ועדת בדיקה מקצועית מטעם פורום תל״מ
לעניין תשתיות למחקר ופתוח בתחום הננוטכנולוגיה

ספטמבר 2002

<u>חברי הועדה:</u>

ד״ר דן מידן - יו״ר
פרופ׳ גד בהיר
פרופ׳ אורי בנין
ד״ר מאיר ויינשטיין
מר דן וילנסקי
פרופ׳ יהושע יורטנר
ד״ר גיורא ירון
פרופ׳ אורי צ׳שנובסקי

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EXECUTIVE SUMMARY

Nanoscience and Nanotechnology (referred to in this report as "Nanotechnology") are the preparation, characterization, manipulation, and control of single or small groups of atoms or molecules to construct new materials (on the billionth of a meter scale) with unique novel properties, which could be used for new applications, and/or for reducing the costs of existing applications. It thus could prompt valuable new innovation in broad areas of electronics, energy, medicine, defense, etc.

Israeli research institutions have at their disposal some of the capabilities enabling initial work in the Nanotechnology arena. Yet in the coming years, Nanotechnology will require a strong infrastructure to promote the essential formation of a very strong industry to meet the special security and economic needs of the state.

Israel is a small country with limited financial resources and impressive human capital. While subjected to severe defense constraints, the country is successfully building its research system, technology infrastructure and modern industry. Due to the unique situation of Israel, it is imperative–for the future economic development and stability of the nation–to ensure close, intensive and effective collaboration among academic institutions, industry, and government.

Professor Jacob Ziv, the President of the Israel Academy of Sciences and Humanities and the chair of the TELEM Forum, has established a Committee, whose mission was to develop a long-term plan to build the R&D infrastructure necessary for making Nanotechnology the next wave of successful industry in Israel. The charge of the Committee was:

1. Survey nanotechnology scientific and technology potential and existing activities (in Israel and abroad) in light of technological, industrial, and military development
2. Map and identify infrastructure required for R&D in Israel within the universities, industry, and national labs, and check the possibilities for local and international cooperation
3. Recommend potential actions for TELEM Forum in Nanotechnology

The Committee members were: Dr. Dan Maydan (Chair) of Applied Materials, Inc., Prof. Gad Bahir of the Technion, Prof. Uri Banin of the Hebrew University, Prof. Ori Cheshnovsky of Tel-Aviv University, Prof. Joshua Jortner of Tel-Aviv University, Mr. Dan Vilenski (Secretary) of Applied Materials, Dr. Meir Weinstein of the Ministry of Defense, and Dr. Giora Yaron of Exanet, Inc. The Committee was supported by two staff members from Applied Materials: Mr. Kalman Kaufman and Mr. Iddo Hadar. Valuable support to the work of the Committee was provided by other staff of Applied Materials.

The Committee has surveyed Nanotechnology work in Israel and abroad, developed and analyzed various alternatives for setting priorities and allocating resources, and has finalized its recommendations in this report.

The Committee recommends *launching immediately a collaborative government/academia/ industry initiative to allow Israel to effectively reach critical mass and global leadership in Nanotechnology*. The Committee also recommends the establishment of the Israel Nanotechnology Program to make Nanotechnology the next wave of successful industry in Israel by creating an engine for global leadership.

We recommend that investments in Nanotechnology research resources and capabilities in Israel be made with an eye towards their opportunity for technology development and their possible commercial viability. This is similar to the approach used in the past to develop capabilities critical for national defense, but is unprecedented within Israel's civilian infrastructure. However, we believe that this approach is warranted due to the unique characteristics and current situation of Nanotechnology:

1. Israel stands the risk of being left behind: Nanotechnology–on a global basis–has already moved beyond the early stages of scientific research. The interest in applications is strong and accelerating: for example, the bulk of the U.S. Department of Defense's spending on Nanotechnology has shifted in 2001 from research to applications. Similarly, companies in multiple industries are beginning to recognize the real-world opportunities of this emerging technology.

2. Focus is critical for Israel's effective use of resources: The scope of Nanotechnology is very broad and cross-disciplinary; This requires focus on selected directions and applications, instead of spreading resources across multiple areas. Concurrently, support of broader research areas by other National and Binational agencies may be implemented. This challenge of Nanotechnology was acknowledged by a recent U.K. report on Nanotechnology, which emphasized the importance of focusing on a few applications, which play to the country's strengths, instead of spreading resources across multiple areas.

3. Israel needs a national policy of resource allocation in Nanotechnology: In civilian applications of Nanotechnology, Israel lacks an obvious strong "user" capable of driving the priorities in research and development towards viable applications. The allocation of resources should thus explicitly aim to properly channel them to appropriate opportunities, as Israel does not yet have a working "market mechanism" for prioritization.

Such increased focus on ultimate technology applications should result in the optimization of the use of resources, faster realization of market viability, more pronounced impact on the Israeli economy, and ultimately the development of local industry, which should be able to support further research work on a self-sustained basis; Nanotechnology can thus become an engine of national strength, academic excellence, and economic growth for Israel.

We recommend launching a five-year Israel Nanotechnology Program aimed at realizing ten-fold increase in the Israeli Nanotechnology capability. The activities of this program should be organized to support scientific research and technology development, as summarized in Table 1:

	Research	Technology Development
Target Result	Know-how and tools required for technology development	Opportunities ready for transfer to product innovation and commercialization, VCs, etc.
Effort led by….	Universities, research institutions, and national labs	Industry
In collaboration with…	Industry	Universities
5-year Investment		
Infrastructure	$100M +	$25M
Prototyping Capability	$100M	
Projects	$15M +	$75M
Source of Funds	Private Donors + Telem (incl. Ministries of Defense, Industry) + matching funds, international collaboration (e.g., BSF, GIF)	Telem, Ministry of Defense, Ministry of Industry (Magnet, OCS), other public (to be negotiated), industry, global, international collaboration (e.g., BIRD, EU programs)
Success Metrics (2007)	• 40 graduates annually • High quality, interdisciplinary publications • 100 patents	• 100 patents • $40 industry funding • 5 start-ups with $150M in VC funding and 750 employees

A National Nanotechnology Board should be set up to allocate funds, monitor performance, and guide implementation of this Program through 2007.

This Committee believes that Nanotechnology can and should become a core driver of academic and economic progress in Israel. Realizing this vision would entail new roles for academy and industry, a clear organization, increased funding, tight collaboration, and a serious approach to oversight and implementation.

Such requirements are difficult for any nation, at any time–let along for Israel at this moment in history. However, we strongly believe that commitment to this vision and its implementation should allow Israel to reap significant rewards for years and decades to come.

THE NANOTECHNOLOGY COMMITTEE

NANOTECHNOLOGY:

NATIONAL STRATEGY FOR ISRAEL

FINAL REPORT

September 30, 2002

THE OPPORTUNITY

- Nanoscience and Nanotechnology[1] represent a potential major disruption to a host of science, engineering, technology, medicine, energy and defense fields.
- This provides Israel with
  – a near-term opportunity to focus research;
  – a long-term opportunity to gain economic and national benefits and foster growth.

MISSION

To make Nanotechnology the next wave of successful industry in Israel by creating an engine for global leadership.

PROBLEM STATEMENT

- Scope of Nanotechnology is very broad – making it currently difficult to focus.
- Israel's resources pale in comparison to global efforts.
- Distribution of diverse efforts across institutions and subjects prevents Israel from reaching critical mass.
- Israel lacks a natural "leading user," especially in civilian applications.
- Accordingly, we need to focus activities in science, technology, and industry in order to leverage Israel's capabilities for benefits in areas of highest national priority.

OVERALL STRATEGY

Launch immediately a *collaborative* government/academia/industry initiative to allow Israel to *efficiently* reach *critical mass* in Nanotechnology.

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[1] Generally in this report the term "Nanotechnology" will be used to also include "nanoscience," that is, the scientific know-how and tools providing the enabling foundation for Nanotechnology

KEY FINDINGS

- Nanotechnology holds great promise for a broad range of new potential applications:
  - Nanotechnology is the preparation, characterization, manipulation, and control of single or small groups of atoms or molecules to construct new materials (on the billionth of a meter scale) with unique novel properties, which could be used for new applications, and/or for reducing the costs of existing applications;
  - It thus could prompt valuable new innovation in broad areas of electronics, energy, medicine, defense, etc.;
  - Nanotechnology worldwide is in the early stage of innovation, with new and original applications yet to be discovered.
  - Nanotechnology leverages the existing infrastructure of microelectronics, chemistry, and molecular biology, and has thus been able to move rapidly into its current stage: on the threshold of the "Technology Development" phase (see Attachment 3);
  - Significant public funding at U.S. institutions is already focused on applications (see Attachment 4)
- In Israel, Nanotechnology research is spread in the universities, initiated by the researchers (over 120 at this time). The quality of research in Israel is high, as reflected in over 100 patents and numerous publications[2]. The universities recognized the importance of the field and are active in setting centers to provide research infrastructure. However, the Israeli effort in Nanotechnology is largely distributed across institutions and subjects, increasing the demands for investment (see Attachment 5).
- Global funding for Nanotechnology exceeds $ 2 billion annually, with basic research done primarily in U.S., Europe, and Japan, and applications pursued in most countries (see Attachment 4).
  - The level of spending required for research is significant

[2] A recent analysis of international science and technology indicators for Nanotechnology during 1997-1999 conducted by the Institute of Physics Publishing (see Attachment 16), places Israel as number 2 in publications and as number 3 in patents ranking (per 1M inhabitants) among the 15 most "effective" countries in Nanotechnology.

        - In the U.S, a typical researcher requires $ 600K to set up and $ 200K per annum in operating budget
        - NASA funds 50 researchers at $220K annually + 4 Centers of Excellence at $3M/year per program
    - U.S. alone is spending close to $ 1B annually, with 70% from public funds; public funding in Japan and Europe is comparable.
    - The U.S. program is broad in its scope (see Attachment 6).
    - Venture capital funding for Nanotechnology reached about $80 million in 2001, and will likely grow to between $200 M and $300 M in 2002.
- Like other small countries, Israel cannot afford the depth and breadth of the U.S. initiative.
    - Capital spending: About $ 80 million already spent on buildings, salaries and equipment; additional $ 100 million required to bridge major gaps in basic instrumentation.
    - Significant spending – required to "productize" initial research – has not been considered so far.
    - Israel (with a total of over 120 key researchers in Nanotechnology) is at the scale of a single leading US center (e.g., UCLA or UC Santa Barbara– see Attachment 9)
    - Israel is still one of the few developed countries lacking a national policy in Nanotechnology. Telem's initiative in appointing the National Nanotechnology Committee is intended to establish such a policy.
- Possible sources of funding:
    - Private donors have been approached with an application to support Nanotechnology infrastructure equipment in the universities.
    - The Ministry of Defense is willing to fund research and technology development for targeted applications (e.g., in armors, explosives, bio/chem sensors, etc.) but not infrastructure (see Attachment 10)
    - No local industry seems to exist which could finance the innovation at an earlier stage.
- Collaboration is of the essence for Israel's success in Nanotechnology:
    - The nature of Nanotechnology dictates a multi-disciplinary approach: problem-, not discipline-oriented.

- Shortage of human capital requires cross-institution collaboration.
- Limitations of financial resources to maximize collaboration among academia, industry, and government, as well as international partnering.

POLICY

Policy Key Principles

In order to create a critical mass, utilize its human capital and optimize resources, Israel has to establish a world-class infrastructure, provide a focus on innovation, maximize collaboration, and build from strength:

- Application focus: We need to seek unique Science & Technology ideas, yet all work should target (a broad class of) applications; focus should be appropriate to define *direction*, without *prescription*.
- National Strategy: We should leverage existing capabilities to drive disruption (lower costs or advanced new applications) in unique areas which are not necessarily “mainstream” (since those could attract global efforts which might overwhelm Israel’s capabilities).
- National interest: Israel should build strength in areas of importance for its special security and economic needs and/or areas offering unique industrial and academic potential. This requires the definition of areas of priority problems and priority fields of research (see Recommendations section).
- Market “Pull”: The users of the applications, e.g., the Chief Scientist of MOI (for civilian applications) and the Ministry of Defense (for military applications) and key industrial partners, should be providing the necessary “pull” (in funds, cooperation, and guidance) to focus and accelerate Israel’s development activities.
- Collaboration: The special nature of Nanotechnology field calls for collaboration across disciplines, within institutions, across institutions, and with industry and global partners.

Measures of Success

To increase Israeli Nanotechnology capability by an order of magnitude within five years by tripling the resources (staff, equipment, funds) AND increasing the focus (on priority fields of research and application)

- Academic excellence: Significant gains in the level of excellence of Nanotechnology-related academic publications, measured by content (merit), impact (citations), and effectiveness (interdisciplinary work, and/or cross-institution collaboration).
- Growing capability: Two-fold increase in the number of qualified graduates, reaching 40 (annually) by 2007.
- Tangible results: at least 200 new patents by 2007, consisting of 100 in Research areas and 100 in Technology Development.
- Active engagement with technology users: Industry funding of Nanotechnology research to reach at least $5M by 2005 and $20M by 2007.
- Economic impact: About 5 local Nanotechnology-related start-ups with $30M each in venture capital funding by 2007; at least 750 employees engaged in Nanotechnology-related business.

RECOMMENDATIONS:
THE 2003-2007 ISRAEL NANOTECHNOLOGY PROGRAM (INP)

1. **Need for New Roles for Academic and Industrial Research**
   - Expanded role for university: adopt academic culture to create environment of basic research together with start-ups contributing to national priorities.
   - Influence industrial decision-makers (e.g., Chief Scientist) to incentivize start-ups, with an eye toward built-to-last enterprises (see Attachment 11)
   - Common representation (single point of national and international contact) of Israeli Nanotechnology scientific and technological resources.

2. General Structure and Function of the 2003-2007 Israel Nanotechnology Program

During a 5-year period the Program will operate via University–National Laboratories–Industry collaboration based on the existing institutions. Two channels of activity are recommended (see Attachments 1 and 3):

(a) **Research** centered in the universities, with academy–industry collaboration.

(b) **Technology development** centered in industry (and start-up companies) with industry–academy collaboration.

3. Areas of National Priority

3(a). Priority Fields of Research

– Nano-materials

– Nano-bio

– Nano-electronics and Nano-optoelectronics

3(b). Priority Technology Development (Problems) Areas

For civilian applications

– Electronics

– Energy

– Environment / water desalination

– Nano-bio

For defense applications

Ministry of Defense will fund necessary application work in addition to the above, leveraging civilian-driven research.

4. Budget

- The projected scope of the Israel Nanotechnology Program should be comparable to that of a major US center. The allocation of a five-year budget of over $300 Million would be necessary to bring Israel's Nanotechnology development to a stage of readiness to transfer to (civilian) industry: three years away from product availability. This will require:

  (a) Investment of $115M for Nanotechnology research ($100M in infrastructure and $15M in projects)

(b) Investment of $100M for Nanotechnology technology development ($25M in infrastructure and $75M in projects)

(c) Investment of over $100M in a common prototyping facility (recommendation 8) containing significant new capital (subject to Board approval within a year[3])

- The INP is targeted to increase the cumulative Nanotechnology infrastructure investment more than three-fold over five years, from $80M today to over $200M (without a prototyping facility) or over $300M (with a prototyping facility).
- A significant amount of the infrastructure investment would be necessary within the first three years of this Program (in order to enable necessary research and development); project work grants would be tied to emergence of attractive opportunities and availability of industrial partners.
- A preliminary outline of the financial resources (see Attachment 12)
  - The projected $100M budget for most of the research investment consists of (not yet approved).

Contribution from the private donors (equipment)	$ 25M
University matching (salaries, building, equipment, donations)	$ 50M
National resources (Telem)	$ 25M
Total for research	$ 100M

  - The sources of additional budget of $215M have to be identified (inside Israel as well as globally); they could include Telem, Ministry of Defense, Ministry of Industry (Magnet, OCS), other public (to be negotiated), private donors, Israeli and global industry, and international collaboration (e.g., BSF, GIF, BIRD, EU programs) [see Attachment 13]. However, there is no need to await the availability of all funds: existing funds should already be used effectively, in a focused way, consistent with the recommendations of this report.

[3] Note: The establishment and operation of such facility, subject to approval of the National Nanotechnology Board (recommendation 11), should be separately conducted by Telem.

A. Nanotechnology Research Investment Recommendations

5. **Research Investment Requirements**

In view of the current nature and development of the Nanotechnology field, a diversified approach with proper coordination should be preferred for investing in research in Israel.

- The research investment will involve Nanotechnology enabling equipment, large Nanotechnology equipment, and research projects.
- The infrastructure equipment will be centered in the universities, and nationally accessible to Universities, National Laboratories, and industry.
- The research projects will involve the Universities, National Laboratories, and industry.

6. **Funding of Research**

Three different funding mechanisms are proposed:

- **Nanotechnology Research Infrastructure Equipment:** Funding for establishing nationwide accessibility and availability of infrastructure for Nanotechnology. Consisting of the majority of funds (~ 80%) and divided into two sub-categories:
  - **Nanotechnology Enabling Equipment (~ 50% - 60% of available funds)**: Equipment with price up to about $ 1 million that is essential for realizing the focused goals on a university level.
  - **National Nanotechnology Large Equipment (~ 20% - 30% of available funds)**: "Large scale" equipment with price in the range of $1to $3 million to serve as a national facility for Nanotechnology.
- **Nanotechnology Research Projects (~ 20% of available funds)**: Interdisciplinary 4-year research programs providing $300,000 – $500,000 per project per year (about $100,000 per year per each participating group) to promote the specific goals, aimed at achieving technological potential.

7. **Criteria for Funding of Research**

- **Nanotechnology Infrastructure Equipment**

A nationwide call will be solicited for the establishment of necessary equipment in the different universities in a three-year program plus two additional years for extension and adjustments. Each University will submit a detailed proposal describing the needed equipment and its use in research programs aimed at achieving the INP's goals. Funding for the different tracks will be administered by a National Nanotechnology Board (see below) according to the following criteria (see Attachment 14):

Nanotechnology Enabling Equipment:

- Relevance to national priorities
- Scientific and technological innovation
- Track record of participating investigators as measured by publications, impact, and patents
- Suitability of researchers
- Commitment of institution as indicated by matching funds, manpower, service of equipment and suitability of existing infrastructure

National Nanotechnology Large Equipment: One piece of equipment of each type to be acquired nationally:

- Relevance to national priorities
- Scientific and technological innovation
- Track record of participating investigators as measured by publications, impact, and patents
- Suitability of researchers
- Commitment and detailed mechanism for serving as a National Facility, including matching funds, operating budget, manpower, service of equipment, uniform users fee for suitable users in Israel

- **Nanotechnology Research Projects**

A nationwide call will be solicited for 4-year research projects. Criteria for funding:

- Applicability to national priorities
- Scientific and technological innovation and potential

- Existing capabilities available to the institution (minimum of $1 million in matching funds for annual operating budget for the relevant application)
- "Team excellence:" Track record of participating investigators as measured by publications, impact, , and patents
- Suitability of researchers
- Interdisciplinary nature: Quality of intra-university, inter-university, and/or university–industry collaboration
- Impact: potential contribution relative to funds required

B. Nanotechnology Technology Development Investment Recommendations

8. **Technology Development Investment Requirements**

Nanotechnology Technology Development (time horizon of 3-7 years) should be supported through four mechanisms:

- Funding development infrastructure and projects (see below), closely tied to national priorities and industry emphasis.
- Creating "market pull":
  - For civilian use, Israel lacks a strong "market pull"; to close this gap, a Nanotechnology Collaborative Center (NCC), a "virtual" joint center of academia and industry for high-priority applications, will be launched:
    - Single point of contact for promoting and accessing resources nationwide (supporting representation and alignment through ision and coordination).
    - 2003 Objective: Pilot one application as a joint industry-academia collaboration (topic selected per the availability of an industrial partner).
    - NCC will receive an annual budget determined by the National Nanotechnology Board from 2004 through 2006; budget commitment beyond 2006 will continue only so long as the Center is able to raise at least the same amount in matching funds from industry.

- NCC director will be appointed by the National Nanotechnology Board for two-year appointments, per the recommendation of a Search Committee.

– For military applications, institutions will receive funding from the Ministry of Defense per mission requirements.

- Building a capability for prototyping and pilot production as means of accelerating development and facilitating transfer to commercialization. Following the launch of national activities and within no less than 12 months, the Committee should be reconvened to evaluate a common facility containing significant new capital, focused on target exploratory work.
- Building a capability for Product Innovation by funding start-ups, while providing incentives to strong business enterprises with global infrastructure and execution capability; this should result in an industry "built to last" (see Attachment 11). In the later years of the INP, areas of Israeli comparative advantage within Nanotechnology will likely emerge, allowing technology development and product innovation to further focus.

9. **Funding of Development**

- Technology Development will require investment of at least $100 million; roughly 25% of this amount will be required to upgrade infrastructure in order to meet requirements of specific applications; 75% of funds will focus on specific project work. It is expected that significant portions of this investment will come from industrial partners in Israel and abroad, as well as from collaboration with international research programs.
- Nanotechnology Prototyping Center:
  - Support for exploratory work through pre-production capabilities via services for technology development and commercialization
  - Examples: fabrication center, prototype medium-volume materials processing, etc.
  - Center to be used by all potential industry and academic users within and outside Israel

- Investment exceeding $100 million over five years (additional to the research infrastructure investments) should be considered for launch within a year; sources include government, foreign partners, and industry
- Center is expected to become self-funding within five years
- Center should be established within an existing institution in order to minimize capital investment

10. **Criteria for Funding of Development**

- Development funds will be allocated in a way seeking to create and maintain a level of **global** excellence in the targeted applications. Distribution of funds will be based upon:
  - Potential application (importance to national priorities)
  - Potential contribution relative to funds required (=impact)
  - Track record of university
  - Track record of applicant
  - Level of collaboration
  - Existing capabilities available to the institution (minimum of $1 million in matching funds for annual operating budget for the relevant application)
    - > Institutions can collaborate on projects in order to reach the necessary scale
    - > Starting 2005, funding will be available only for institutions that establish strong formal collaboration with a global partner in the relevant application
- As a specific incentive for commercializing scientific know-how, the National Nanotechnology Board will establish a special grant which will be provided once a year to Israeli researchers, based on the number and quality of Nanotechnology-related patents issued to these researchers.

GOVERNANCE

11. **National Nanotechnology Board**

Telem will appoint a National Nanotechnology Board. The Board's charter will be

- To recommend policy, research and technology development investments, program goals, and management processes
- To oversee the selection of the projects per agreed national priorities, allocate budgets and review progress on approved projects so as to make Nanotechnology the next wave of successful industry in Israel by creating an engine for global leadership

Specific activities of the Board will be

- Implement and adjust policy
- Allocate funding: Select projects of high quality which serve national priorities
- Oversee performance (including publications and patents)

- Chairman and Board will be appointed by Telem and will operate until 2007
- Board's size will be seven members:
  - Three members from the academia
  - Three members from the industry
  - One member from Telem
- Frequency of meetings: once a quarter
- Minimum membership quorum: five

ACKNOWLEDGEMENTS

We wish to thank all Israeli universities and research institutions–particularly the respective Vice Presidents for research–for their cooperation and support for the Committee's work. We appreciate the insights received from several leading American researchers, including Dean A. Richard Newton of U.C. Berkeley and Prof. Noel MacDonald of U.C. Santa Barbara. We would like to thank several Israeli industry leaders for their useful comments and feedback on an early draft of this report. Finally we wish to recognize the significant contribution of various staff from Applied Materials, Inc., throughout the work of the Committee.

ATTACHMENTS

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16. Forecasting the Development of Nanotechnology

Overview

	Research	Technology Development
Target Result	Know-how and tools required for technology development	Opportunities ready for “transfer” to product innovation and commercialization, VCs, etc.
Effort led by….	Universities, research institutions, and national labs	Industry
In collabo-ration with…	Industry	Universities
5-year Infrastructure Investment	$100M + *Future: $100M+*	$25M
5-year Project Investment	$15M +	$75M
Source of Funds	Private Donors + Telem (incl. Ministries of Defense, Industry) + matching funds, international collaboration (e.g., BSF, GIF)	Telem, Ministry of Defense, Ministry of Industry (Magnet, OCS), other public (to be negotiated), industry, global, international collaboration (e.g., BIRD, EU programs)
Success Metrics (2007)	■40 graduates annually ■High quality, interdisciplinary publications ■100 patents	■100 patents ■$40 industry funding ■5 start-ups with $150M in VC funding and 750 employees

SENSITIVE

The Nanotechnology Committee

The TELEM Forum combines the primary public bodies supporting Research and Development in Israel. The Forum has decided on February 19, 2002 to establish a professional multi-disciplinary committee for the studying national infrastructure required for Nanotechnology R&D.

TELEM assigned the committee the following roles:

1. Survey nanotechnology scientific and technology potential and existing activities (in Israel and abroad) in light of technological, industrial, and military development
2. Map and identify infrastructure required for R&D in Israel within the universities, industry, and national labs, and check the possibilities for local and international cooperation
3. Recommend potential actions for TELEM Forum in this area

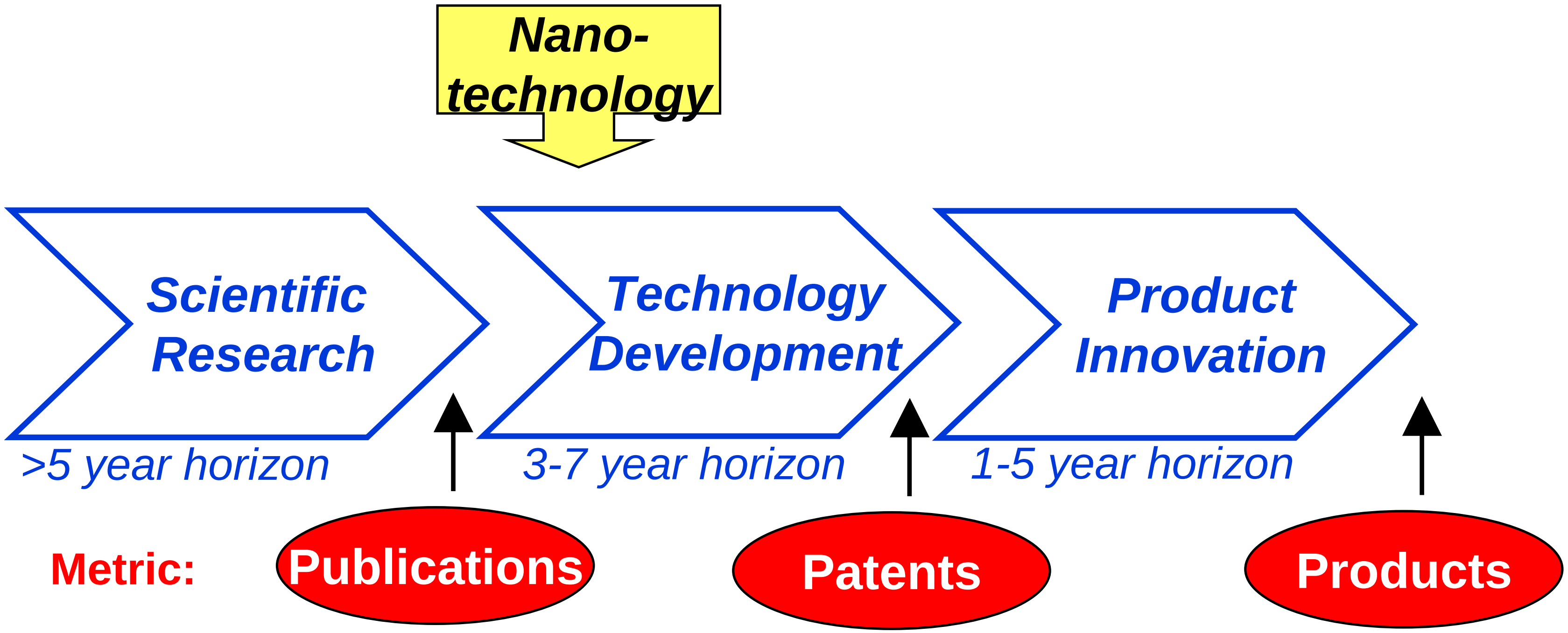
The committee members were:

Dr. Dan Maydan (Chair)
Prof. Gad Bahir
Prof. Uri Banin
Dr. Meir Weinstein
Mr. Dan Vilenski (Secretary)
Prof. Joshua Jortner
Dr. Giora Yaron
Prof. Ori Cheshnovsky

The committee was also supported by two staff members:

Mr. Kalman Kaufman
Mr. Iddo Hadar

Stages of Innovation



SENSITIVE

NANOTECHNOLOGY
Level of Spending

Highlights

- World-wide Nanotechnology spending has exceeded $2 Billion this year
- U.S. is the largest spender–fastest growth is in Japan, Europe, and certain other countries (e.g. Singapore)
- The focus of funding–e.g., for the DOD–has shifted from basic to applied and exploratory research
- An application-focused Nano program requires about $2 Million in annual funding; an average research center may require $10 Million annually (??)
- The breadth of the U.S. effort may be excessive, as suggested by the National Academy of Sciences

Israel's Resources Pale in Comparison to Global Efforts

	2001 Government Spend on Nano ($ M)	2000 GDP ($ B)	Ratio (% of 1/1000th)
W. Europe	$225	$7,039	3.2%
USA	$696	$9,927	7.0%
Japan	$550	$3,247	16.9%
Other OECD	$380	$6,578	5.8%
TOTAL OECD	$1,851	$26,791	6.9%
Israel	$10	$110	9.1%

Assumptions: USA: assume local government spend 1/2 as much as federal government; Israel–estimate

Sources: Dr. M.C. Roco, OECD Statistics, World Bank

Federal Government National Nanotechnology Investment

(In $Millions)	FY 2000	FY 2001 (year 1)		FY 2002 (Yr 2. Appropriation)		FY 2003 (Yr. 3 Request)	
		First Three Years of the National Nanotechnology Initiative (NNI)					
Department/Agency	Actual	Appropr	Actual	2/4/02	Total	2/4/02	Total
Department of Defense	70	110	123	180		201	
Department of Energy	58	93	87.95	91.1		139.3	
Department of Justice	-	-	1.4	1.4		1.4	
Department of Transportation (FAA)	-	-	0	2		2	
Environmental Protection Agency	-	-	5	5		5	
National Aeronautics and Space Administration. (NASA)	5	20	22	22	46	22	51
National Institutes of Health	32	39	39.6	40.8		43.2	
National Institute of Standards and Technology (NIST)	8	10	33.4	37.6		43.8	
National Science Foundation	97	150	150	199		221	
US Department of Agriculture	-	-	1.5	0	1.5	0	2.5
TOTAL	270	422	464	579	604	679	710

Three new R&D areas are planned (FY2003) in all federal budgets and agencies: manufacturing processes at the nanoscale, use of nanotechnology for chemical-biological-radioactive-explosive detection and prevention and development of instrumentation and metrology at the nanoscale.

DOD Investment in Nanotechnology

(First Three Years of NNI)

($ Millions)	FY 2001 (Actual)		FY 2002 (Current Plan)		FY 2003 (Request)	
	Basic Research (6.1)	Applied Research (6.2), Exploratory Develop-ment (6.3)	Basic Research (6.1)	Applied Research (6.2), Exploratory Develop-ment (6.3)	Basic Research (6.1)	Applied Research (6.2), Exploratory Develop-ment (6.3)
DUSD [R]	36	-	26	-	28	-
DARPA	28	12	9	88	11	90
Army	6	-	18	2	18	5
Air Force	6	4	8	7	13	5
Navy	31	-	21	1	26	5
SUB TOTAL	107	16	82	98	96	105
TOTAL	123		180		201	

National Science Foundation Nanotechnology

(First Three Years of NNI)

($ Millions)	FY 2001 Enacted	FY 2002 Current Plan	FY 2003 Request
Biological Sciences	2.33	2.33	2.98
Computer and Information Science and Engineering	2.20	10.20	11.14
Engineering	55.27	86.30	94.35
Geosciences	6.80	6.80	7.53
Mathematics and Physical Science	83.08	93.08	103.92
Social and Behavioral Sciences	0.00	0.00	1.11
Educational and Human Resources	0.00	0.00	0.22
Total, Nanoscale Science and Engineering	149.68	198.71	221.25

National Science Foundation Nanotechnology

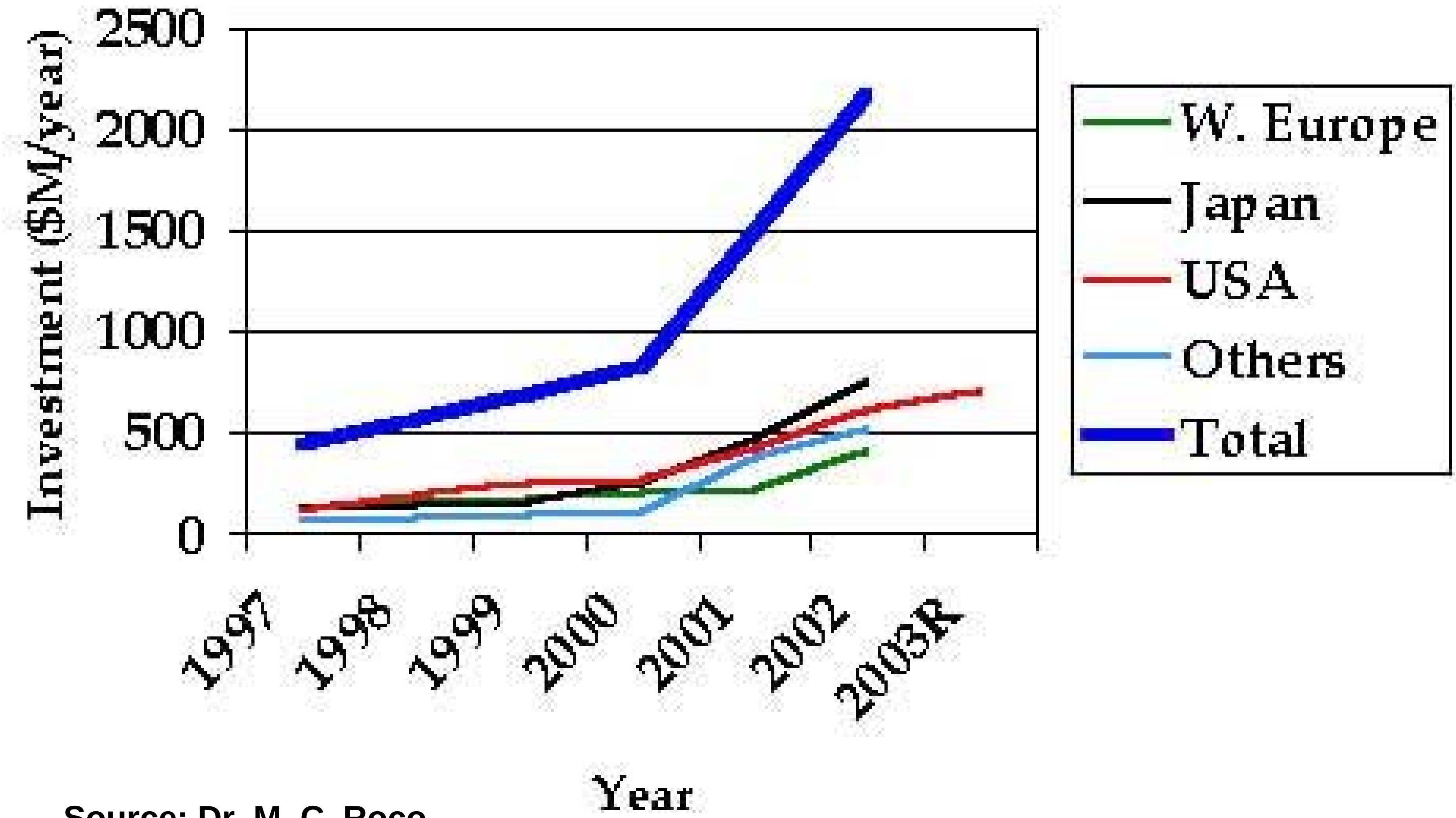
Programmatic Focus in FY2003

Program Focus		Requested Funding ($M)
Fundamental Research and Education		140.93
	Biosystems at the Nanoscale	20.7
	Nanoscale Structures, Novel and Quantum	53.5
	Device and System Architecture	27.8
	Nanoscale Processes in the Environment	9.6
	Multi-scale, multi-phenomena theory, modeling, and simulation at the Nanoscale	20.84
	Manufacturing processes at the Nanoscale	8.49
Grand Challenges		10.7
Centers and Networks of Excellence		38.64
Research Infrastructure		21.70
Societal and educational impacts of science and technology advances		9.28
TOTAL		221.25

Six Application-Oriented Centers Funded by the National Science Foundation

Center for Integrated Nanopatterning and Detection Technologies	Northwestern University	Chemical and biological sensors	$11.1M/5 years
Center for Nanoscale Systems in Information Technology	Cornell University	Electronics, information storage and communications	$11.6M/5 years
Center for the Science of Nanoscale Systems and Their Device Applications	Harvard University	Electronic and magnetic devices and quantum information processing	$10.8M/5 years
Center for Electronic Transport in Molecular Nanostructures	Columbia University	Materials for electronics, photonics and biology	$10.8M/5 years
Center for Biological and Environmental Nanotechnology	Rice University	Materials for environmental engineering and medicine	$10.5M/5 years
Center for Directed Assembly of Nanostructures	Rensselaer Polytechnic Institute	Composites, drug delivery devices and sensors	$10.0M/5 years

Global Nanotechnology Funding



Source: Dr. M. C. Roco
Chair, Subcommittee on Nanoscience, Engineering and Technology (NSET)
National Science and Technology Council (NSTC)
Senior Advisor for Nanotechnology, National Science Foundation
Mroco@nsf.gov
Dated August 2001 so does not reflect recent increases in US funding

Estimated Government Sponsored Nanotechnology R&D

Area	1997 a	1997 b	1998 a	1998 b	1999 a	1999 b	2000 a	2000 b	2001 a	2001 b	2002 a Request
W. Europe		126		151		179		200		225	
Japan		120		135		157		245		410 + 140*	
USA	116		190		255		270		422		519
Others*		70		83		96		110		380	
Total (% of 1997)		**432 100%**		**559 129%**		**687 159%**		**825 191%**		**1,577 365%**	

Notes:
a = Financial year begins in USA on October 1st.
b = Financial year in most other countries begins on March 1 or April 1
1. W. Europe includes countries in EU and Switzerland
2. Others include Australia, Canada, China, FSU, Korea, Singapore, Taiwan and others with nanotechnology R&D
•= Japan has supplemented its initial $410M with additional $140M for nanomaterials including polymers and metals
Dated August 2001 so does not reflect recent increases in US funding

Source: Dr. M. C. Roco

Survey of Academic Nanotechnology Research in Israel

Nanotechnology Committee

September 2002

- *The aim of this document is to provide a general perspective of the research activity in Israel and the level of resources required to create a competitive infrastructure to support the Nano-research*
- *This overview was compiled from un-audited information provided by the Universities.*

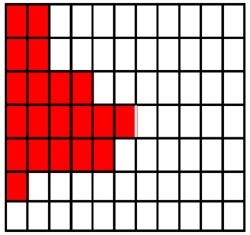
Nanotechnology Centers

University	Center Name	Mission
Tel Aviv University	The University Research Institute for Nano-Science and Nano-Technologies	*To provide a framework for the advancement of interdisciplinary research and development within the nano-scale dimension.*
Technion	Multidisciplinary Board for Nanoelectronics and Nanooptics	*The board will guarantee successful structuring, and coordination of all activity in nanoelectronics and nanoptics at the Technion. The board will generate educational activities, appropriate infrastructure and international symposia. Furthermore, the board will serve as a port to industry and other external agencies (universities, start ups etc).*
Hebrew University	Hebrew University Center for Nanoscience and Nanotechnology (HUCNN)	*To promote basic and applied research in nanoscience and nanotechnology to newgrounds. To educate and train the future generation of leaders in nanoscience and nanotechnology in Israel. Creating conditions so that nanotechnology industries in Israel will become world leaders in the field.*
Bar Ilan University	Bar Ilan Center For Advanced Materials (Nano science initiative)	*Develop newmaterials for energy biomedical environmental applications*
Weizmann Institute	1. Braun Center for Sub-micron Research. 2. Center for Nanoscale Science	*1. Variety of projects in Lowdimensionsl structures in Semiconductors, III-V compounds. organic and inorganic Fullerens. The projects include complex fabrication and testing* *2. Promote research in Nanoscale Science including Biological research*
Ben Gurion University	Ilse Katz Center for Nano Science and Nanotechnology	*To integrate basic disciplines in Natura Science and Engineering to a coherent unit. To promote basic and applied research in nanoscience and nano technology to newgrounds. Create conditions so that nanotech industries in Israel will become world leaders*

Relative Activity Level by Projects

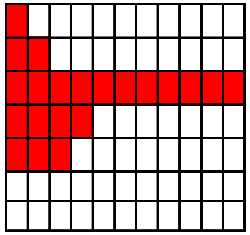
Ben Gurion University

Nano Electronics	10%
Nano Optics	10%
Nano Materials	20%
Nano Bio-,biosensors	30%
Charact.and nanodevices. fab	25%
The science of nanoscale	5%
Nano medical science	0%



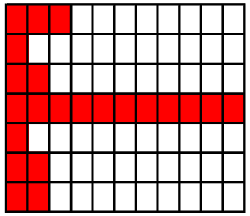
Bar Ilan University

Nano Electronics	5%
Nano Optics	8%
Nano Materials	53%
Nano Bio-,biosensors	18%
Charact.and nanodevices. fab	16%
The science of nanoscale	0%
Nano medical science	0%



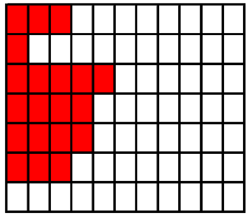
Tel Aviv University

Nano Electronics	13%
Nano Optics	3%
Nano Materials	9%
Nano Bio-,biosensors	53%
Charact.and nanodevices. fab	6%
The science of nanoscale	8%
Nano medical science	8%



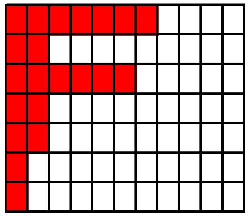
Weizman Institute

Nano Electronics	14%
Nano Optics	2%
Nano Materials	26%
Nano Bio-,biosensors	21%
Charact.and nanodevices. fab	21%
The science of nanoscale	16%
Nano medical science	



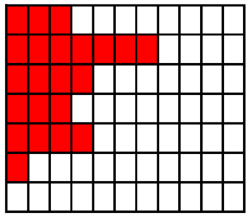
Hebrew University

Nano Electronics	36%
Nano Optics	12%
Nano Materials	28%
Nano Bio-,biosensors	8%
Charact.and nanodevices. fab	8%
The science of nanoscale	4%
Nano medical science	4%

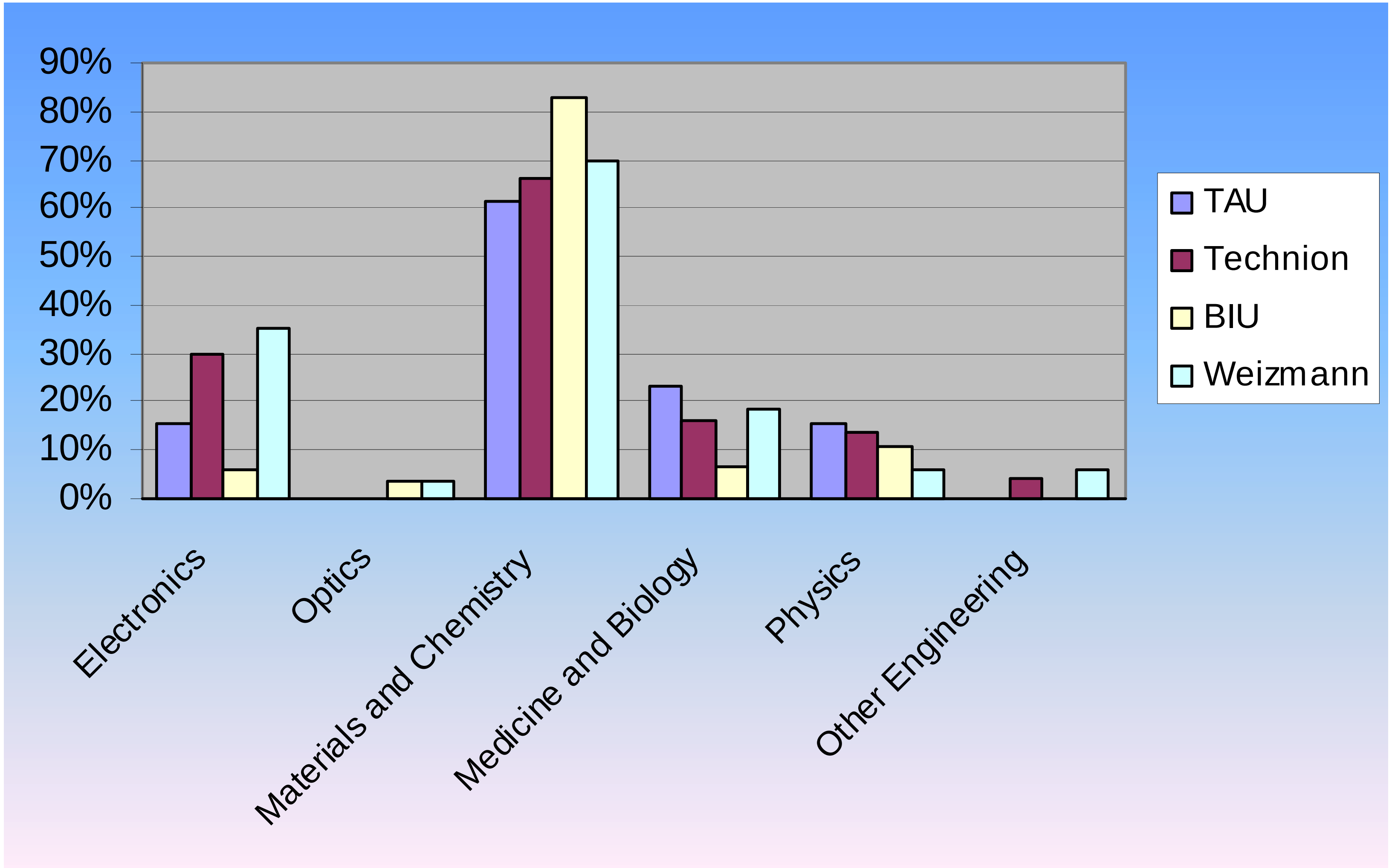


Technion

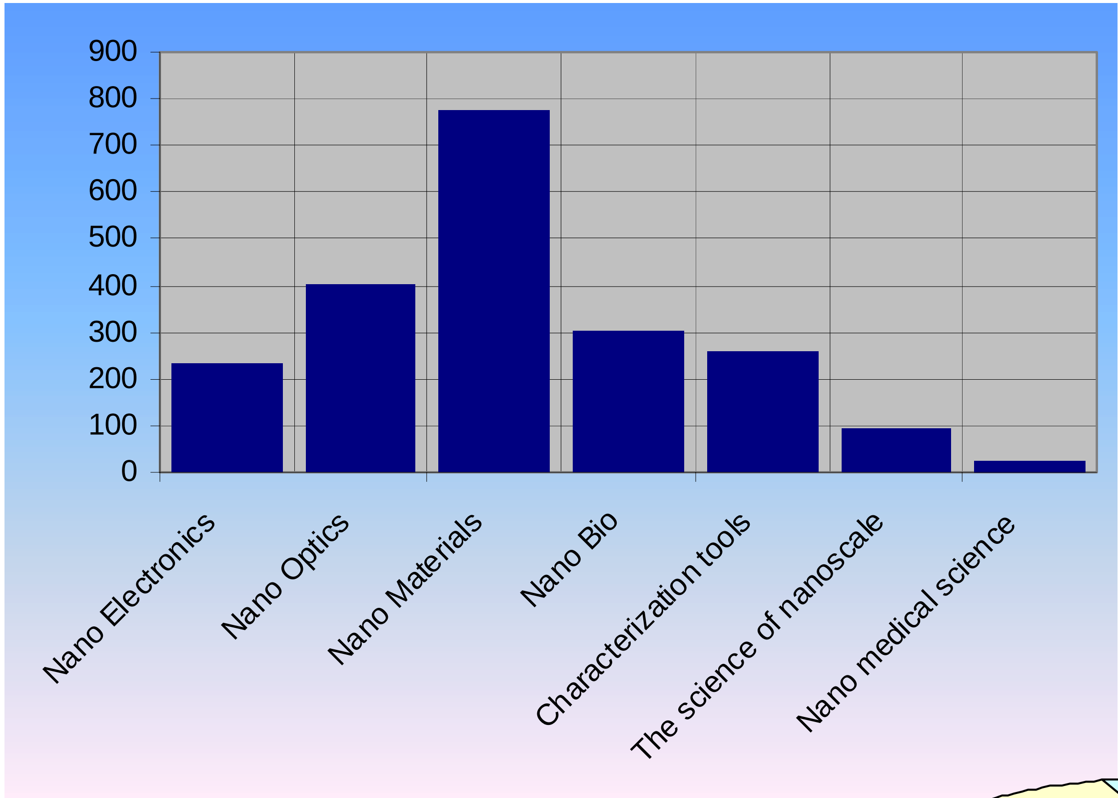
Nano Electronics	16%
Nano Optics	33%
Nano Materials	18%
Nano Bio-,biosensors	13%
Charact.and nanodevices. fab	18%
The science of nanoscale	2%
Nano medical science	0%

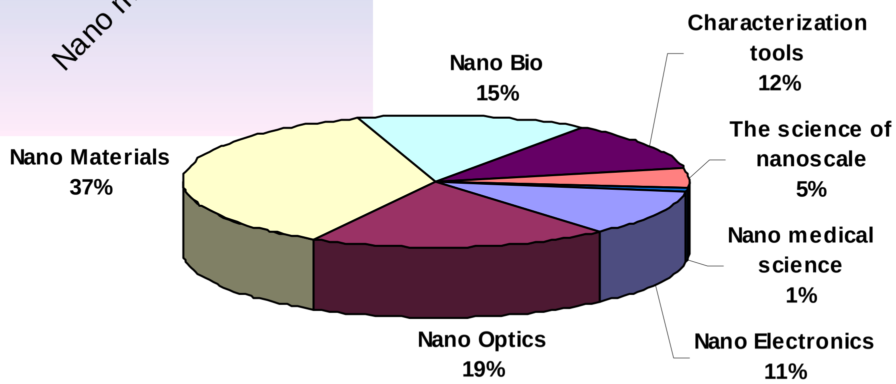


Internal Distribution of Research Disciplines

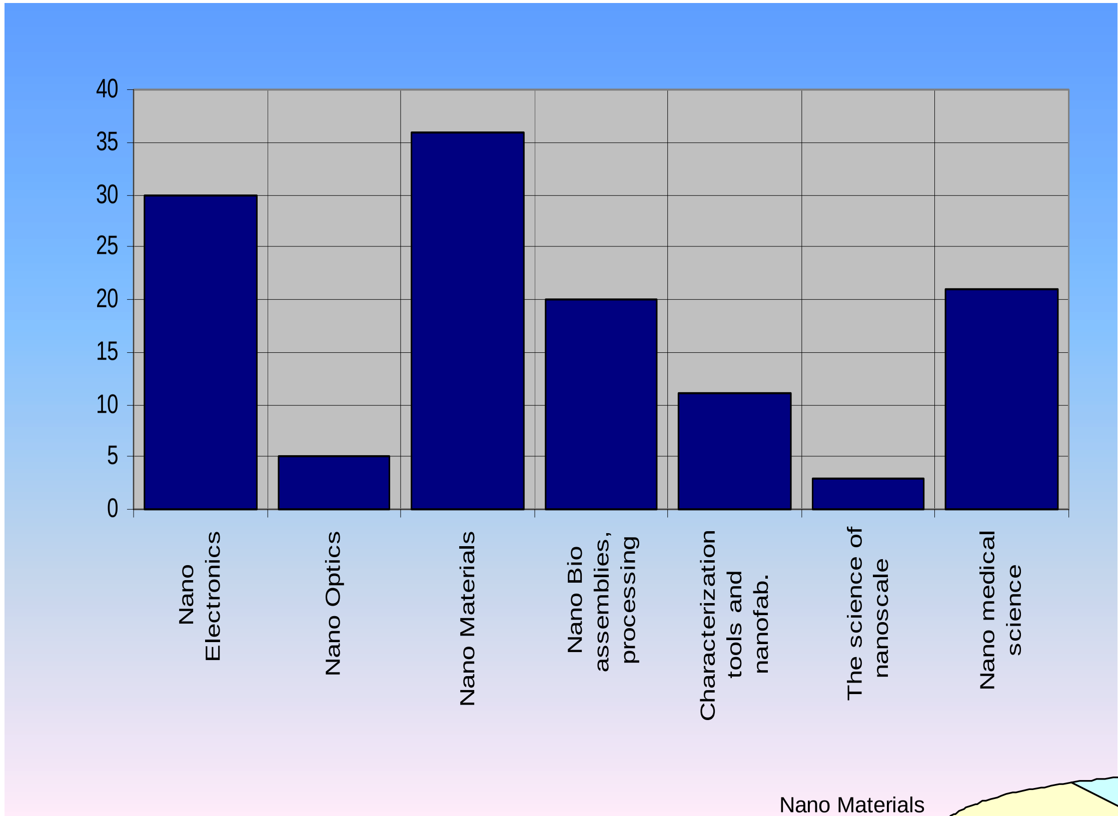


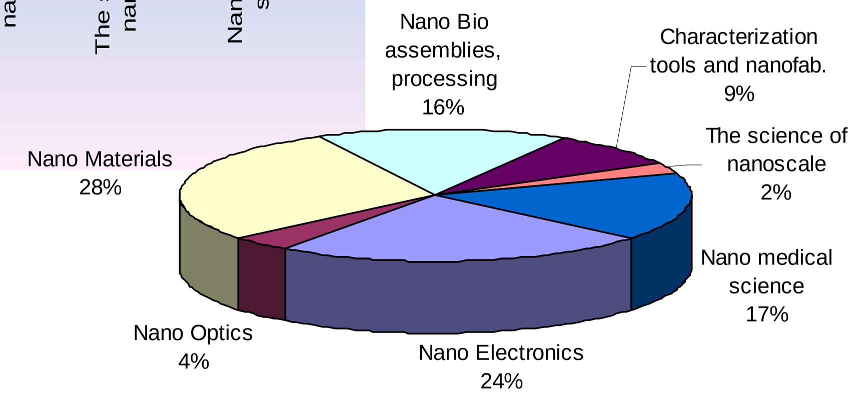
Number of Publications by Research Field





Number of Patent Applications by Research Field*





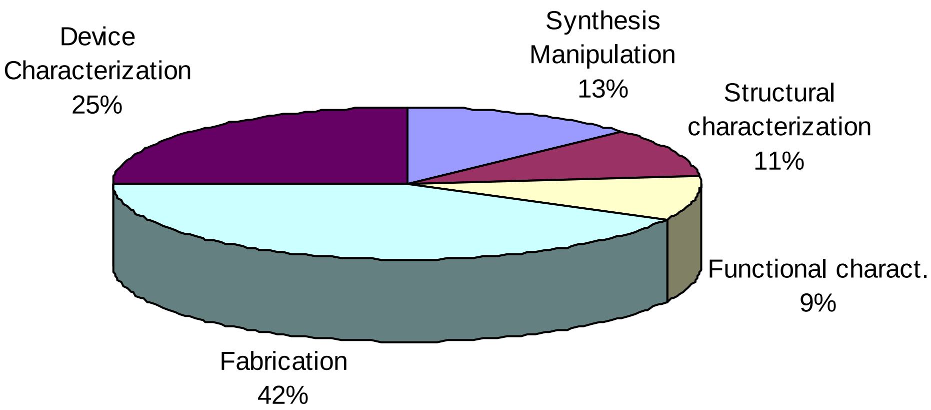
* Partial list. Does not include TAU

Investment Summary

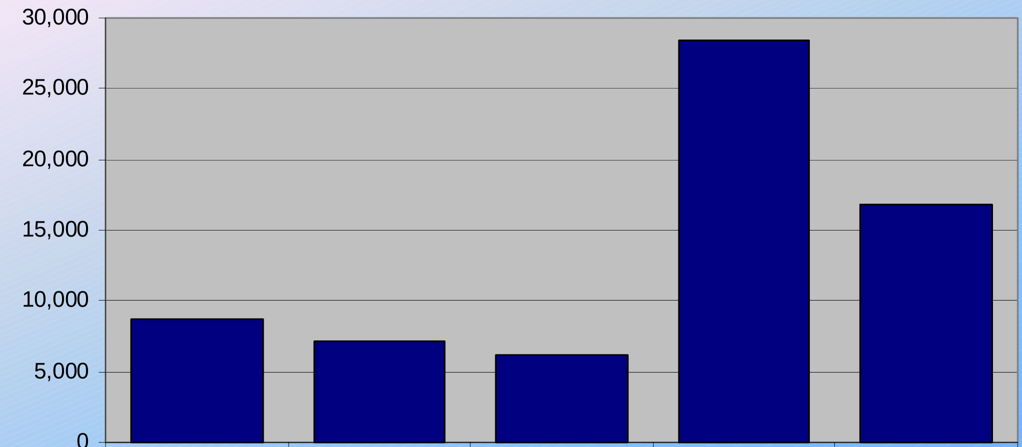
Institute	Existing Equipment (M$)	Other Capital (M$)	**Requested Equipment (M$)**	**Requested other Capital (M$)**	Operating Budget (M$)	Number of Key researchers
TAU	3.50	1.00	**4.70**	**3.15**	0.75	12
HU	6.00	0.80	**10.70**	**2.40**	0.00	23
BIU	8.80	2.40	**10.00**	**0.00**	4.10	13
Technion	24.50	26.60	**15.58**	**9.00**	13.50	48
BGU	4.50		**8.67**	**10.00**		15
1.Weizmann	17.00	3.00	**10.00**	**2.00**	3.00	7
2.Weizmann	1.50	2.00	**3.00**	**1.00**		10
Total	65.80	35.80	**62.65**	**27.55**	21.35	128

Equipment Summary by Application

Distribution

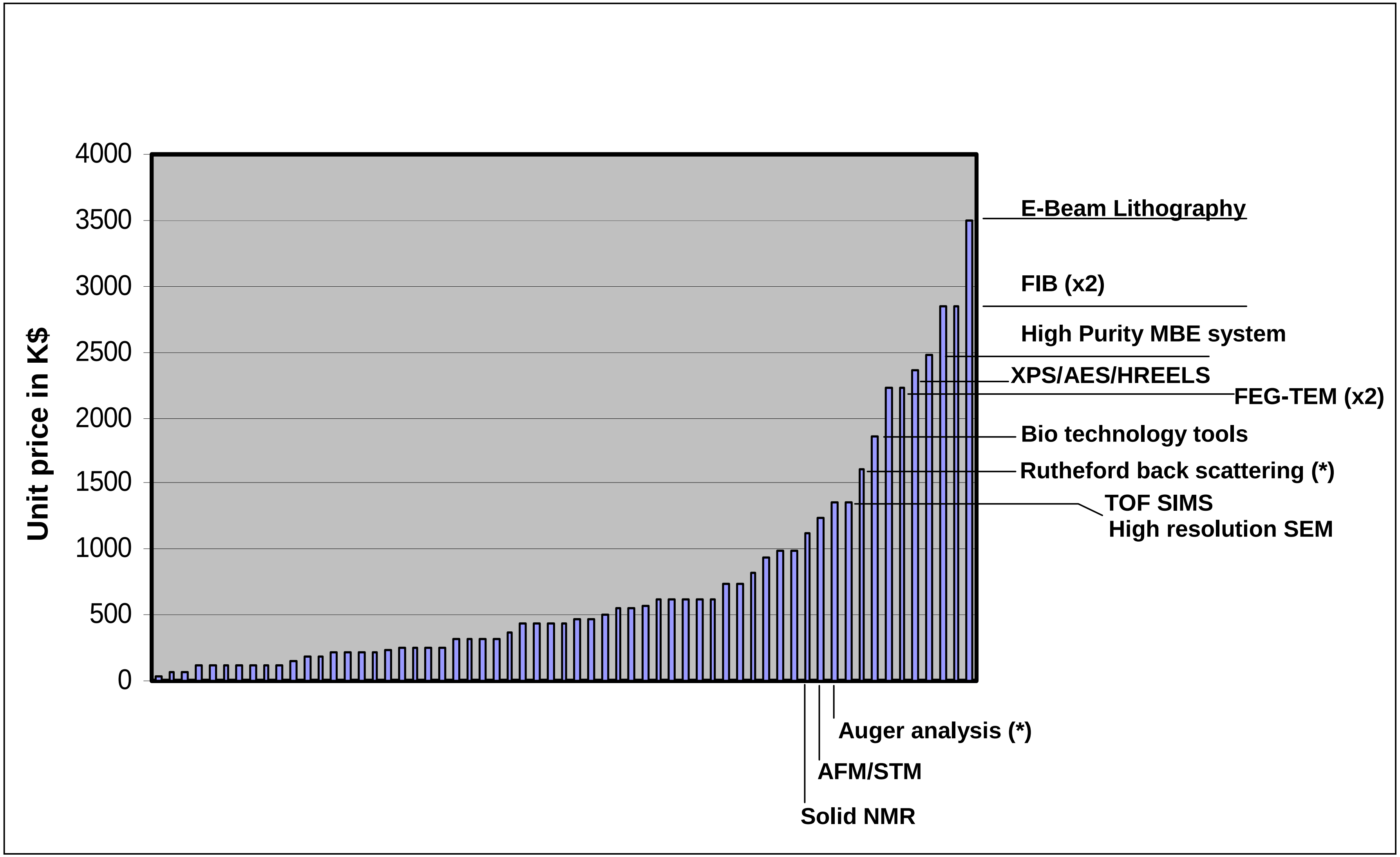


Cost (US$)



	Synthesis Manipulation	Structural characterizatio	Functional charact.	Fabrication	Device Characterizatio
K$	8,705	7,130	6,152	28,467	16,754

Equipment Price Distribution



Industrial Co-operation - (1) *

Company	TAU	Technion	BIU	BGU	HU	Weizmann
Abbott					✓	
Amcol					✓	
Applied Materials		✓		✓		✓
Aprion			✓		✓	
Ashot		✓				
Cargill Denmark		✓				
Carmel Olefins			✓			
Dexxon, Israel					✓	
ECR			✓			
Eger		✓				
Electronics Ferro Corp		✓				
ELOP		✓	✓		✓	✓
ELTA						✓
Gal El						✓
General Motors		✓	✓			
Indigo			✓			
Intel	✓	✓		✓	✓	
Israel Aircraft Industries			✓			
Israel Ministry of Defence		✓	✓			✓
Kafrit Brom			✓			
Kamag		✓				
KLA		✓				
LG Korea			✓			
Lucent	✓					

(*) Main examples. Not a full list Many other engagements exist with start-up companies

Industrial Co-operation - (2) *

Company	TAU	Technion	BIU	BGU	HU	Weizmann
Machteshim					✓	
Magma			✓			
Merck (Germany			✓			
Nanonics					✓	
Nanopowders		✓	✓			
Nanozise			✓			
Nova		✓			✓	
Orbotech			✓			
P&G USA		✓				
PolyGene Ltd Israel					✓	
Rafael		✓				
Ranbaxy India					✓	
Research Cooperation		✓				
Savion Diagnostics			✓			
SCD		✓				
Scitex			✓			
Sensy					✓	
Sol-Gel Technologies		✓	✓		✓	
Tadiran			✓			
Tahasiot Laser			✓			
TI	✓					
Tower Semiconductor					✓	
Vitramon Corp		✓				

(1) **Main examples. Not a full list Many other engagements exist with start-up companies**

Appendix A
Key Opportunities

Which potential applications of nanotechnology represent the most important opportunities for Israel's national benefit on the view of each research institute?

Key Opportunities Tel Aviv University

Nanotechnology Field	Military Applications	Civilian Applications	Rationale
Nano-bio technology	Anti-Non-conventional warfare Biological sensors	New bio-technologies for biological material synthesis and analysis. Functionality detection (as opposed to molecular detection)	Strong knowledge base at TAU
Nano-medical	Drug or vaccine release Selective treatment “smart” medicine.	Drug or vaccine release	Existing knowledge
Nano-materials	Novel coatings : super-hard, wear resistant	Novel thin films with unique properties: eg. high magnetization, improved adhesion, etc.	Combine nano- scale properties to improve micro and macro scale characteristics.
Nano–electronics	High speed devices High density low-cost arrays	Plastic based technology – low-cost, flexible.	
Integrated bio-chips (Integrate nano & MEMS)	Field deployable testing		Pragmatic approach High chance for success

Key Opportunities:Technion

Nanotechnology Field	Military Applications	Civilian Applications	Rationale
Nano electronics	Denser and faster electronics. Danser and larger memory	Same as military application	Fast, denser, low currents, inexpensive, utilizes novel effects
Nano optics	Tele-communication fast lasers, Optical switches and logic gates LEDs, IR detectors	Same as military applications	Fast, small, inexpensive, safer utilizes novel effects
Nano Bio	Detection of biological warfare	Healthcare, therapeutics, diagnostics, molecular computing, molecular electronics	Human and environmentally friendly, inexpensive, small, fast, utilizes novel effects
Nano materials	Harder materials, resistance to various external conditions and chemicals	Same as military application	Flexible chemical processing, inexpensive, molecular scale control, harder, more resistant, self repairing, environmentally friendly

Key Opportunities : Hebrew University

Nanotechnology Field	Military Applications	Civilian Applications	Rationale
Nano-electronics and opto-electronics(1,2,3,6,7, 11…)	Sensors and detectors	Integrated optoelectronic on SI chips: Si based lasers, modulators and detectors; optical communication systems, tunable LEDs and lasers	Size dependent optical and tunneling properties of nanoparticles and nano-layers can be utilized for tunable light sources and single electron transistors
Nano- bioelectronics (3,3a,11)	Chemical and Biological Sensors	Sensors for medical and biological essays	
Functional nano-particles (13, 14)	Sensing and marking, material hardening	Catalysis, Environmental applications, bio-markers, fire retardnets. Digital printing. Immunodiagnostics, Cosmetics	
Biocompatible solid interfaces (6,7)		Biology research for medicinal applications	
Medicinal nano-systems (10)	Field sensors and detoxification for nerve gas and biological specieses (viruses) by molecular imprinted nano-particles designed for biological and chemical warfare	Novel drug therapies including gene therapy and peptide and protein delivery systems, detoxification of blood via specific removal of toxicants by interaction with imprinted nano-particles.	Nano-medicine provides a high value added to the biotechnology field by providing the tools for their safe and efficient delivery of specific detoxification systems. The production of the systems is relatively simple and affordable.

Key Opportunities: Weizmann Institute

Nanotechnology Field	Military Applications	Civilian Applications	Rationale
Nanobiotechnology incl. Nano-biophysics and – chemistry		Medical Lab – on – chip	The infrastructure of life sciences exists already and should be combined with nano-technology
New materials	High performance nanocomposites Superlubricants High Performance Smart ceramics	Tribology, catalysts, fuel cells, High density rechargeable batteries, high strength materials	The defense related projects exist already and the beverage of new nano-materials is of substantial potential

Key Opportunities: Bar Ilan University

Nanotechnology Field	Military Applications	Civilian Applications	Rationale
Fabrication of amorphous nanoparticles and nanoporous material, including supported nanocatalysts	Ferrofluids, Lubrication	Ferrofluidics, catalysis, lubrication, drug carriers, medical imaging and cell straining contrast agents, supported catalysis for drug synthesis	Amorphous nanomaterials are more reactive than the corresponding nanocrystalline materials. Nanoparticles and nanoporous structures provide higher surface areas. Israeli nanoscience has great expertise in these areas making it very competitive internation
Nanoscale sensors arrays, including hybrid materials and nanoscale electronics	Nanoarrays detectors for nerve gas, pathogens, toxins, and explosives	Disease diagnostics, high throughput screening, implatable bio sensors, electrical wiring of proteins	Significant Israeli expertise. Urgent priority needs. Cost effective and highly automated/ integrated systems. Screening tools are enabling technology
Surface coating thin films, barrier coatings including electrical and photoactive films	Anti-reflective and anti detection coatings, barrier layers	Bio compatible surfaces, self healing , barriers level against abraision or corrosion, energy collection devices	Short term realistic technology. High value added, low amount material usage.
Optics based on nano-structures	Micro-lens arrays, filters active materials, high power compact solid state lasers	Same as military	New material properties will lead to devices with unique capabilities

Appendix B
Projects Not Addressed Today

Projects not addressed today: Hebrew University

Project Description	Objective	Benefit	Rationale
Quantum Computation	Developing Si-based hardware for quantum computation	Enhanced computation speed is expected to be achieved, in particular for various specific problems such as cryptography.	Due to the well-developed and mature Si technology it is advantageous to employ it also for fabricating devices that will serve as the basis for future quantum computers
Active Bio-Chips and Microfluidity	Integration of Si-based microelectronic technology with biological molecules: triggering biological events *in-vitro,* with possible applications for molecular based electronics, switches, etc.	1. Studying various bio-molecular processes at well defined conditions. 2. Applications for bio-electronics and bio-sensors.	
MEMS, NEMS and MEOMS	Developing these techniques at the HU and implementing them for basis research and technology.	Development of integrated electrical, mechanical and optical platforms for various applications including: opto-electronic, inertial sensors bio-sensors and more.	Most MEMS devices and their derivatives are fabricated using the mature Si technology thus allowing fast integration with electronic chips.
Novel nano-fabrication methods	Development of novel SPM-based nano – lithography techniques that will enable to manipulate molecules and nano-particles and “write” structures with nano-meterscale accuracy and resolution	Providing the means for the final and most crucial step in fabrication nano-devices that will be used for both basis and applied research.	The strength of the Lewis group (at the HU) in developing novel SPM – based applications, on one hand, and the need for SPM–based lithography at the HU, on the other, calls for the development of such an effort at the HU.
Raman and Sum frequency vibrational Spectroscopy of single molecules	Single molecules vibrational spectroscopy	Structure of single molecules on surface	

Projects not addressed today: Tel Aviv University

Project Description	Objective	Benefit	Rationale
Si based Nano-electronics	Advanced Si research	Extend current knowledge Link to future electronics	Relevant to engineering Support micro-technologies
Organic based nano-electronics	Nano-electronics on plastics, polymers	Advanced electronics	Can integrate between chemistry, physics and electronics.
Nano-medical systems	Integrate nano medical technologies	Apply nano-medical technologies	Relevant to the multi disciplinary nature of the center.
Nano-Lithography	Develop novel nano-scale lithography techniques	Support the infra-structure	Allow long term planning and stabilize the nano-processing section
Nano-physical chemistry	Enhance core competency	Support infra-structure	Chemists are the key to the activity

Projects not addressed today: Technion

Project Description	Objective	Benefit	Rationale
Nano-catalysis	Synthesis and properties	Chemical industry	Supported by other projects at the Technion
Environmental studies	Identification and characterization	Medicine, Public Health	Presently, investigated by a small no. of researchers at the Technion
MEMS	Design and fabrication	Micromachines	Supported by another project at the Technion and Magnet
Nanorobotics	Design and fabrication	Medicine, Mechanical Eng.	Presently, investigated by a small no. of researchers at the Technion

Projects not addressed today: Ben Gurion University

Project Description	Objective	Benefit	Rationale
Double tip STM	To develop a technique in which two tips are scanning a surface within nanometer distance	To help study the directional dependency of the electron structure of surfaces. To perform local gatings of surfaces.	Support the fundamental study of nanostructure surfaces

U.S. Nanotechnology Investment (links only)

(Due to the size of these attachments, the URL link to each document can be found below)

1. The original NNI Plan:
http://itri.loyola.edu/nano/IWGN.Implementation.Plan/nni.implementation.plan.pdf

2. The conclusions of the report evaluating U.S. Nano efforts that highlighted the need for more collaboration and integration of dispersed efforts, as well as the need to provide more long-term, basic research investment:

http://books.nap.edu/books/0309084547/html/index.html

3. Comments about the U.S. nanotechnology efforts:

http://www.devicelink.com/mddi/archive/02/07/014.html

4. NANO R&D: IS U.S. GOVERNMENT APPROACH TO FUNDING ALL WRONG?

http://www.semi.org/web/wmagazine.nsf/e1ea2a68535718d9882567cf005f1d96/a283b9d997074e0c88256be3007c9e4a!OpenDocument

U.K. Nanotechnology Priorities (links only)

(Due to the size of this attachment, the URL link to the document can be found below)

1. New Dimension for Manufacturing: A UK Strategy for Nanotechnology:

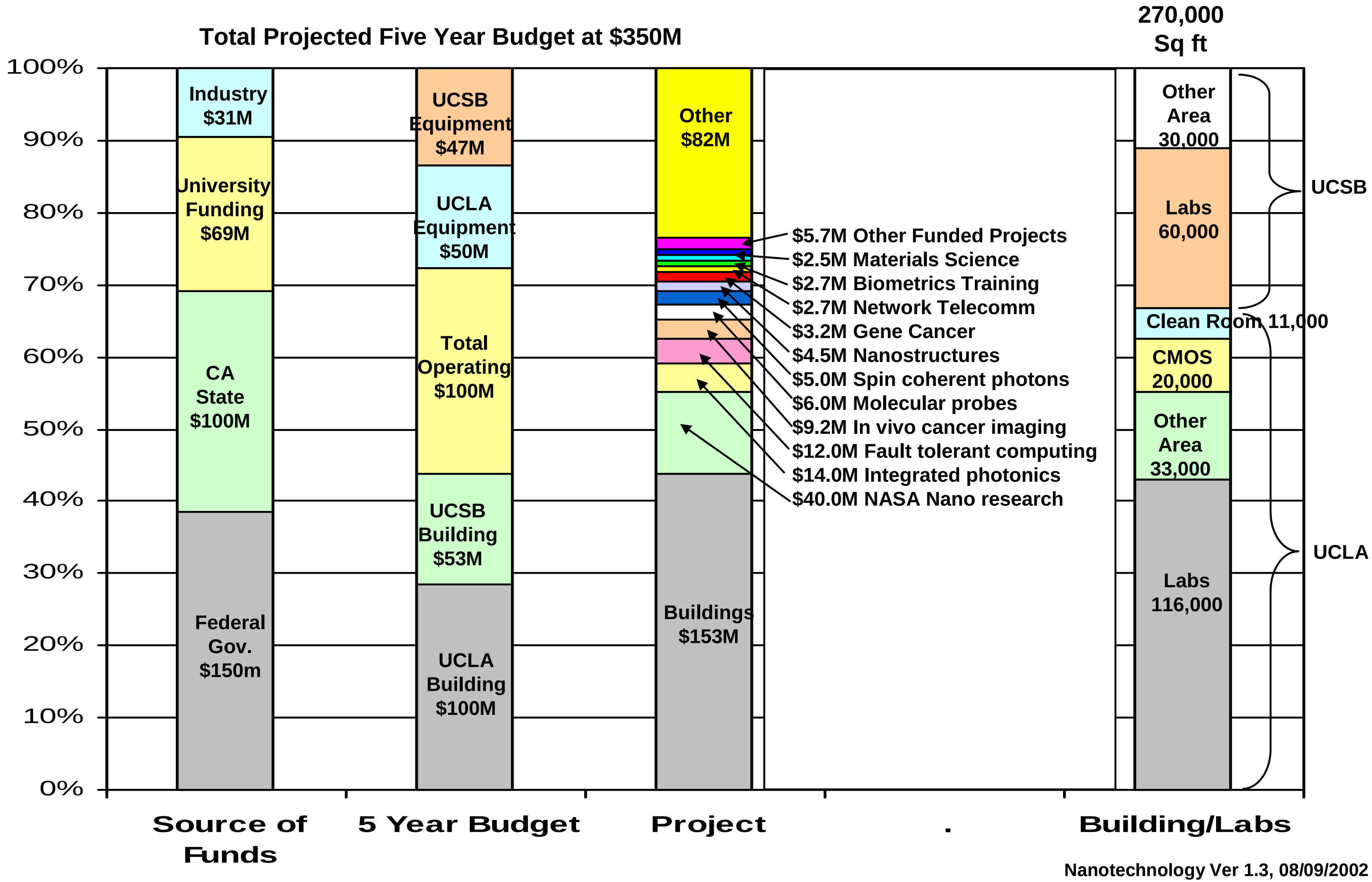
http://www.dti.gov.uk/innovation/nanotechnologyreport.pdf

Nanoelectronics and Nanomaterials (ICTAF)

Due to the size of this attachment, a CD is available on request.

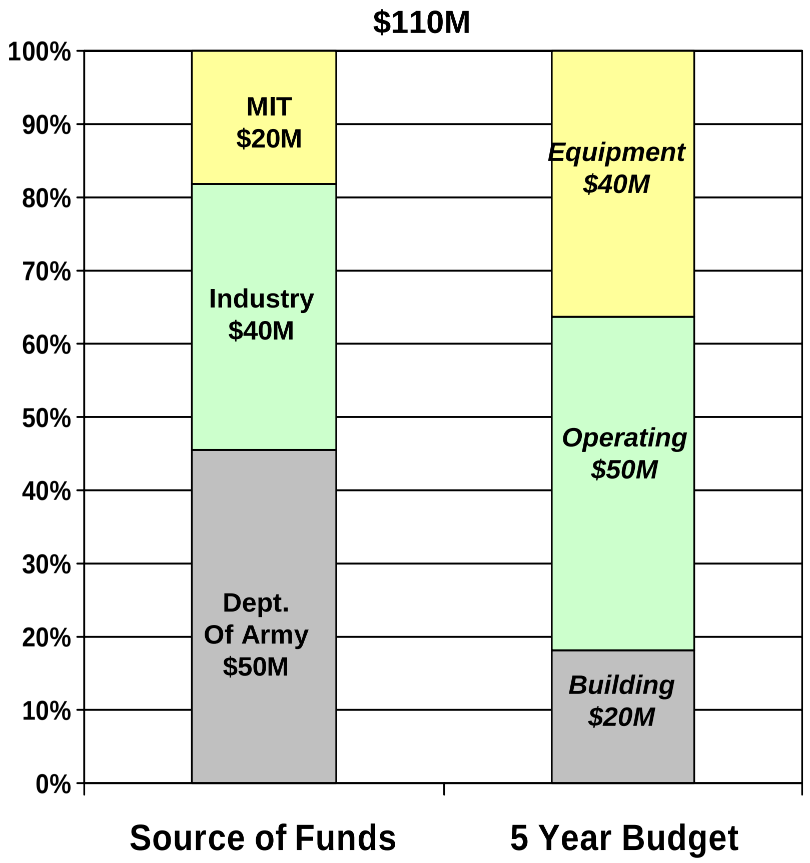
NANOTECHNOLOGY
U.S. Centers: Examples

California Nanotechnology Institute Overview



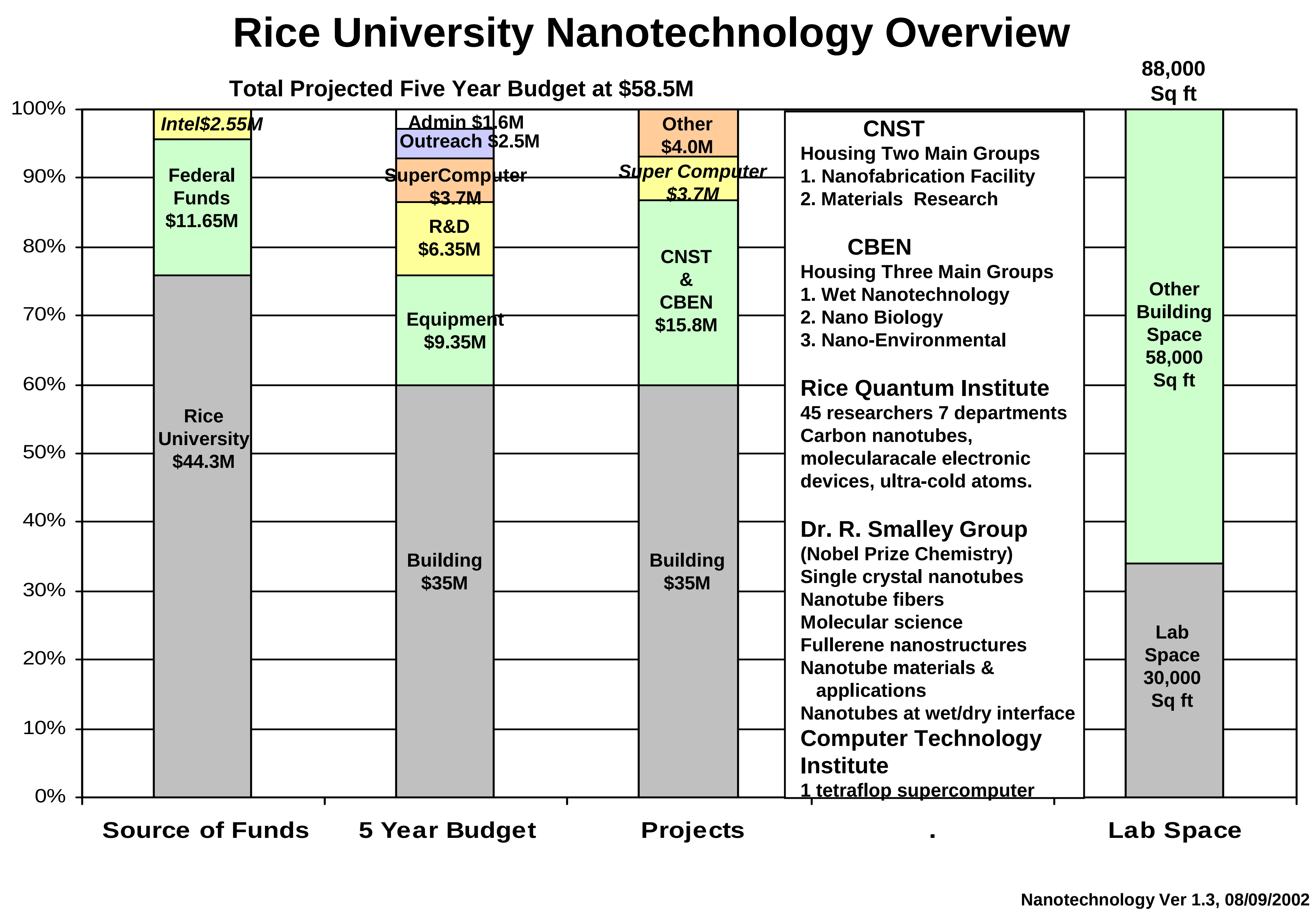
Nanotechnology Ver 1.3, 08/09/2002

Nanotech Soldier Center at MIT Overview



- SEVEN MAJOR PROGRAMS
  - Energy absorbing materials
  - Active materials
  - Threat detection & signature
  - Soldier medical functions
  - Modeling & simulation
  - Systems integration
  - Manufacturing and materials processing
- NINE MAJOR DISCIPLINES
  - Mechanical Engineering — Aero and Astronautics
  - Electrical Engineering — Micro Systems
  - Chemical Engineering — Nuclear Engineering
  - Materials Science — Computer Science
  - Biotechnology Engineering
- 21 Laboratories as potential participants
  - Artificial muscle - Humanoid robotics
  - Artificial intelligence - Human machine haptics
  - Biopolymers - Leg robotics lab
  - Biotechnology - Space nanotechnology
  - Biomedical - Man vehicle lab
  - Materials and structures - Materials processing
  - Materials science - Microphotonics
  - Chemical EPI - Mobile robotics
  - Computational structures - Nanomechanical lab
  - Control systems - Nanostructure lab
  - Electron microprobe
- Army – MIT 5 year contract signed in March 2002
- Additional $20M in technology acceleration (6.2) funds
- 35 MIT Professors, 20 post doctoral associates and 80 graduate students to support the program. Total 150.
- *Estimate of $20M for building/wing to support project as mentioned in bid documents..could also be leased.*
- Additional industry funding expected
- Center will be at 500 Tech Square, total area not yet allocated
- New Director in process of being hired

Nanotechnology Ver 1.3, 08/09/2002


Rice University Nanotechnology Overview
Total Projected Five Year Budget at $58.5M
88,000 Sq ft
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Intel$2.55M
Federal Funds $11.65M
Rice University $44.3M
Admin $1.6M
Outreach $2.5M
SuperComputer $3.7M
R&D $6.35M
Equipment $9.35M
Building $35M
Other $4.0M
Super Computer $3.7M
CNST & CBEN $15.8M
Building $35M
CNST
Housing Two Main Groups
1. Nanofabrication Facility
2. Materials Research
CBEN
Housing Three Main Groups
1. Wet Nanotechnology
2. Nano Biology
3. Nano-Environmental
Rice Quantum Institute
45 researchers 7 departments
Carbon nanotubes,
molecularacale electronic
devices, ultra-cold atoms.
Dr. R. Smalley Group
(Nobel Prize Chemistry)
Single crystal nanotubes
Nanotube fibers
Molecular science
Fullerene nanostructures
Nanotube materials &
applications
Nanotubes at wet/dry interface
Computer Technology
Institute
1 tetraflop supercomputer
Other Building Space 58,000 Sq ft
Lab Space 30,000 Sq ft
Source of Funds
5 Year Budget
Projects
.
Lab Space
Nanotechnology Ver 1.3, 08/09/2002

Nanotechnology for the Defense System

- **Budgets and ingenuity are being invested mainly in system development, to answer specific (unique) operational needs.**
- **Lower priority to the development of technological building blocks.**
- **Great difficulties to obtain certain state of art (SOA) technologies.**
- **Results: - use of technologies after they become available commercially**
  - **- many SOA systems include older technologies.**
- **Today, more than ever, the control of SOA technologies is critical for the development of SOA systems.**

Defense Nanotechnology
Use of R&D “central” Budget - Policy

- Identify useful technological building blocks, buy or make (don’t be a pioneer, be a sophisticated follower).
- Identify critical technologies – investment in tech-base.
- No support of basic science.
- Exploratory development.
- Guidance of R&D investments of the defense industry.

Defense Nanotechnology Opportunities & Requirements

- Short & long range R&D activity in typical defense technologies.
- Development of technologies that are expected to lead to device/product in relatively short time (e.g. 5 years)
- Examples:
  - Nanomaterials (ceramics, metals, organics, composites) for armor, structures, electronics, production methods.
  - Nano-energetic materials for explosives, propellants.
  - Bio and other sensors for detection of chemical or biological agents.

Summary of Federal Nanotechnology Investment ($US millions)

Department/Agency	2000	2001	2002
Dept. of Defense	70	110	133
Dept. of Energy	58	93	97
Dept. of Justice	0	0	1.4
Environment Protection Agency	0	0	5
NASA	5	20	46
National Institute of Health	32	39	45
National Institute of Standards	8	10	17.5
National Science Foundation	97	150	174
Total	**270**	**422**	**518.9**

Source: National Science Foundation http://www.nano.gov/2002budget.htm

NSF Investments

Directorate	FY 2001 Current Plan	FY 2002 Request
Biological Sciences	2.33	2.33
Computer & Information Science & Engineering	2.20	6.20
Engineering	55.27	70.30
Geosciences	6.80	6.80
Mathematics & Physical Science	83.08	88.08
Total, Nanoscale Science & Engineering	$149.68 M	$173.71 M

DOD Budget request for nanotech

2002	**M $**
Tech base (AF, NAVY, Army)	70
OSD (Office of Strategic Defense)	30
University – DOD collaborative research:	
AF	10
NAVY	13
ARMY	10
Total	133

Source: National Science Foundation http://www.nano.gov/2002budget.htm#1

DARPA Molecular Electronics (Molectronics) Research Projects

Organization	Title
Molecular Electronics Based on Quantum-Dot Cellular Automata	University of Notre Dame
Multiporphyrin Molecular Memories Riverside	University of California, Riverside
Moleware and the Molecular Computer	Rice University
Theory and Simulation of Moletronic Devices and Systems	Vanderbilt University
Chemically-Assembled, Defect-Tolerant Architectures for Computing and memory Applications	Hewlett Packard and UCLA
Carbon Nanotube Molecular Electronics	Harvard University
Inorganic Self-Assembly Routes to Three-Dimensional Memories	The Pennsylvania State University
A Molecular and-or Gate Pair	University of Colorado
Architectural Design, Analysis, and Prototyping for Next-Generation Molecular Electronic Systems	MITRE Corporation

“BUILD TO LAST” INDUSTRIES

Over the past decade, there has been growing interest in applying the principles of successful business management to the establishment of strong industries[1]. At the same time, there has been an expanding body of research and analysis on the key practices which allow businesses to thrive and succeed through successive business cycles and technological generations[2]. These, combined with some practical experience, allow to draw some observations on the requirements for building strong, sustainable high-tech industries (or “build to last,” to borrow Collins and Porras’s term).

Specifically, there seem to be four “paradoxical” requirements:

1. **Innovation and Commercialization**: pursuit of innovative research and technology only to the extent that they can be rapidly commercialized into viable, profitable products and services with sufficient market opportunity; conversely, willingness to “cannibalize” existing commercial positions with next-generation innovations.
2. **Focused Vision and Pragmatic Flexibility**: sharp clarity on how new technologies could provide high-value solutions to customers and continuous commitment to delivering such value; at the same time, willingness to “roll with the punches” and modify implementation approaches as required to quickly realize desired results.
3. **Start-ups and Strong Business Enterprises**: valuing individual entrepreneurship and allowing innovators the opportunity to challenge established companies, while at the same time encouraging the development of solid business organizations with the operational capabilities and global infrastructure required for success.
4. **Global Collaboration and Local Excellence**: access to resources on a global basis is critical in order to leverage unique capabilities in technology, costs, materials, etc.; however, there needs to be strong local excellence which allows to build viable business enterprises; only such organizations can build the necessary base of employment required for a self-sustaining industry.

Consistently meeting these requirements could allow local industry to thrive and ultimately reach the critical scale necessary for global leadership. At that stage, there is sufficient local strength throughout the “food chain”–including manufacturers, suppliers, service providers, third-party partners, users, academic researchers, employees (at different skills levels), investors, physical infrastructure, etc.–that the industry is self-sustaining. In other words, it is capable of withstanding multiple macroeconomic, political, and technological shifts–or “built to last.”

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[1] One of the most prominent pieces in this area is: Michael E. Porter, *The Competitive Advantage of Nations* (New York: The Free Press, 1990)

[2] See James C. Collins and Jerry I. Porras, *Built to Last: Successful Habits of Visionary Companies* (New York: HarperCollins, 1994), as well as Clayton M. Christensen, *The Innovator's Dilemma: When New Technologies Cause Great Firms to Fail* (Boston: Harvard Business School Press, 1997)

Nanotechnology Programs – Financial Resources
1.INFRASTRUCTURE
($ First approximation)

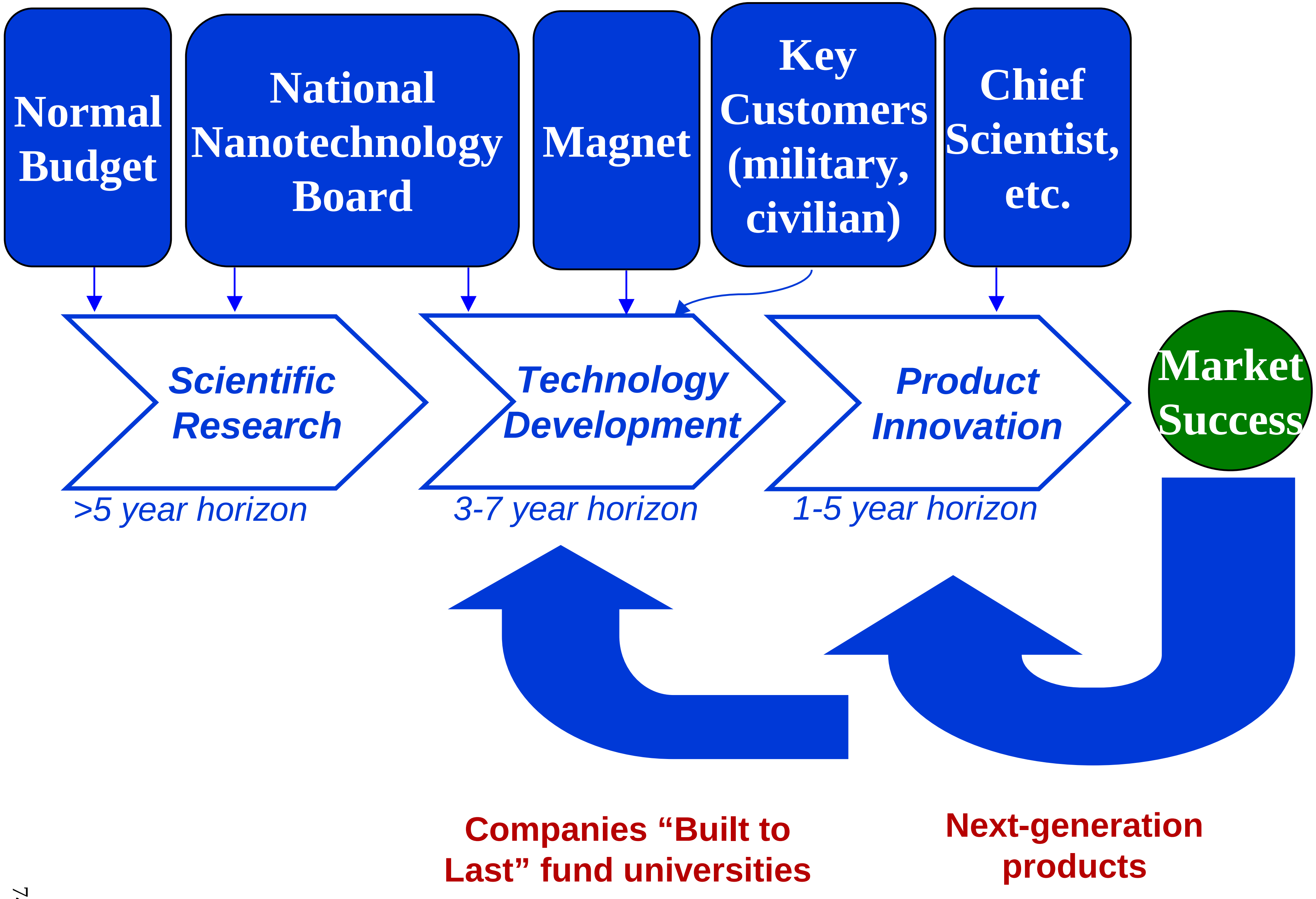
Organization	5 years commitment *	Sources
Private Funding	25,000,000	Private Donors
University matching X2 to Private Funds	50,000,000	Financial resources budgets 30,000,000 and contributions 20,000,000
National resources matching X1 Private Funds	25,000,000	Financial resources are TELEM 25,000,000
Total Funding (1)	100,000,000	

* Not approved yet

Nanotechnology Programs - Financial Resources
2.PROJECTS
($ First approximation)

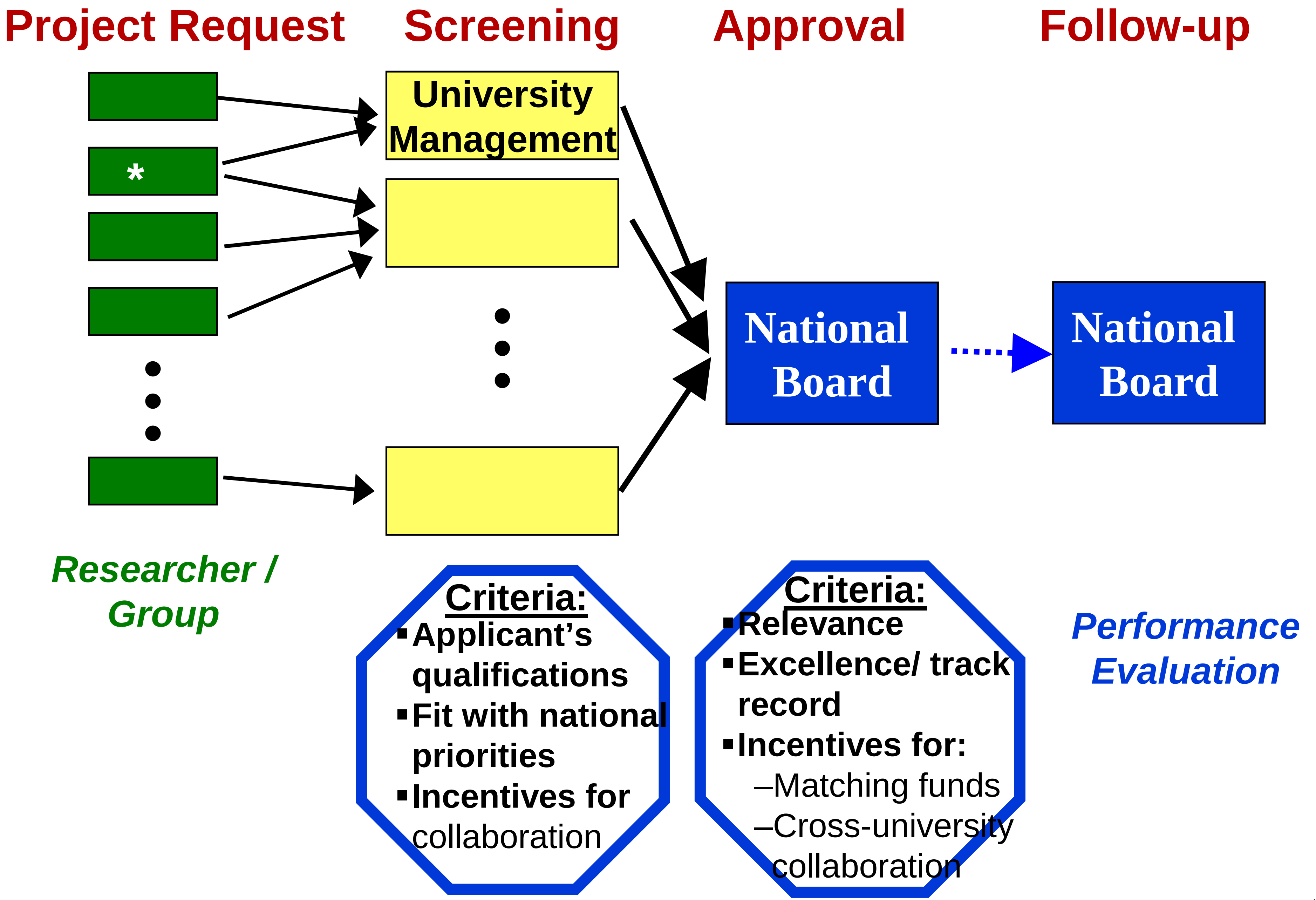
Organization	5 years / to be negotiated	Comments
Ministry of Industry MAGNET	25,000,000	
Ministry of Defense	2,000,000	
US-Israeli BSF	400,000	
European R&D Commission	2,000,000	Require Academy-Industrial cooperation
Sub total (2)	29,400,000	
Industry	For discussion	

Overall Funding Model



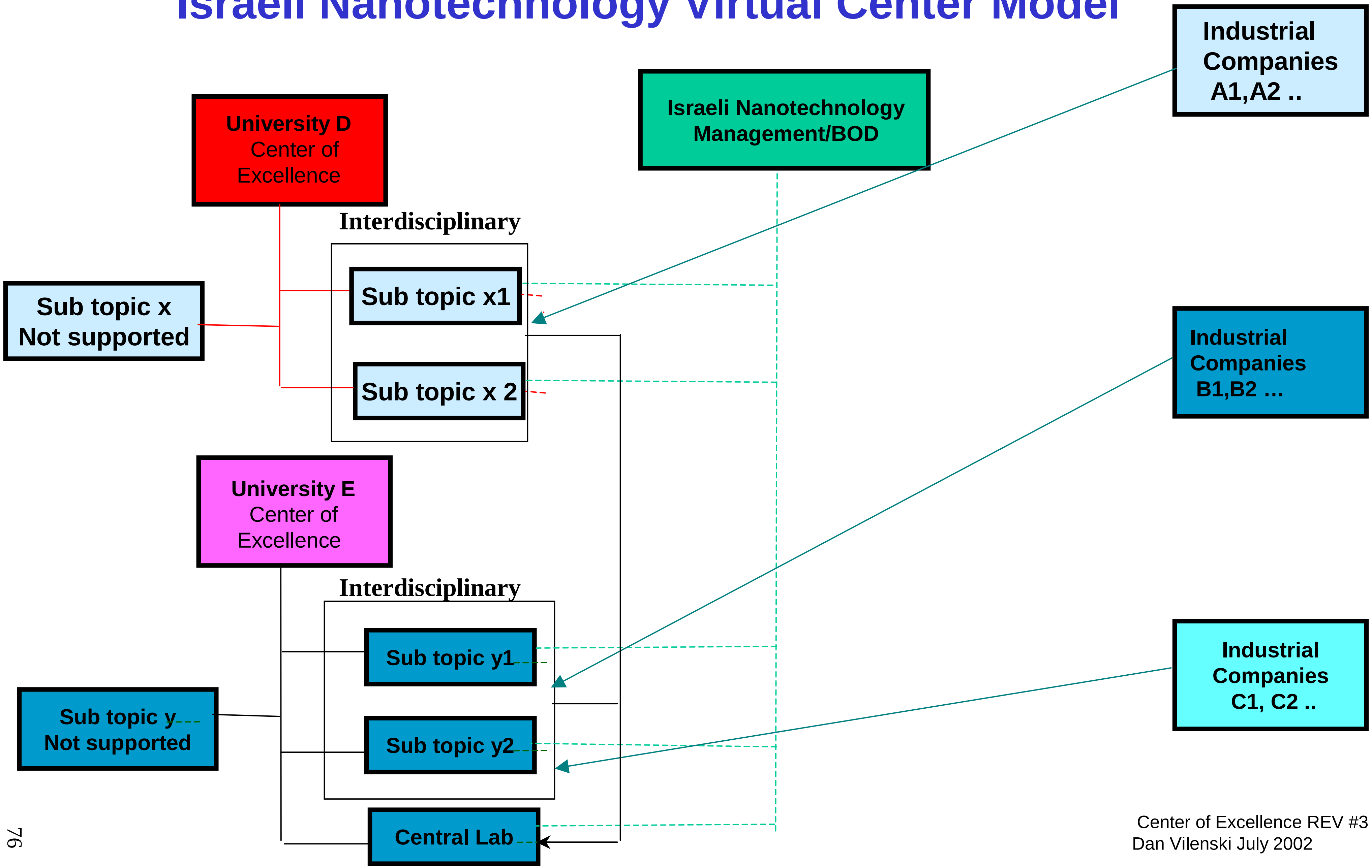
SENSITIVE

Investment Process



** Collaborative projects: joint submission by respective institutions*

Israeli Nanotechnology Virtual Center Model



Center of Excellence REV #3
Dan Vilenski July 2002

INSTITUTE OF PHYSICS PUBLISHING NANOTECHNOLOGY
Nanotechnology **13** (2002) 243–247 PII: S0957-4484(02)31421-1

Forecasting the development of nanotechnology with the help of science and technology indicators*

Ramón Compañó and Angela Hullmann

European Commission, Rue de la Loi/Wetstraat 200, 1049 Brussels, Belgium

Received 30 November 2001
Published 26 April 2002
Online at stacks.iop.org/Nano/13/243

Abstract
Nanotechnology is supposed to become one of the key enabling technologies of the 21st century. Its economic potential is forecast to be a market of several hundred billion Euros in the next decade. Therefore, nanotechnology has attracted the interest of many industry sectors and many companies redirecting internal activities to prepare themselves for this new challenge. At the same time governmental R&D decision makers all over the world are setting up new nanotechnology-specific research programmes aiming at putting their respective countries in a favourable position for the future. The aim of this paper is to use scientific and technological indicators to make predictions on economic development and to compare the situation in different countries.

1. Introduction

In the last two decades, nanoscience has made big progress. We have witnessed many important scientific discoveries and technological breakthroughs. Exemplary breakthroughs are the invention of the scanning tunnelling microscope in 1982 [1] or the discovery of fullerenes in 1985 [2]. A few nanotechnology-based products are already commercially available. However, does actual scientific knowledge justify the world-wide enthusiasm? How likely is it that the world-wide market size will be more than $1 trillion annually in 10–15 years from now [3]?

To evaluate the potential of mature technologies is not easy. For an emerging technology, such as nanotechnology, this task is even more difficult. A forecast, however, can be attempted using a set of indicators that in the past have proven to give good results to predict the potential of other emerging technological fields. The two most obvious indicators are the number of scientific articles and the number of patents. The former is usually a good indicator for scientific activity, the latter for the ability to transform scientific results into applications. Figure 1 shows the evolution of publications and patents in nanotechnology from the beginning of the 1980s up to 1998. The data on the world-wide number of publications in nanotechnology have been extracted from the Science Citation Index (SCI) database. The nanopatents are those filed at the European Patent Office (EPO) in Munich. The EPO patents cover the rights for a large number of countries and are therefore usually more expensive than national patents. In view of the large coverage and the higher cost, it appears reasonable to assume that the inventors are confident that they may exploit the patent commercially. The list of nanoscience- and nanotechnology-related keywords for extracting the publication and patent data, as well as the methodology, is reported elsewhere [4].

Between 1980 and 1985, the number of publications is rather modest, but slightly increasing year by year. From 1986 onwards, an acceleration of the number of publications is visible. This jump can be attributed to the fact that the scanning tunnelling microscope was invented some years before [1], and started to penetrate as an efficient research tool in academic and industrial research laboratories, favouring research at the nanoscale. The publication rate continues to increase, and additional acceleration peaks can be attributed on one hand to the availability of atomic force microscopes (invented in 1986 [5]) broadening the range of applicability with respect to STM to non-conductive structures, and on the other hand to significant breakthroughs, such as the discovery of the buckyball molecule C60 in 1985 [2] or carbon nanotubes in 1991 [6]. For the period between 1989 and 1998, the increase in the number of publications is impressive, jumping from 1000 publications to more than 12 000 in 1998.

* The views expressed in this article are those of the authors and do not necessarily reflect the official European Commission view on the subject.

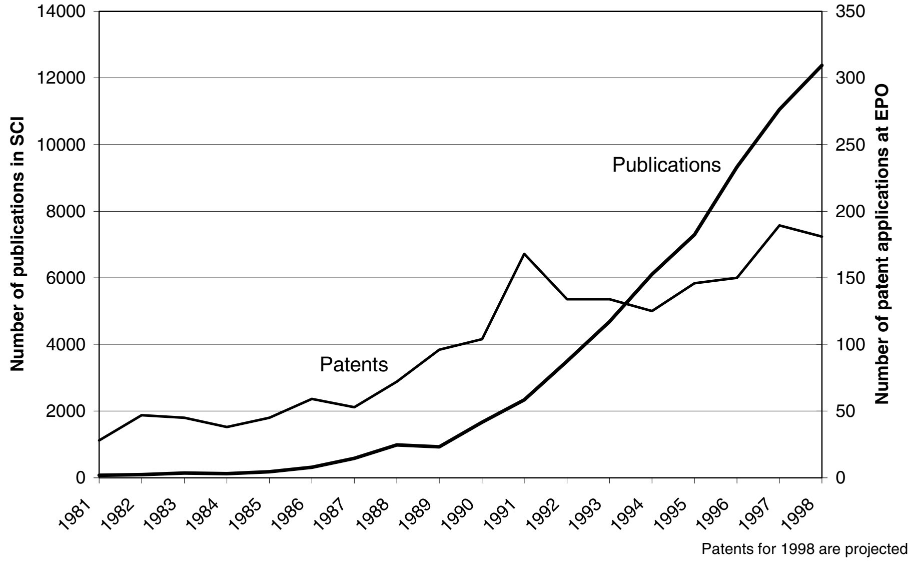


Figure 1. Publications and patents in nanotechnology from 1981 to 1998 world-wide. The number of publications comprises all nanotechnology-related articles published world-wide and covered by the SCI database. The data have been extracted searching the nanotechnology keyword list given in [8]. A similar keyword list, which can be found in the same reference, has been used for retrieving the nanotechnology patent field at the EPO. Note the different scales for the two curves. Sources: SCI, EPO Database (EPAT) and own calculations.

The average annual growth rate is 27% and the yearly increase fluctuates from 10 up to 80% per year. Previous data from the US patenting office [7] show a similar evolution to the European data.

The number of filed patents is an appropriate indicator to estimate the capacity of the laboratories to transfer their research results into industrial applications. Figure 1 shows the development of the numbers of patents in nanotechnology at the EPO for the same period as the scientific publications. As generally expected, the number of patents follows the pattern of the scientific publications with a certain time delay. Over the whole 1981–98 period, the curve shows a clear increase in the number of patents, from 28 up to 180, with an average growth rate in the 1990s amounting to 7%. This patent curve shows larger fluctuations with respect to the publication data. This is due to the effect that statistical fluctuations have more impact when applied to a smaller number of data. In addition, industrially relevant technological breakthroughs in a specific year have a more significant weight.

The evolution of the scientific and technological activity on nanotechnology can be compared with previous enabling technologies. In a first approach a lineal technological development model can be employed. For such a model, which is stylized in figure 2, Grupp [8] has defined eight phases, in which he describes the evolution from basic research to the massive penetration of products. Phase I defines when exploratory scientific work begins. Science continues to make further progress while technology starts to emerge (phase II). In phase III the scientific basics are mostly understood and the first technological prototypes appear. Difficulties at the transformation into commercial applications appear (phase IV) and progress in science and technology seems to stagnate (phase V). Following a reorientation in industrial research new opportunities emerge (phase VI) and commercial applications appear, which mobilize extensive industrial research activities (phase VII). Finally, all markets are penetrated and the volume

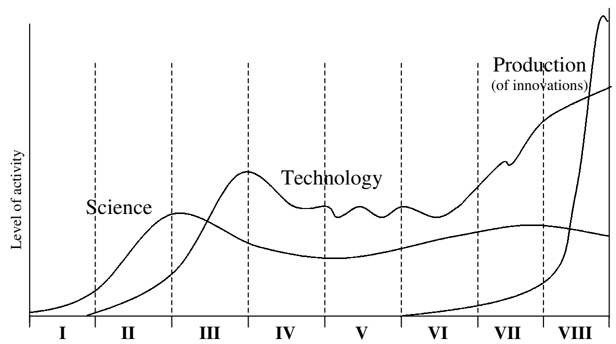


Figure 2. Stylized technological development. For an enabling technology, the evolution of scientific activity (publications), technological activity (patenting) and commercialization is sketched as a function of time [8]. Following a theoretical model, the actual situation of nanotechnology would be roughly in development phase II and III.

of research diminishes with respect to the production of innovative products (phase VIII). Such a model, based upon publications and patents as indicators, gives good results when used to explain today's mature technologies such as biotechnology or microsystem technology [9].

Comparing both the patent and publication nanotechnology data (figure 1) with the model (figure 2), the field of nanotechnology as a whole appears to be currently at the end of phase II or early phase III. Assuming that the model describes the data correctly, the peak of scientific activity in nanosciences is still to come, possibly in three to five years from now, and large-scale exploitation of nanotechnological results might arise ten years from now. In a first approximation, the curve for nanotechnology (understood as the ensemble of all technologies operating at the nanoscale regime) can be seen as the convolution of a number of nanotechnologies for different purposes, whose timely evolution might change significantly. For example, nanoscale electronic devices are supposed to be a

Table 1. Publications and patent share for the 15 most active countries. The data are given as a fraction (percentage) of the world-wide production. The period for publications in nanotechnology comprises the years between 1997 and 1999. In the case of patents registered at the EPO and PCT, the period covers the years from 1991 to 1999. This enlarged period is chosen as the absolute numbers of patents per year are small and may be distorted in the case of shorter time periods. Sources: SCI, EPAT, PCT database (PCTPAT) and own calculations.

	Publications (1997–99) (%)		Patents EPO&PCT (1991–99) (%)	
1	23.7	USA	42.0	USA
2	12.5	Japan	15.3	Germany
3	10.7	Germany	12.6	Japan
4	6.3	China	9.1	France
5	6.3	France	4.7	UK
6	5.4	UK	3.7	Switzerland
7	4.6	Russia	2.0	Canada
8	2.6	Italy	1.7	Belgium
9	2.3	Switzerland	1.7	Netherlands
10	2.1	Spain	1.7	Italy
11	1.8	Canada	1.4	Australia
12	1.8	South Korea	1.1	Israel
13	1.6	Netherlands	1.1	Russia
14	1.4	India	0.9	Sweden
15	1.4	Sweden	0.5	Spain

huge market but may reach the market place only 12–15 years from now. At the other extreme, TiO_2 nanoparticles used as UV-B ray absorbers in sun-cream lotions or nano-sized carbon particles (carbon black) employed to increase the wear resistance of tyres are already on the market.

Currently, slightly more than one-quarter of all patents filed are focused on the instrumentation [7]. This supports the view that nanotechnology is at the beginning of the development phase of an enabling technology where the first focus is to develop suitable tools for nanostructuring of surfaces, the production of nanomaterials, the analysis of nano-objects etc. By industrial sectors, the most important ones are information technologies (IT), and pharmaceutics and chemicals. For the first sector, massive storage devices, flat panel displays or electronic paper are prominent IT patenting areas. In addition to this, extended CMOS approaches and alternative nanoscale information processing, transmission or storage devices are also dominant, the reason being the continuous shrinking process of CMOS technology, which—following the semiconductor industry associations and other forecasts [10, 11]—will soon reach the nanometre regime (forecast 22 nm gate length for processors in the year 2011). Being well aware of the apparent problem for the future, the semiconductor industries have already started to investigate solutions towards extending CMOS into the nanoscale as well as novel devices operating at the nanoscale.

In the case of chemistry and pharmaceutics, a large number of patents are directed towards finding new approaches for drug delivery, medical diagnostics, cancer treatments etc, which are supposed to become huge future markets. Nanotechnology patenting for other sectors, such as aerospace, construction industries, food processing, automotive, oil refining, environmental monitoring etc shows yearly increasing values, but their absolute numbers are smaller with respect to the areas discussed above (instrumentation, IT, and pharmaceutics and medicine).

2. The world-wide actors

Most countries have activities in nanoscale science and technology. The 15 most active countries in terms of publications and patents are given in table 1. The publications, recorded for the period 1997–99, are divided by the country of their authors' affiliations. The data for the patents cover a larger period, namely from 1991 to 1999, and include the EPO patents as well as those of the Patent Cooperation Treaty (PCT). The PCT patents are filed at the World Intellectual Property Organization (WIPO) in Geneva and can afterwards be transferred to any national patent office in the world or to the EPO. Double-counts between PCT and EPO patents are eliminated. The additional analysis of the international PCT patents reduces distortions due to the bias of the number of EPO patents towards Europe. In addition, the higher number of analysed patents improves the statistical reliability to compare countries.

The most active country in nanoscale research is the United States, with roughly one-quarter of all publications, followed by Japan, Germany, China, France, the United Kingdom and Russia. These first seven countries alone account for nearly 70% of the world's scientific papers on nanotechnology. All EU member states and most EU candidate countries (except Luxembourg where there is no university) are among the top 50 (not shown here). The shares for China and Russia are outstanding in comparison with their general presence in the SCI database and show the relatively strong significance of nanoscience in their research systems. The same table shows the number of patents at the EPO by country. A comparison of the most active countries in publications with those of patents shows that most of the first 15 countries are in common. However, the spread between the countries is significantly larger. Note that the first country (US) publishes 16.9 times as much as the fifteenth (Sweden), but files 84 times more patents (US with respect to Spain).

The absolute values of publications and patents, however, are not the most appropriate way to measure the effectiveness of the countries. For this purpose, the data need to be normalized. There are many possible methods for such a 'normalization', for example by the gross national product, GNP *per capita*, the country's investment in research etc. Unfortunately, none of them is without complications. For example a normalization by the country's research investment is difficult as usually only the governmental spending is publicly available.

Table 2. Publications and patent ranking normalized by size of country for the 15 most effective countries. The period for publications in nanotechnology comprises of the years between 1997 and 1999. In the case of patents registered at the EPO and PCT, the period from 1991 to 1999 is taken, due to the fact that the absolute numbers of patents per year are small and may be distorted. The population data are taken from the Population Reference Bureau (PRB) data for mid-2001. Sources: SCI, EPAT, PCTPAT, PRB and own calculations.

	Normalized publications (1997–99) per million inhabitants		Normalized patents EPO&PCT (1991–99) per million inhabitants	
1	150.2	Switzerland	12.2	Switzerland
2	91.4	Israel	4.4	Germany
3	73.5	Sweden	3.9	Israel
4	61.5	Germany	3.8	Belgium
5	56.9	Denmark	3.6	France
6	56.8	Singapore	3.5	USA
7	52.6	Austria	2.4	Netherlands
8	50.0	France	2.4	Sweden
9	48.3	Finland	2.3	Japan
10	47.7	Netherlands	1.8	UK
11	46.4	Japan	1.5	Canada
12	43.6	Belgium	1.3	Australia
13	42.7	UK	1.0	Austria
14	39.2	USA	0.5	Italy
15	36.0	Slovenia	0.3	Spain

The financial effort from industry is to a large extent not published; however, the industrial research effort is generally more prone to deliver patents. In spite of the difficulties of finding a good normalization factor, we can assume that, in a first-order approximation, the efficiency and productivity of countries can be depicted by dividing the number of publications by the country's population. Based on the previous table, table 2 lists the 15 most productive countries per million inhabitants.

In this ranking, Switzerland comes out top. This is not astonishing, as since the invention of the STM at the IBM Zurich laboratories, Switzerland has maintained a long tradition in nanotechnology research. Many world-class laboratories exist, and the Swiss government has played an active role in promoting nanotechnology through different specific programmes. The high value in the table may be partially distorted by the fact that the international CERN institutes appear in the database research as Swiss. However, even removing CERN from the data, Switzerland would still remain at the top of the list. Israel, another ten European states, Singapore, Japan and the USA complete the rest of the first 15 countries for publications. Most of these countries find themselves also in the list of the most efficient ones for patent filing. As already observed in the table for the absolute values, the spread between the most effective countries for patenting is roughly ten times larger (12.2–0.3) than for publications (150.2–36.0). This indicates a larger capacity to transfer research results into potential applications for some countries with respect to others. The USA is an exemplary case, it is only in position 14 in terms of publications per million inhabitants (39.2), but climbs to position number 6 for EPO&PCT patents per inhabitants (3.5). Such a large divergence between the ranking in normalized publications and patents may be explained by close academia—industry collaborations and by cultural influences (for example, additional financial incentives for academic personnel). China, which is the fourth most active country in absolute publications (6.3% share of the world-wide value, table 1), disappears in the normalized table (with less than 0.01 publications per million inhabitants) due to its huge population. Russia does not appear in the normalized tables as it occupies place 18 for both publications and patenting (with values of 15.0 publications per million inhabitants and 0.16 patents per million inhabitants)[1].

3. Conclusions

Science and technology indicators can give insights into the stage of maturity of a given technology and may be used to depict scenarios for future evolution and for decision makers to design an appropriate strategy. Nanotechnology—as a whole—is still an emerging area with the need to make progress in both scientific and technological terms before massive commercialization of products may occur. Some nanotechnology-based products are already on the market and others will follow. A forecast of which will be the most promising application to reach the market would require a more detailed analysis of the nanotechnology indicators by the industrial sector and by nanotechnology sub-areas. Such a prediction based on indicators is currently difficult to carry out due to the fact that nanotechnology is still an emerging area, and due to its cross-cutting nature it is difficult to make assignments to a sectorial or industrial branch.

An indicator analysis of nanotechnology activity by country confirms that the scientific expertise is not evenly distributed across the industrial countries, and that for countries with similar scientific potential some of them are more capable of transferring research results into application and, finally, into industrial products.

Acknowledgments

The authors thank Hervé Pero, Renzo Tomellini and Ben Tubbing for their critical reading.

[1] Note that for the time period 1991–93 the data for Russia are not available, as it belonged to the former USSR. However, the number of missing patents is expected to be small and should hardly have any influence on the discussion of the data.

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