BLN.

Topics Selection

A NUMBER OF TOPICS REPRESENTATIVES OF NANOTECHNOLOGY APPLICATION WERE IDENTIFIED IN EACH OF THE THREE SECTORS CONSIDERED.

BASING ON A SET OF CRITERIA AGREED UPON BY THE CONSORTIUM, DISCUSSION WHITH INTERNATIONAL EXPERTS OF NANOTECHNOLOGY, IMPUT FROM THE INTERNATIONAL CONFERENCE, WERE SELECTED FOUR TOPICS FOR EACH SECTOR.

THE TOPICS WERE VALIDATED IN DIALOGUE WITH THE EUROPEAN COMMISSION

Roadmaps Elaboration

FOR THE PREPARATION OF THE ROADMAPS A DELPHI – LIKE APPROACH WAS USED BASED UPON A TWO CYCLES EXERCISE CONSISTING IN:

1) SELECTING TOP INTERNATIONAL EXPERTS ON THE FIELD

2) PREPARATION OF A DEDICATED QUESTIONNAIRE FOR EACH OF THE TOPIC TO BE ROAD MAPPED

3) CIRCULATING THE QUESTIONNAIRES AMONG THE EXPERT AND GATHERING OF THEIR RESPONSES (1ST CYCLE)

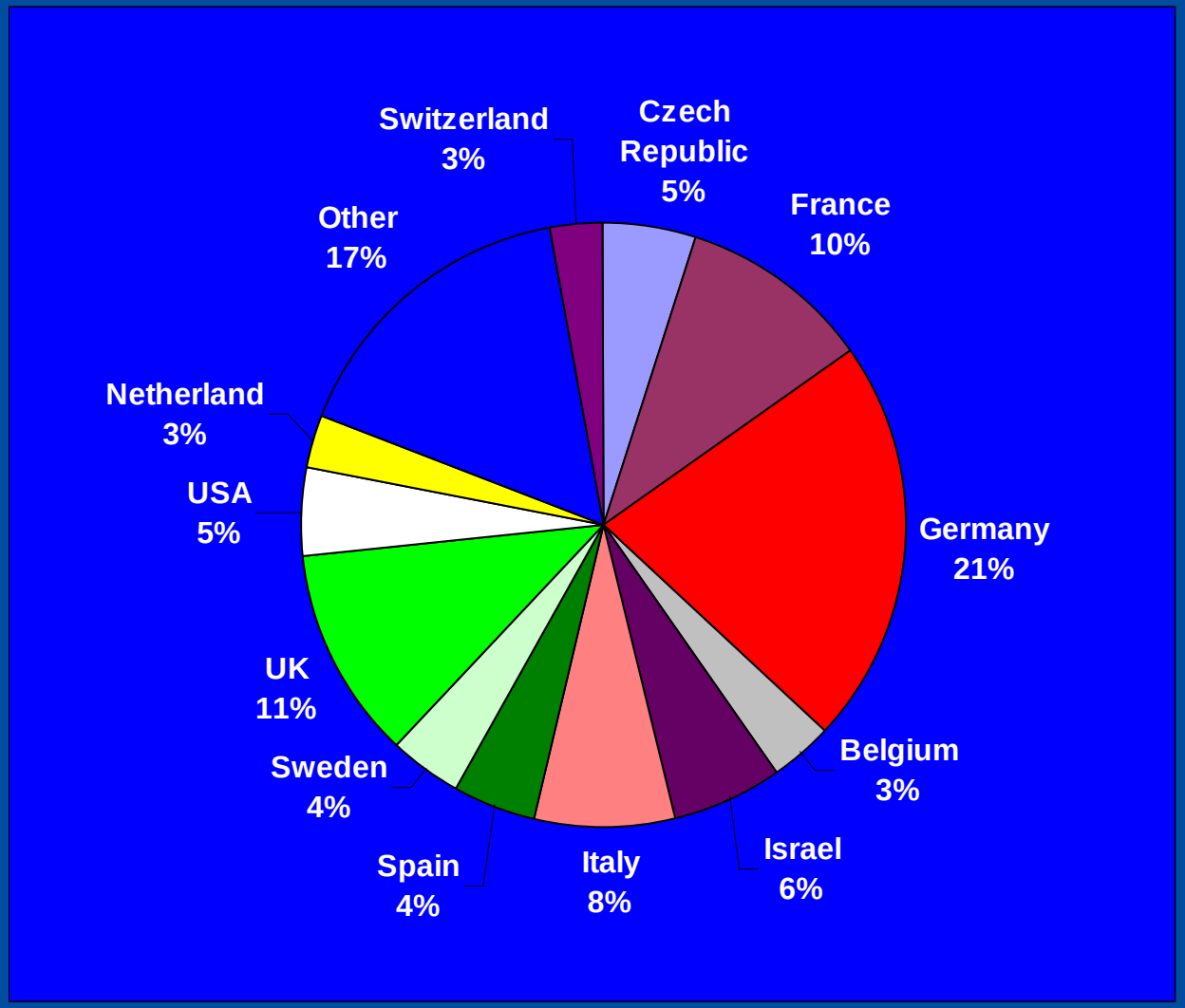
4) PREPARATION OF A FIRST SUMMARY/DRAFT ROADMAP FROM THE GIVEN ANSWERS

5) CIRCULATING THE DOCUMENT AMONG THE EXPERTS, ASKING FOR COMMENTS AND FEEDBACKS (2ND CYCLE)

6) ELABORATION OF THE FINAL ROADMAPS

Experts by Country

The Total number of experts contacted was about 350, around 60% (213) completed the Delphi Exercise.



Others (below 3%) : Austria, Australia, Finland, Ireland, Slovenia, Slovak, Republic, Poland, Japan, Portugal, South Africa, Taiwan, Russia, Estonia, Turkey

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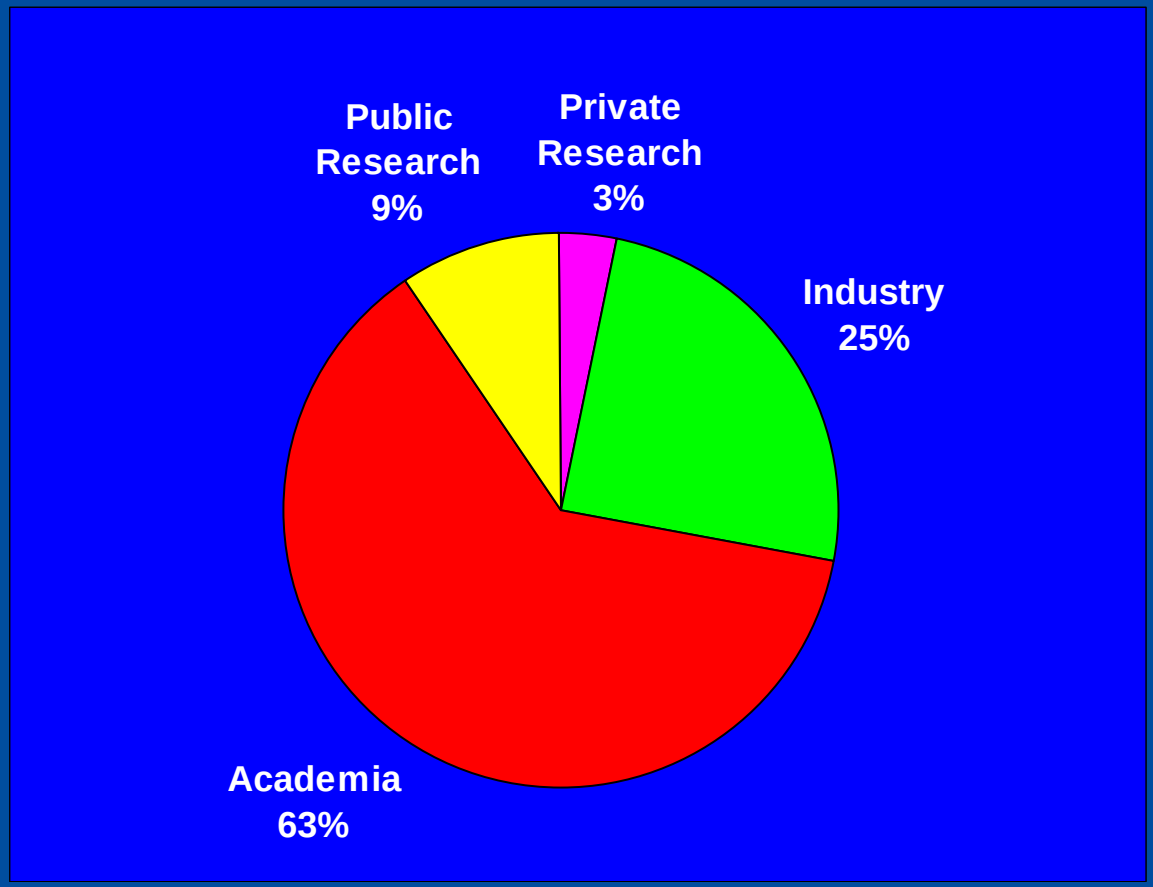
Experts by Organization Type



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MATERIALS ROADMAPS

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Topics Selection

1) Nanostructured materials
2) Nanoparticles / nanocomposites
3) Nanocapsules
4) Nanoporous materials
5) Nanofibres
6) Fullerenes
7) Nanowires
8) Single-Walled & Multi-Walled (Carbon) Nanotubes
9) Dendrimers
10) Molecular Electrics
11) Quantum Dots
12) Thin Films

1) Nanoporous materials
2) Nanoparticles/nanocomposites
3) Dendrimers
4) Thin Films & coatings

Source: willems & van den wildenberg España sl

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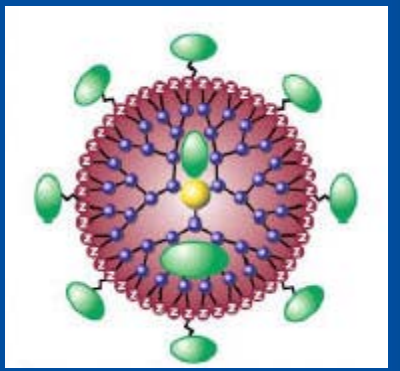
Dendrimers



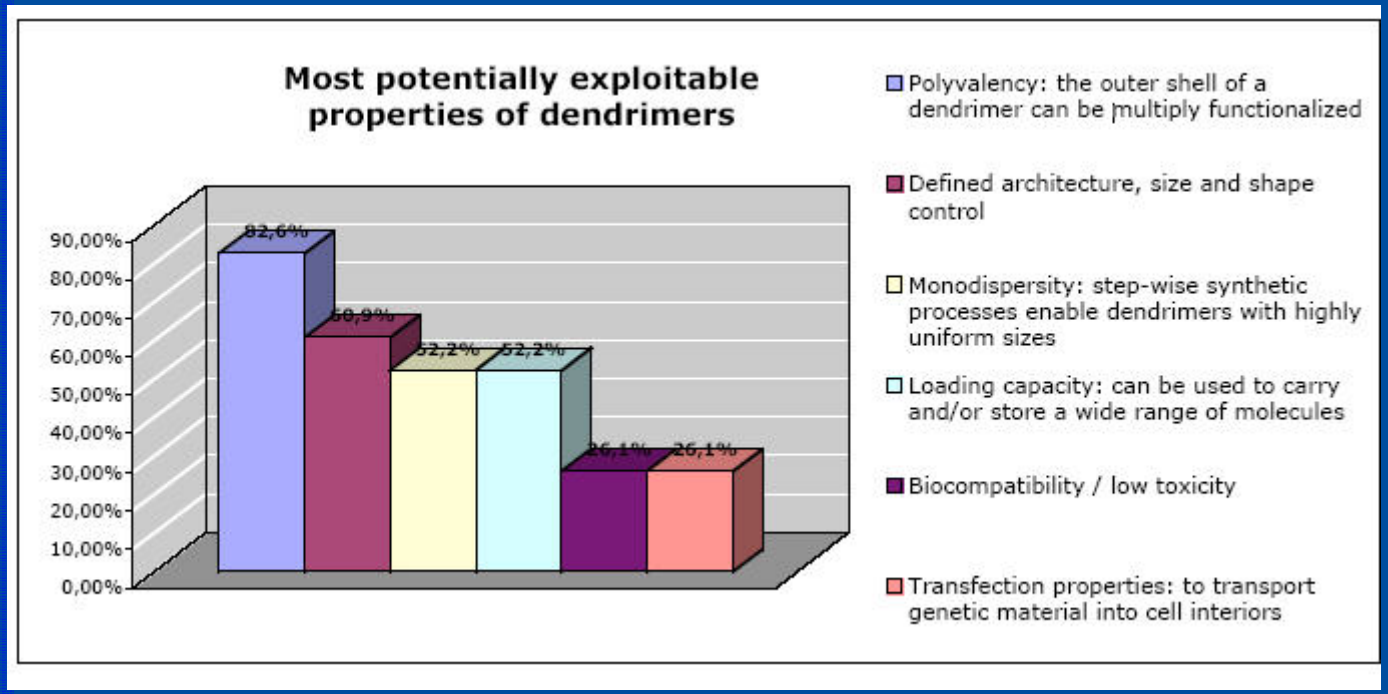
A DENDRIMER IS GENERALLY DESCRIBED AS A MACROMOLECULE, WHICH IS CHARACTERIZED BY ITS HIGHLY BRANCHED 3D STRUCTURE THAT PROVIDES A HIGH DEGREE OF SURFACE FUNCTIONALITY AND VERSATILITY. ITS STRUCTURE IS ALWAYS BUILT AROUND A CENTRAL MULTI-FUNCTIONAL *CORE MOLECULE*, WITH *BRANCHES* AND *END-GROUPS*.

DENDRIMERS CAN BE MADE OUT OF VIRTUALLY ANYTHING THAT CAN BRANCH (METAL ATOMS, ORGANOMETALLIC GROUPS, OR PURELY ORGANIC MATERIALS) AND THEY CAN HAVE A VARIETY OF FUNCTIONALITIES DEPENDING WHAT THEY ARE BUILT OF AND HOW.

Source: willems & van den wildenberg España sl

Impact/Advantages

- Polyvalency
- Defined architecture, size and shape control
- Monodispersity
- Loading capacity ("molecular container")
- Biocompatibility/Low toxicity
- Transfection Properties



Source: willems & van den wildenberg España sl

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Some of Possible Applications

- DYES , PAINTINGS, INDUSTRIAL ADHESIVES
- INKS/LASER-PRINTING TONERS
- POLYMER&PLASTIC ADDITIVES
- CATALITIC AGENTS
- TARGETED DELIVERY SYSTEMS
- MRI CONTRAST AGENTS
- CELLULAR TRANSPORT
- DIAGNOSTIC&ANALYSIS
- LIGHT ARVESTING SYSTEMS
- OLED
- BUILDING BLOCKS FOR NANOSTRUCTURED MATERIALS
- DECONTAMINATION AGENTS

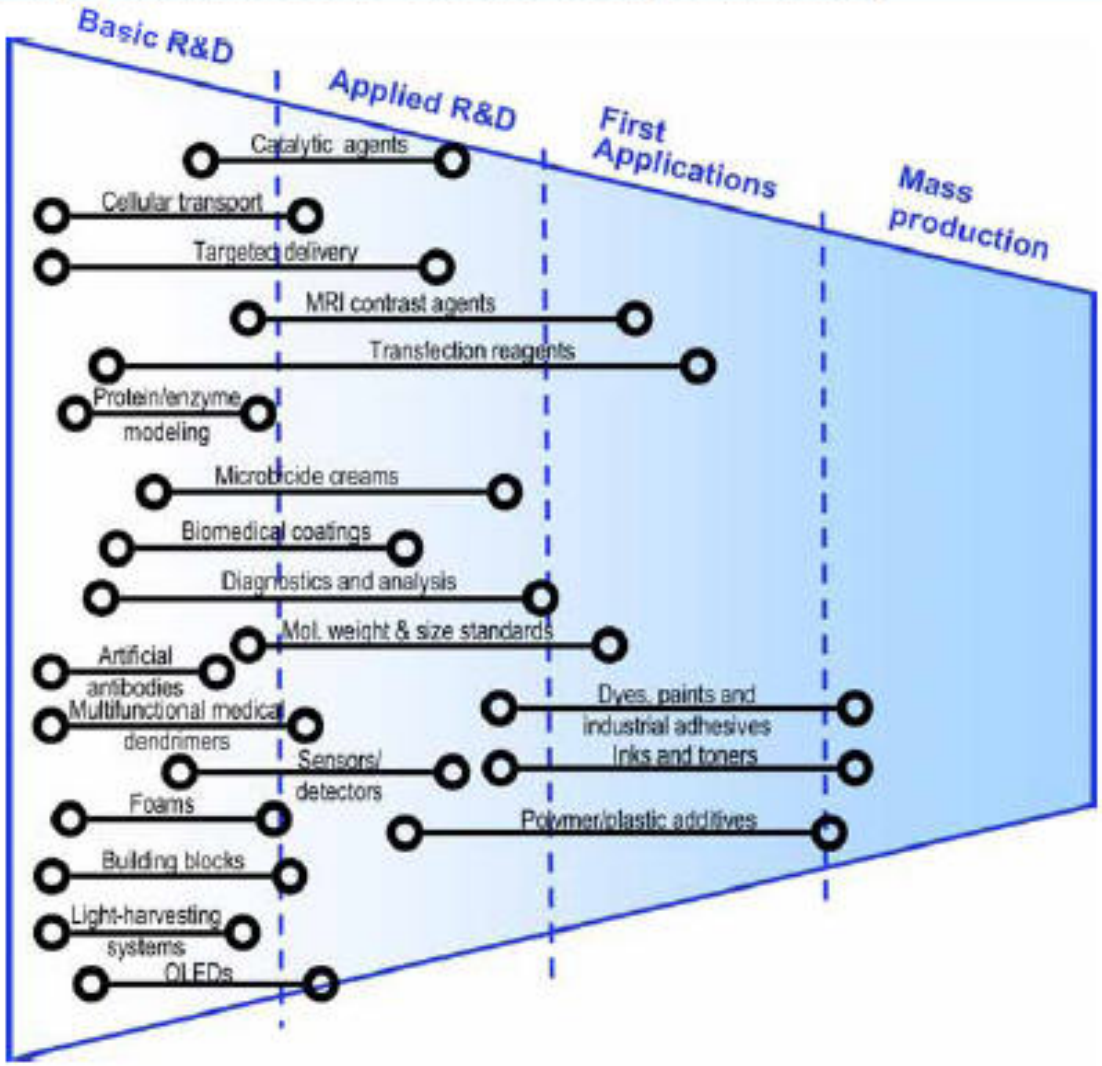
Source: willems & van den wildenberg España sl

Time to market: Situation at 2005

Dendrimer research is very much application-oriented.

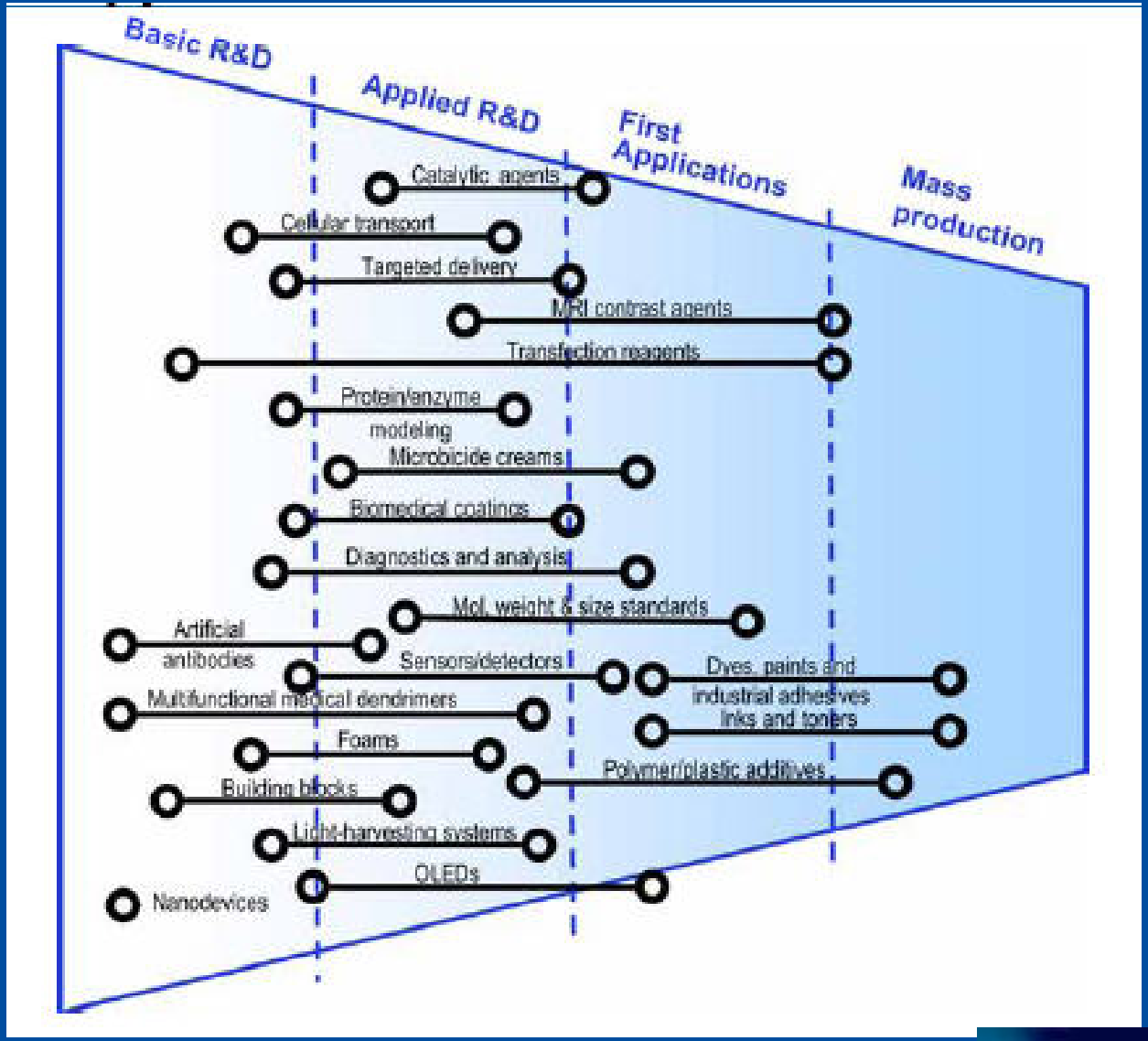
Development timeframes of different applications are difficult to estimate.

Barriers are not so much linked to the synthesis or the functionalisation, but to the final application being researched and the cost for a given volume.



Source: willems & van den wildenberg España sl

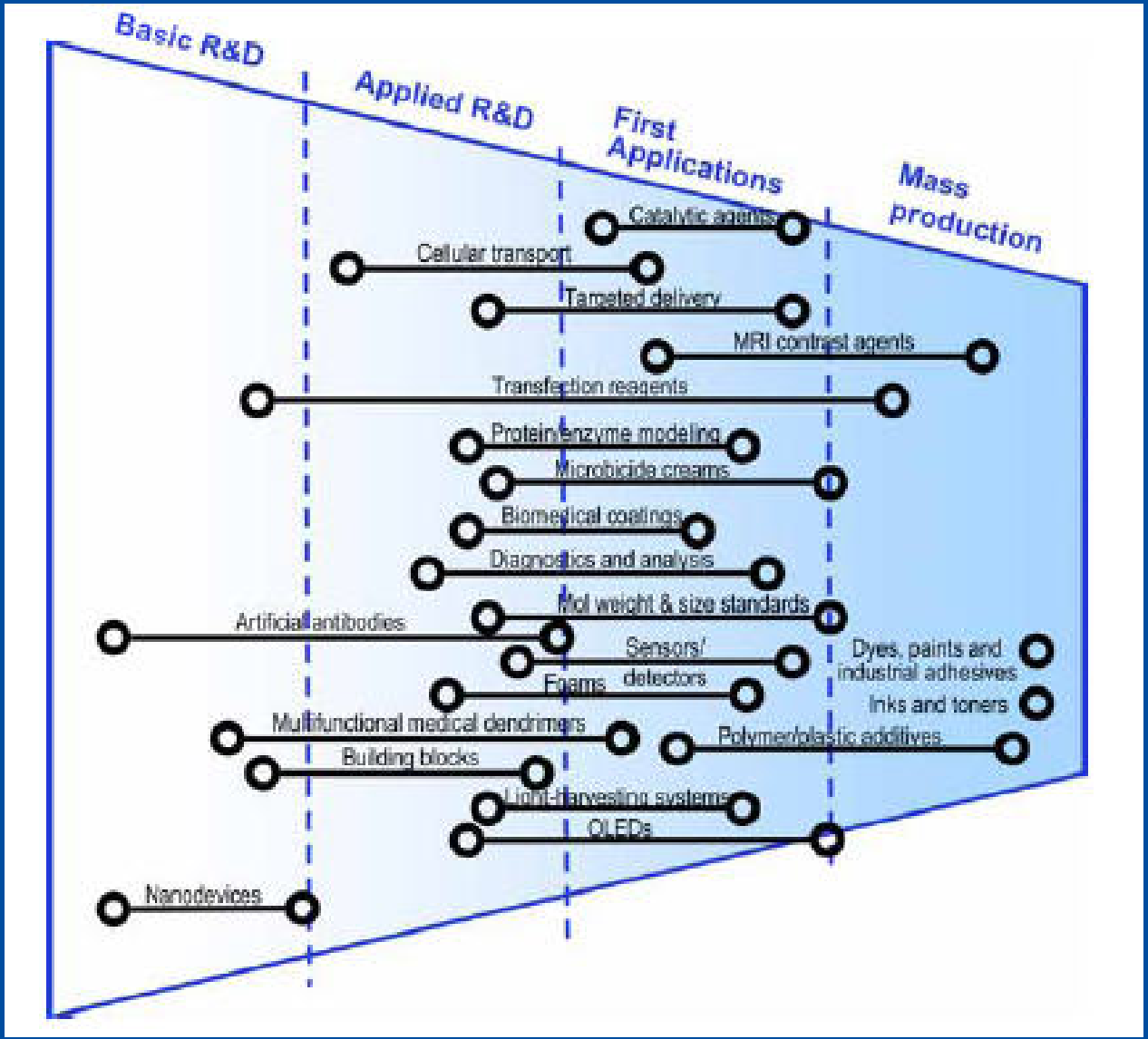
Time to market: Situation at 2010



Source:

willems & van den wildenberg España sl

Time to market: Situation at 2015



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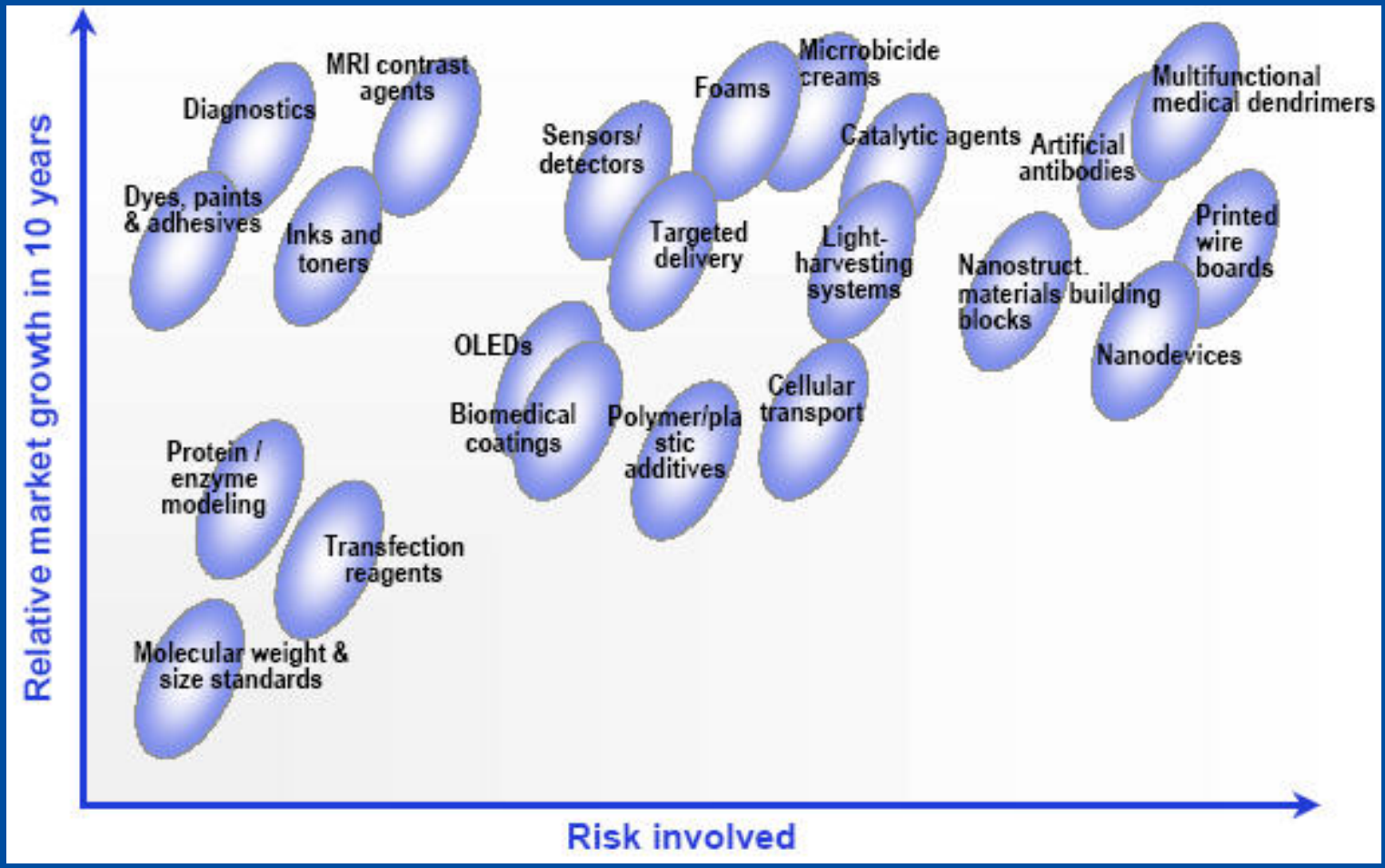
Source: willems & van den wildenberg España sl

Estimated market growth vs. risk involved



Source: willems & van den wildenberg España sl

Some Barriers to Breakthrough

• **HIGH COSTS FOR SYNTHESIS AND FUNCTIONALIZATION:**
- ***A LIMITING FACTOR FOR MATERIALS APPLICATIONS***
- ***LESS IMPORTANT IN MEDICAL APPLICATIONS***

• **PROCESS CONTROL METHODS, SPECIFICATION and FINAL PRODUCT ANALYTICAL METHODS ARE NEEDED TO ENSURE REPRODUCIBLE, HIGH PURITY AND WELL DEFINED PRODUCTS.**

• **POSSIBLE HSE IMPACT**

Source: willems & van den wildenberg España sl

HEALTH AND MEDICAL SYSTEMS ROADMAPS

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Topics Selection

1) Tissue Engineering/
Regenerative Medicine
2) Bio Nano Structures
3) Drug Encapsulation /
Drug Delivery /
Drug Targeting
4) Molecular Imaging
5) Biophotonics
6) Biocompatible implants
7) Biomimetic Membranes
8) Biomolecular sensors
9) Biochips/
High Throughput Screening
10) Lab-on-a-chip
11) Functional Molecules:
Switches, pumps,
means of transportation

1) Drug encapsulation/
Drug delivery/
Drug targeting
2) Molecular Imaging/
Biophotonics
Biochips/
3) High-Throughput Screening/
Lab-on-a-chip technology
4) Biomolecular Sensors

Source: VDI VDE IT

Drug Encapsulation/ Drug Delivery/Drug Targeting

NANOTECHNOLOGY WILL BE INCREASINGLY USED TO ANSWER THE DEMAND FOR EVER MORE SPECIFIC DRUGS AND DIAGNOSTIC AGENTS BY MAKING POSSIBLE THE CREATION OF SYSTEMS WHICH CAN ALLOW THE DRUGS TO BE DELIVERED TO DISTINCT AREAS WITHIN THE BODY TO PROVIDE A BETTER AND MORE EFFECTIVE WAY OF TREATMENT.

Source: VDI VDE IT

Main Advantages of Nanoparticles for Drug Encapsulation/…

•SPECIFICALLY DRIVEN GUIDANCE COMBINED WITH A SUITABLE ENCAPSULATION IN A NANOPARTICULATE FORM.

• ABILITY TO OVERCOME BIOLOGICAL BARRIERS (SUCH AS PERMEATE THROUGH CELL WALLS).

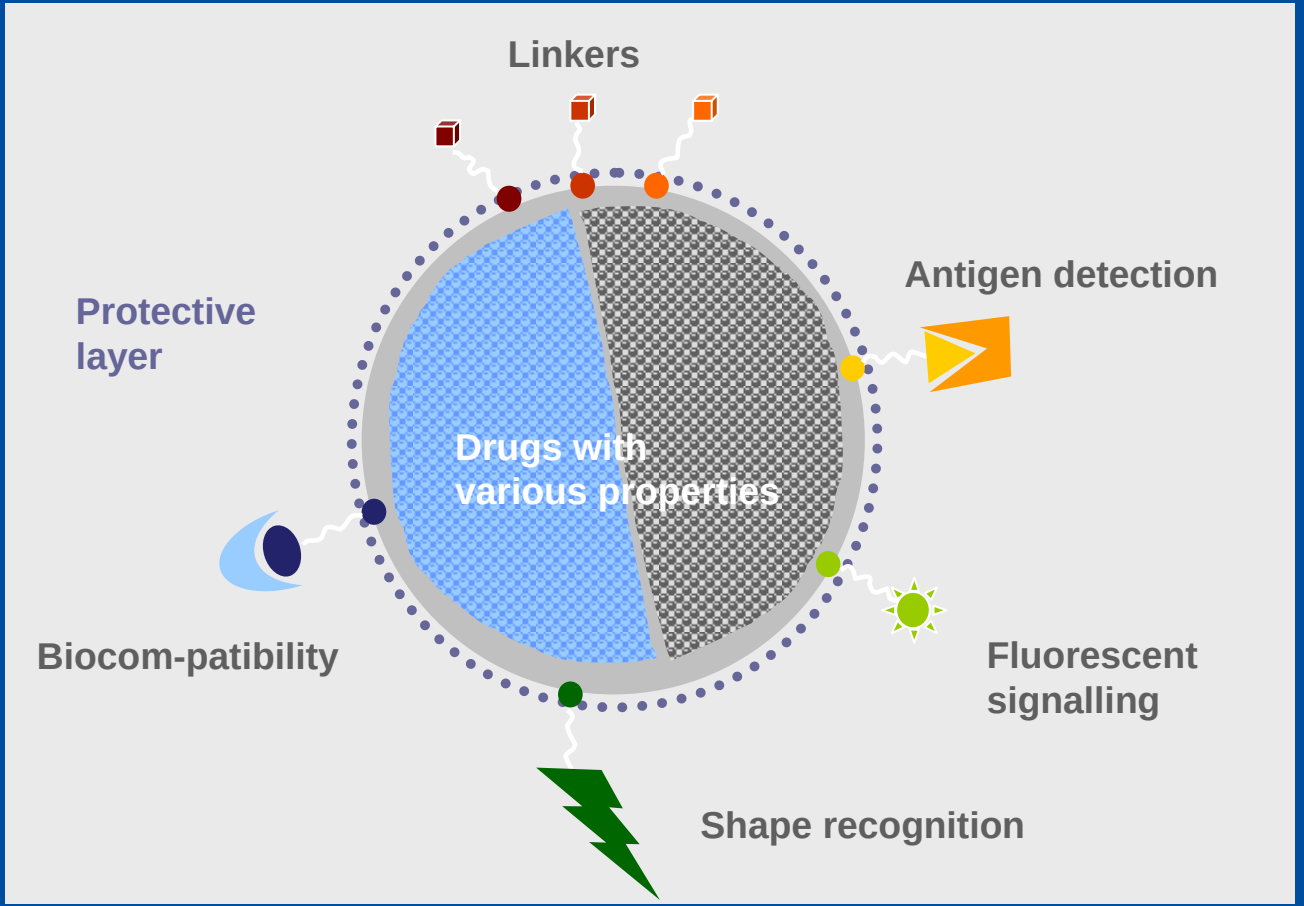
•ABILITY TO RELEASE DRUGS IN A CONTROLLED MANNER.

• FUNCTIONALIZATION FOR TARGETING AND TO BE DETECTED BY DIAGNOSTIC SYSTEMS.

• LARGE SURFACE/VOLUME RATIO RESULTING IN ENHANCED ACTIVITY.

Expected Impact/Advantages

- Reduced drug degradation
- Specificity
- Less side-effects
- Longer therapy duration
- Administration of difficult deliverable pharmaceuticals
- "Solubilisation"
- Controlled drug release



Source: VDI VDE IT

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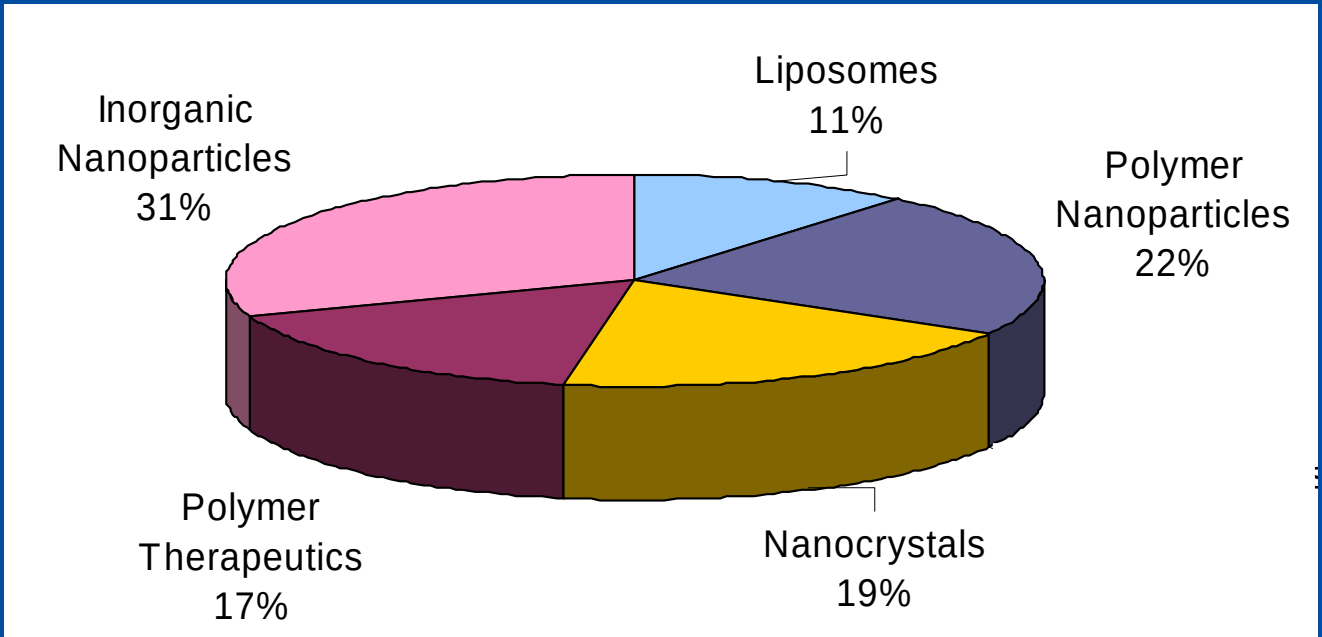
The Nano-particles

SEVERAL TYPES OF NANOPARTICLES ARE USED:

- **INORGANIC NANOPARTICLES (EX. GOLD, SILICATE, CALCIUM PHOSPHATE, MAGNETIC NANOPARTICLES, ETC.);**
- **POLYMER NANOPARTICLES (EX. POLYSACCHARIDES, POLY LACTIC ACID, POLYACRILATES, ETC.);**
- **POLYMER THERAPEUTICS (EX. POLYMER DRUGS, POL. DRUG CONJUGATES, POL. MICELLES, ETC.);**
- **NANOCRYSTALS (EX. NANO-SIZED MILLED DRUGS);**
- **LYPOSOMES.**

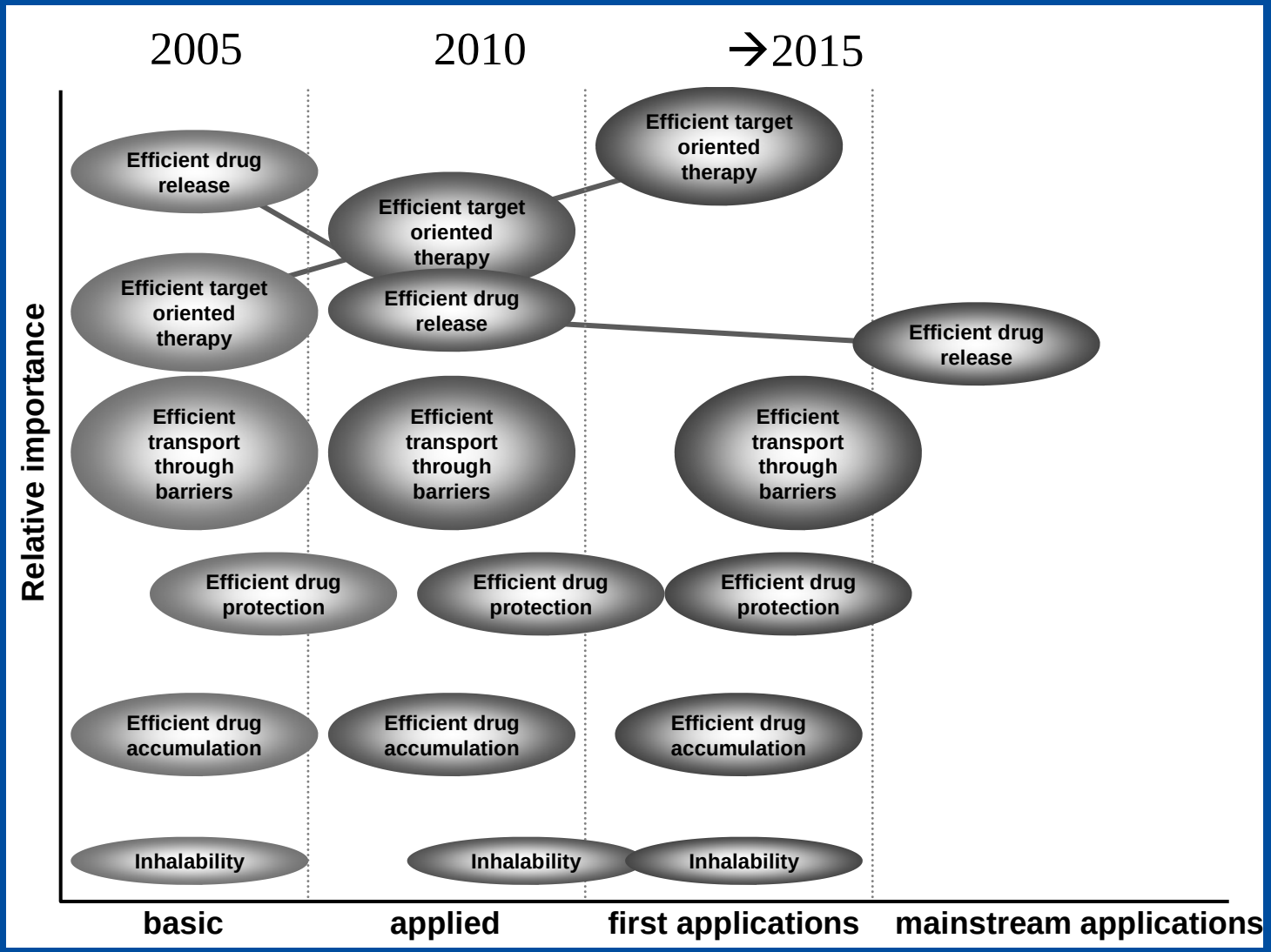
Source: VDI VDE IT

Most Suitable Nanoparticles



Source: VDI VDE IT

Time to Market



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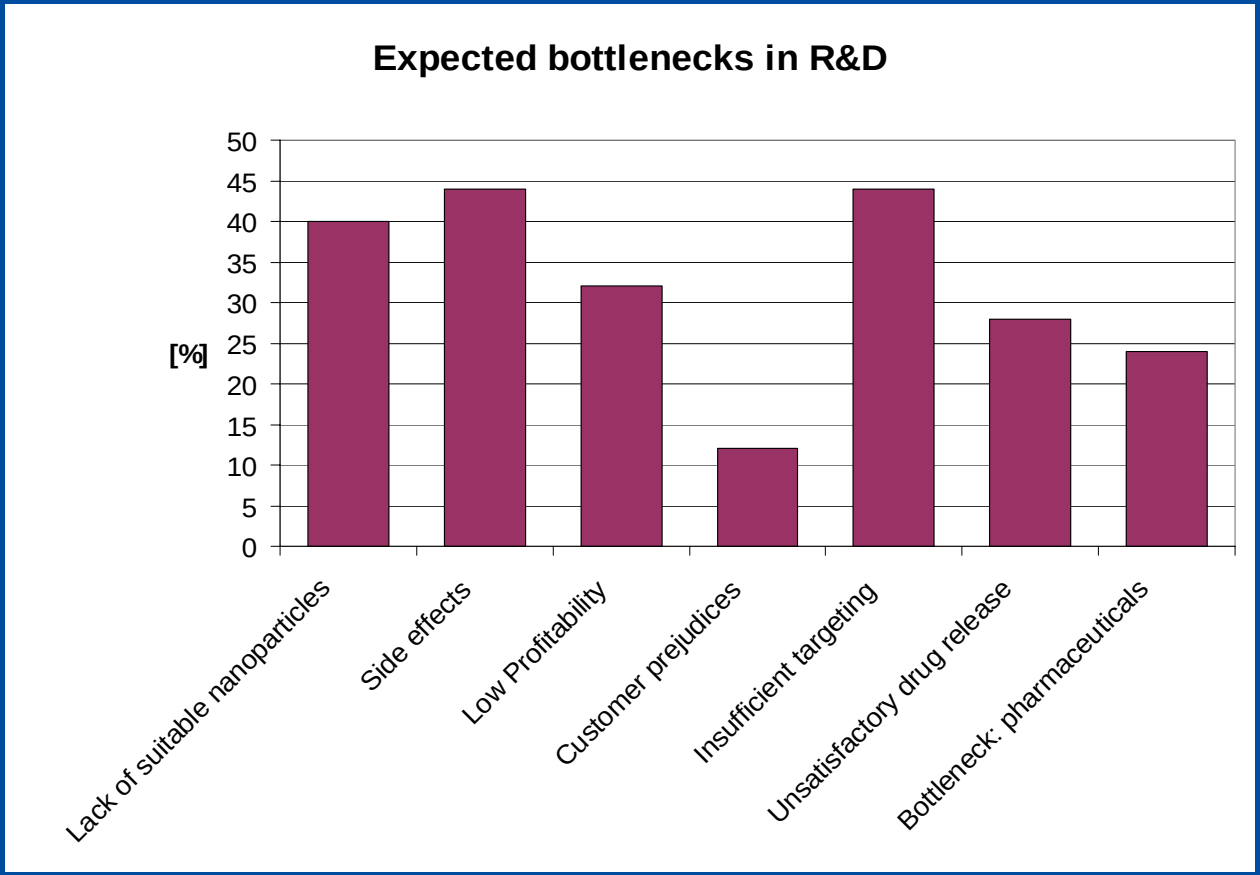
Source: VDI VDE IT

Gaps and Barries in Nano-Drug Delivery/……

Lack of nanoparticles: Investigation on new type of nanoparticles is needed!

Side effects (general cell toxic effects!!)

Insufficient targeting (coupling of specific particle-linked side-groups to their correspondent target molecule)



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Source VDI VDE IT

NANO-RELATED DRUG THERAPY IS STILL AT ITS EARLY STAGE

- **DRUG RELEASE AND THERAPY RESULTS AS THE MOST PROMISING AND IMPORTANT FIELD OF APPLICATION WITH TARGET ORIENTED TERAPY TAKING THE LEAD BY 2015.**
- **INORGANIC NANOPARTICLES AND POLYMER NANOPARTICLES ARE CONSIDERED THE MOST APPROPRIATE NANOPARTICLES (NP), EVEN THOUGH EXPERTS AGREE THAT CURRENTLY AVAILABLE NP IS INSUFFICIENT TO SOLVE ALL EXISTING DRUG - DISTRIBUTION PROBLEMS.**
- **THE NARROW SPECTRUM OF SUITABLE NP AND INADEQUATE TARGETING ARE THE MAIN BOTTLENECKS IN R&D.**
- **SCALABILITY OF NP PRODUCTION, MANUFACTURING STANDARDS FOR NANOMATERIALS AND A DEEPENED KNOWLEDGE OF NP PROPERTIES ARE CHALLENGES TO FACE IN THE FUTURE**
- **SAFETY ISSUES OF NP (ex. CELL TOXICITY) MUST BE CONSIDERED WITH RESPECT, BESIDES CLINICAL USE, TO THE ENVIRONMENTAL AND MANUFACTURING.**

Source: VDI VDE IT

ENERGY ROADMAPS

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Topics Selection

1) Solar cells
2) Fuel cells
3) Thermoelectricity
4) Rechargeable batteries
5) Supercapacitors
6) Hydrogen storage
7) Insulation
8) Glazing Technology for Insulation
9) More efficient lighting
10) Combustion

1) Solar cells
2) Thermoelectricity
3) Rechargeable Batteries and Supercapacitors
4) Heat Insulation and Conduction

Source:

THE INSTITUTE OF NANOTECHNOLOGY

Solar Cells

SILICON IS CURRENTLY THE MOST COMMON ELEMENT USED TO MANUFACTURE SOLAR CELLS, TO CONVERT DIRECTLY SUN ENERGY INTO ELECTRIC ENERGY BUT OTHER INORGANIC AND ORGANIC MATERIALS AT NANOSCALE BEING DEVELOPED LOOK PROMISING:

CRYSTALLINE SOLAR CELLS
(PRESENTLY MONO AND POLYCRISTALLINE SILICON)

AMORPHOUS/THIN FILMS
(CURRENTLY AMORPHOUS SILICON,COPPER INDIUM DISELINIDE)

ORGANIC DYE SENSITISED
(TITANIUM DIOXIDE NANOPARTICLES&DYES)

POLYMER CELLS
(ADDITION OF** LIGHT ABSORBING NANOMATERIALS IN CONDUCTIVE POLYMERS, **EX. POLYPHENILENE VINYLENE)

QUANTUM DOTS
(NANOSCALE CRYSTALS SEMICONDUCTORS)

QUANTUM WELLS
(UNLTRATHIN LAYER SEMICONDUCTORS)

CARBON NANOTUBES and FULLERENE

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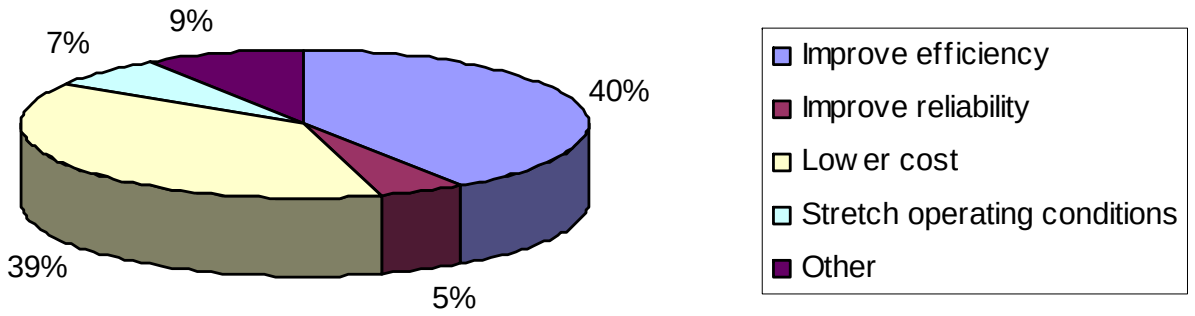
Impact/Advantages from Nanotechnology

Advantages:
Increase efficiency
Decrease costs

Major focus:
-Thin films,
-Nanocrystalline materials
-Nanoparticles

Most revolutionary properties in nanomaterials compared with existing technologies



Nanotechnology will play a relatively minor role in market applications in 2010, strengthening by 2015.

Source:

THE INSTITUTE OF NANOTECHNOLOGY

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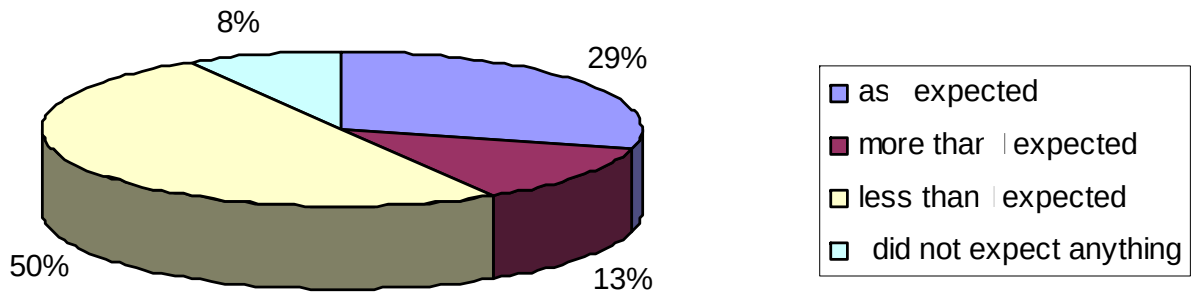
According to the experts, current nanotechnological progress is advanced ….



+

- dye-sensitized solar cells
- nanostructured solar cells
- carbon nanotubes
- molecular modeling
- advances and applications in chemical synthesis
- ionic liquids (and their semi-solidification)

−

- solid organic electrolytes
- charge separation/efficiency
- high gas barrier films
- air-stable polymers
- efficient thin-film modules
- commercially available nanotechnology-based solar cells

Source: THE INSTITUTE OF NANOTECHNOLOGY

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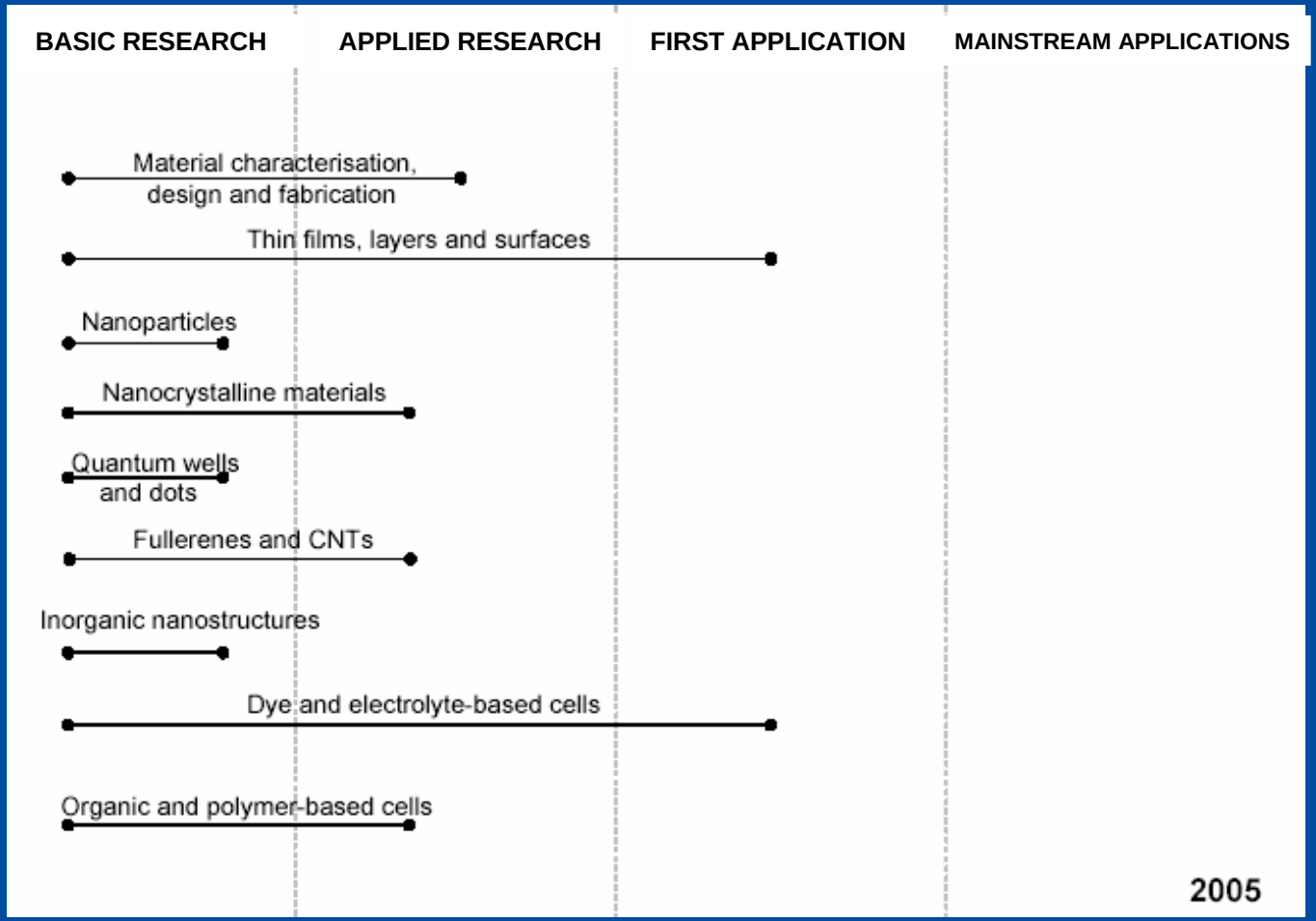
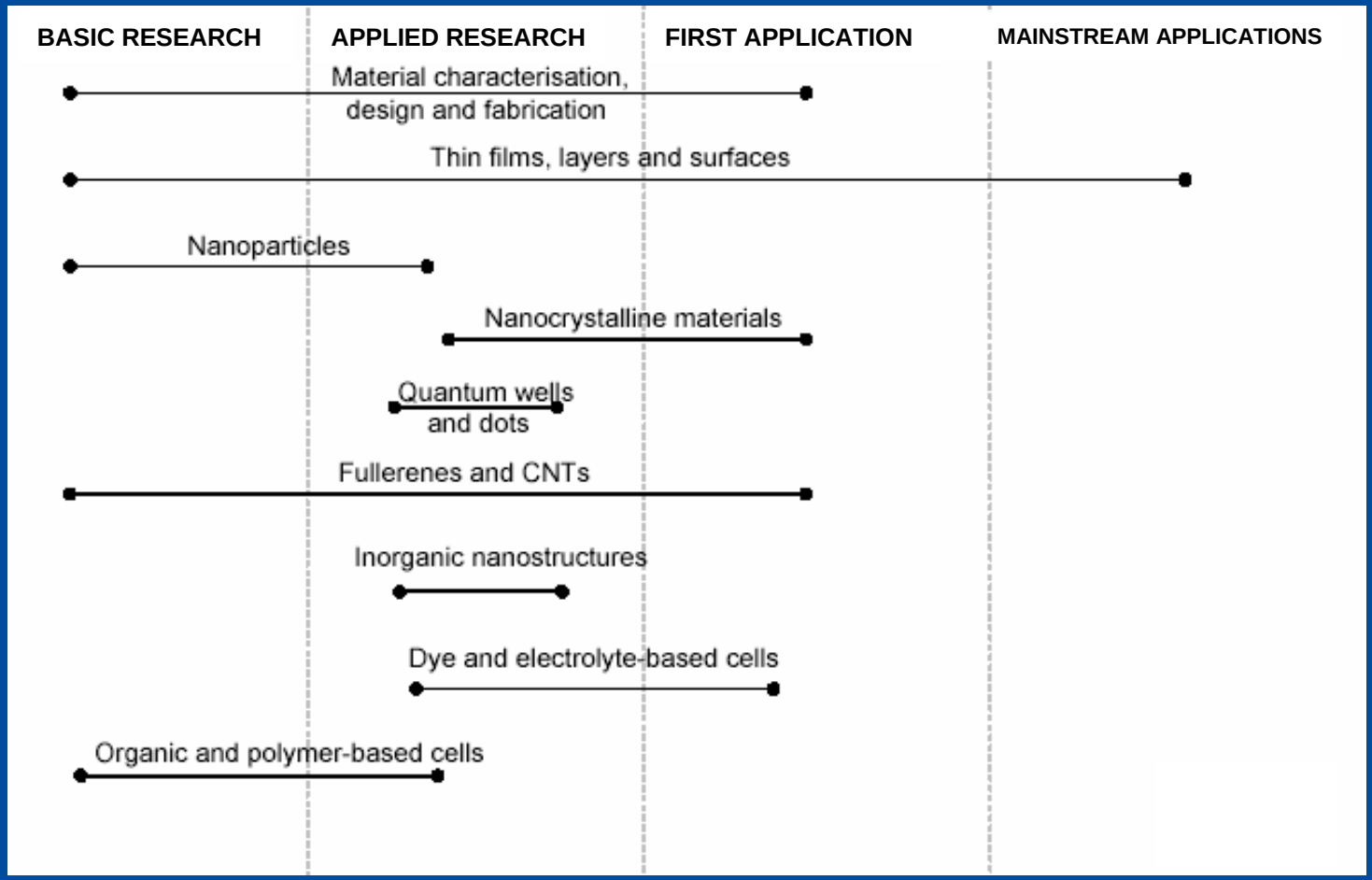
Time to market: Situation at 2005



Source:

Time to market: Situation at 2010



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Source:

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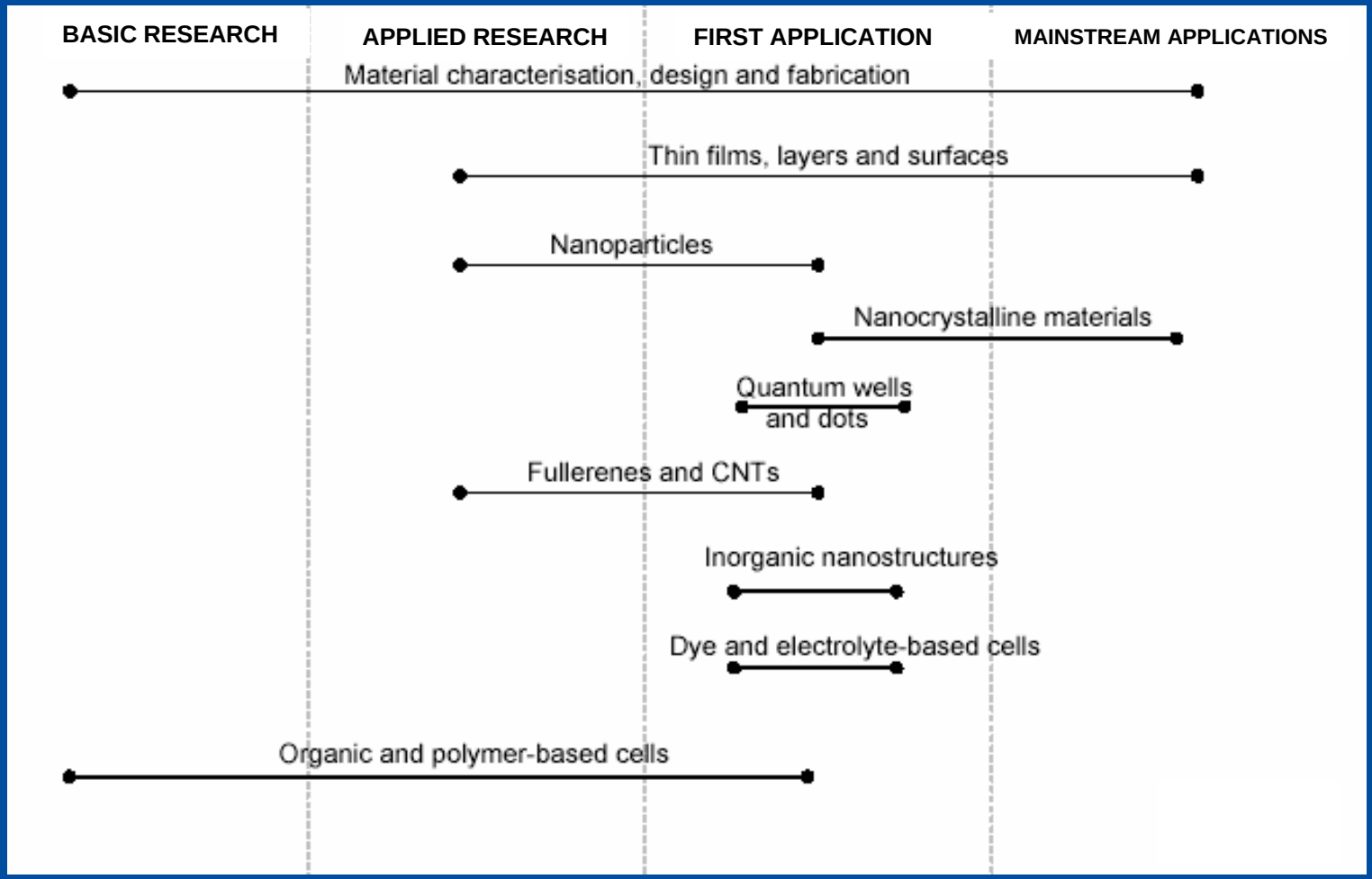
Time to market: Situation at 2015



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Source:

THE INSTITUTE OF NANOTECHNOLOGY

- **AT PRESENT NANOTECHNOLOGY IMPACT ON SOLAR CELLS IS IN THE BASIC RESEARCH PHASE.**
- **NANO-THIN FILMS ARE SEEN AS THE MOST PROMISING AREA IN THE MEDIUM TERM.**
- **FIRST APPLICATIONS ARE EXPECTED FOR 2010, TO BE WELL ESTABLISHED BY 2015 .**
- **CELLS INCORPORATING NANOCRISTALLYNE MATERIALS AND DYE-BASED WILL CLOSELY FOLLOW THIN FILMS TO REACH COMMERCIALISATION BY 2015.**
- **TECHNOLOGIES INCLUDING QUANTUM DOTS, FULLERENES AND CARBON NANOTUBES ARE NOT EXPECTED TO SEE FULL COMMERCIAL APPLICATION BEFORE 2015.**

Source: THE INSTITUTE OF NANOTECHNOLOGY

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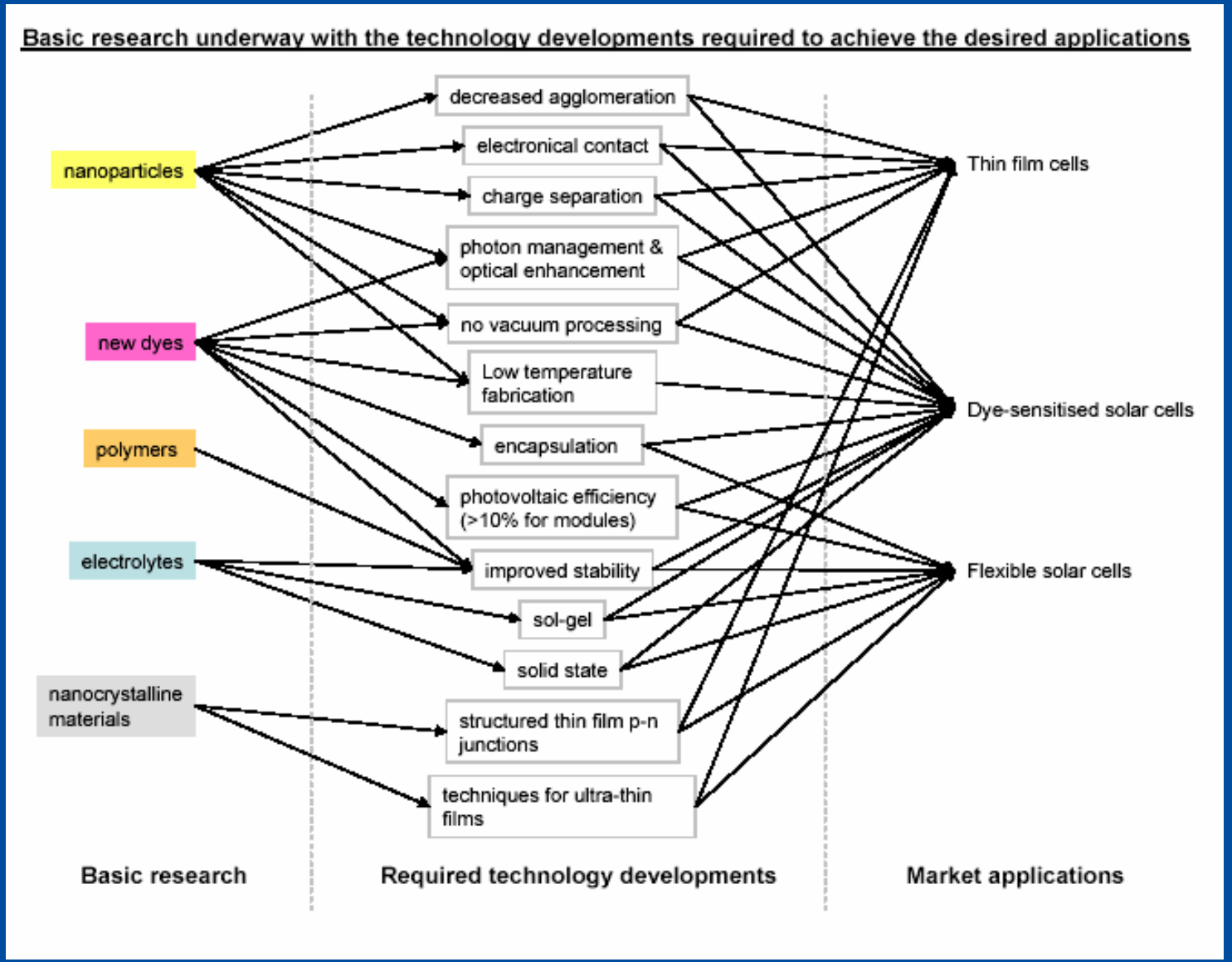
General Challenges Over the Next Decade

- REDUCE COSTS OF BOTH THE FABRICATION PROCESS AND FINAL PRODUCTS.
- INCREASE RELIABILITY.
- INCREASE EFFICIENCY OF FABRICATION AND PRODUCT.
- INCREASE LIFETIME.
- DEVELOP INNOVATIVE LIGHT TRAPPING STRUCTURES.
- OBTAIN AND STABILISE NANOPARTICLE CONCENTRATION AT>60%.
- NEW TECHNIQUES TO FORM ACTIVE LAYERS IN THIN FILM SOLAR CELLS.
- IMPLEMENT NANOTECHNOLOGY INTO INORGANIC SOLAR CELLS.

Source:

THE INSTITUTE OF NANOTECHNOLOGY

Research and technology development underway



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Source:

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Conclusion…

NANOTECHNOLOGY IS POSED TO REVOLUTIONISE THE INDUSTRIAL LANDSCAPE AND EVERY DAY LIFE.

FOR THIS TO HAPPEN TO THE FULL THE WAY IS, HOWEVER, STILL LONG.

THE ROADMAPS PROVIDE A COHERENT SCENARIO ABOUT THE POSSIBLE EVOLUTION OF NANOTECHNOLOGY APPLICATION IN THE THREE SECTORS CONSIDERED, USEFUL TO OPTIMISE AND BETTER ADDRESS THE EFFORTS IN THESE FIELDS.

RESEARCHERS, PUBLIC BODIES, THE EC INFIRST PALCE FOR FP7, INDUSTRIES (IN PARTICULR SMEs), POLICY MAKERS, PLANNERS, THE FINANCIAL COMMUNITY, CAN ALL TAKE ADVANTAGE OF THEM.

THANKS FOR YOUR ATTENTION!

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