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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.

[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

1. Overview (Table 1)
2. The Nanotechnology Committee
3. Stages of Innovation
4. Global and U.S. Nanotechnology Funding
5. Survey of Academic Nanotechnology Research in Israel
6. U.S. Nanotechnology Investment
7. U.K. Nanotechnology Priorities
8. Nanoelectronics and Nanomaterials (ICTAF)
9. U.S. Nanotechnology Centers
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14. Investment Process
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16. Forecasting the Development of Nanotechnology

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