Ma'moun Al-Rawashdeh, Bassam Alfeeli, Abdel Monem Rawashdeh and Volker Hessel*

Development highlights of micro-nano technologies in the MENA region and pathways for initiatives to support and network

Abstract: Current developments in the field of micro-nano technologies in the Middle East and North Africa (MENA) region are highlighted. Firstly, the scientific outcome of micro-nano technologies from the MENA region is analyzed. Egypt and Saudi Arabia are the leading countries, with >50% of the total MENA publications. More than 50% were joint publications with France and the United States as the major partners. Secondly, different kinds of existing initiatives to develop and support micro-nano technologies in the MENA region are presented. The working principle of current respective initiatives is demonstrated. Despite the importance of these initiatives, they are fragmented and lack a regional framework and a common goal. Thirdly, therefore, a recommendation is suggested to create a platform and a road map for boosting the development of micro-nano technologies in the MENA region.

Keywords: Arab world; microtechnology; Middle East; nanotechnology; road map.

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1 Introduction

In its original sense, microtechnology is a set of processes, techniques and tools used to create structures having at least one dimension of a functional feature in the order of micrometer, and application of those structures in more complex systems [1]. Nanotechnology is the understanding and control of matter at the nanoscale, at dimensions between approximately 1 and 100 nm, where unique phenomena enable novel applications [1].

Micro-nano technologies are highly multidisciplinary, with very widespread applications [2–8]. There is even a growing appreciation that it is difficult to find areas of manufacturing and industry where micro-nano technologies will not have an impact. Thus, industrially advanced countries have invested heavily in these technologies. The United States has set the pace for nanotechnology innovation with the National Nanotechnology Initiative (NNI) in 2000 [9]. The cumulative NNI funding since 2000 amounts to >$12 billon, including about $1.8 billion in 2011, making it second only to the space program, in terms of civilian science and technology investment. In Europe, micro-nano technologies are considered as Key Enabling Technologies (KETs) according to the European Union's Horizon 2020, with a budget of >€4 billion [10].

Despite the spectacular development in nanotechnology by the industrially advanced nations, the potential effect of nanotechnology on human health and the environment is still not fully identified [11]. However, several efforts are being made to attach nanotechnology to the metrics of green chemistry, which can be named "Green Nano" [12]. Such efforts aim at the advancement of new nano products which are more environmentally friendly through their life cycles, and minimize the health risks associated with the manufacture and use of nanotechnology products in general. Producing new clean technologies using nanotechnology could replace the currently non-green technologies used by the industry.

In the last 20 years, the scientific developments in micro-nano technologies were geographically concentrated in three regions: Europe, Japan/China, and North America [13, 14]. However, this is rapidly changing, as new developments in this domain in other parts of the world have been recently observed, especially in the Middle East and North Africa (MENA) region. In fact MENA is currently entering a new phase of social, political and economical reforms; a phase which has been identified by the media as the "Arab spring" [15]. Moreover, industrial development in the MENA region is expected to be boosted, as shown in Figure 1. According to the A.T. Kearney study "Chemical industry vision 2030: A European Perspective", two to three of the top 10 world players in the chemical industry will be from the MENA region [16].

Developing micro-nano technologies in developing nations is essential because it:

1. Helps facing the growing challenges in health, energy and environment.
2. Captures and utilizes the unused human potential in these countries toward the development of these technologies.
3. Contributes toward the United Nations Millennium development goals [17].
4. Contributes toward building and strengthening science in low and middle-income countries.

This paper provides highlights of the current developments related with the micro-nano technologies in the MENA region. Israel and Iran are excluded from the study because they are scientifically more advanced and can better fit into a different category. For example, the number of publications from Iran and Israel together is more than twice that of the rest of the MENA region, according to analysis using scopus (www.scopus.com).

This study is composed of three parts. The first part analyses the publications produced from the MENA region related to micro-nano technologies. The second part highlights the different initiatives that contributed to the recent micro-nano technologies development in the MENA region. The working principle of the different initiatives will be highlighted. The third part provides recommendations to spur the development of micro-nano technology in the MENA region.

2 Methods

2.1 Background information

Excluding Iran and Israel, the MENA region consists of 19 countries, as shown in Figure 2, and is home to about 380

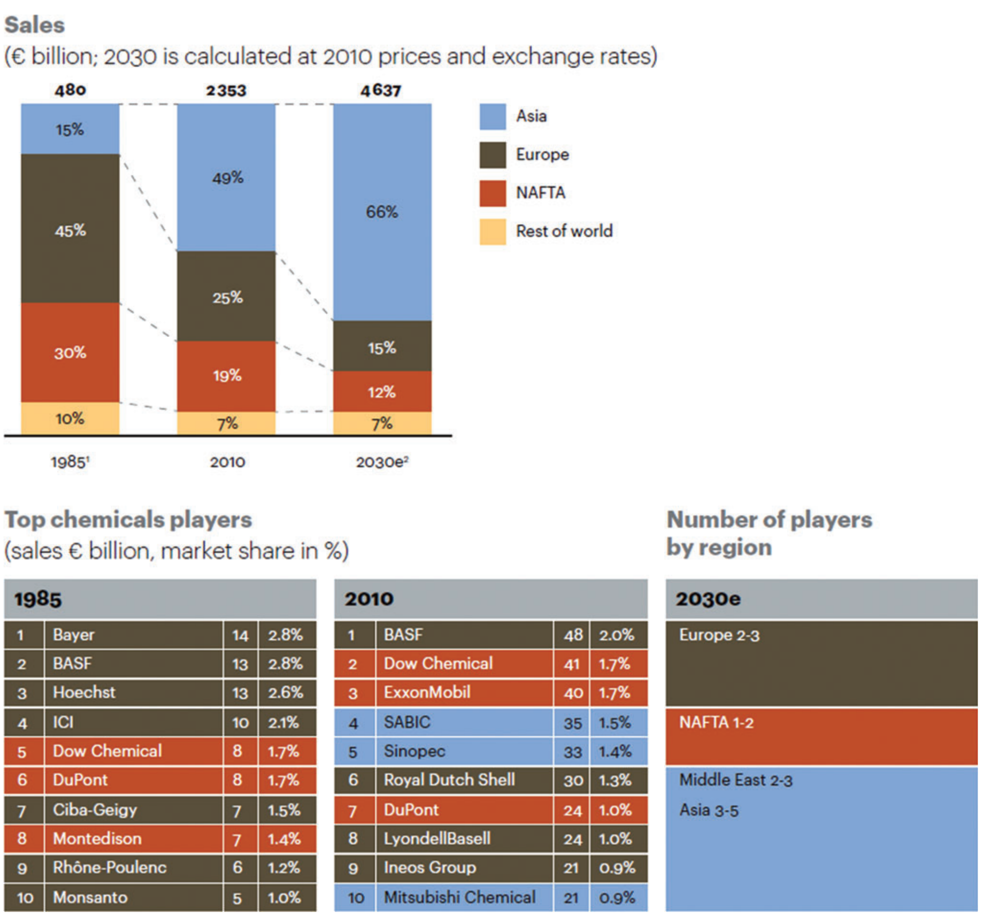

Figure 1 Results/Figure reproduced with kind permission from the following analysis report: Chemical industry vision 2030: a European perspective, © A.T. Kearney 2012.

Figure 2 Map of the countries in the Middle East and North Africa (MENA) region. Reproduced with kind permission from © Worldbank (www.worldbank.org).

million, representing 5.4% of the world's population [18]. Apart from Israel and Iran, these countries can be divided into two groups [19]. The first is characterized by its total dependence on oil (Bahrain, Emirates, Kuwait, Oman, Qatar, and Saudi), with gross domestic product (GDP) per capita income being the highest in Qatar and the lowest in Oman. The science, technology and innovation (STI) and higher education system in these countries are new but developing rapidly. According to the Global Competitiveness Report (GCR) and among 144 countries, Qatar, Saudi Arabia, and the United Arab Emirates have moved up from 31st, 35th, and 37th ranking in 2007 to 11th, 18th and 24th in 2012, respectively [18, 19]. The second group consists of Algeria, Egypt, Iraq, Palestine, Jordan, Lebanon, Libya, Morocco, Syria, Tunisia and Yemen. Here, the GDP per capita is the highest in Libya and the lowest in Yemen and Egypt. Although the countries in this category have modest oil reserves, with the notable exceptions of Iraq and Libya, they possess a relatively mature higher education infrastructure, which includes some of the oldest universities in the MENA region. The population of this group amounts to around 70% of the population in the MENA region.

2.2 Analysis methodology

The scientific contribution from the MENA region is analyzed using Scopus (www.scopus.com) between the years 1980 and 2012. The search has been made by specifying the following keywords: nanotechnology, nanotubes, nanowires, nanostructures, nanoparticles, microstructures, microreactor, microfluidic, lap-on-a chip, microelectromechanical systems (MEMS), and nanoelectromechanical systems (NEMS). Using the analysis option in Scopus, analysis per country, per topic, and per institute was made. Searching for the different initiatives to develop micro-nano technologies in the MENA region was performed by internet search and using information available in the public domain.

3 Results and discussion

3.1 Scientific output of micro-nano technologies in the MENA region

The total scientific contribution from the MENA region in the field of micro-nano technologies, compared to other developing nations such as Brazil, China and India, is shown in Table 1. The contribution of the MENA region, relative to the population, is similar to that of India and close to that of Brazil. However, China is ahead compared to these nations. The scientific yearly publication normalized by the cumulative total number for Brazil, China, India, MENA and the world is shown in Figure 3. Despite

Table 1 Percentage of the population and scientific publications of the micro-nano technologies for some developing nations and the Middle East and North Africa (MENA) region.

	Population of a country relative to the world (%)	Publications contribution relative to the world (%)
Brazil	2.8	1.1
China	19.2	20.7
India	17.1	3.4
MENA	5.4	0.8

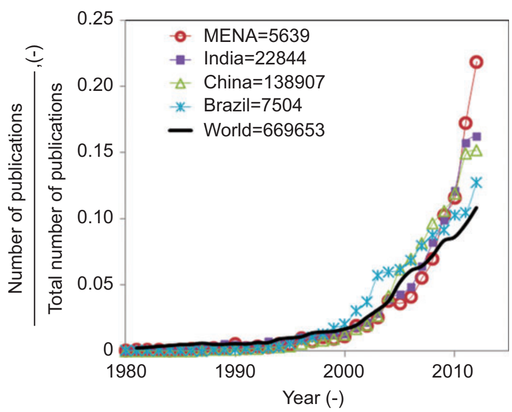

Figure 3 Scientific publications per year for the world and the Middle East and North Africa (MENA) region normalized by their total publications given in the figure legend.

the small scientific contribution from the MENA region, the rate of development in the last 4 years is three to four times more than the average rate for the rest of the world. Additionally, it is larger than that given for India, China and Brazil by three, two and one half times more, respectively.

When analyzing the publications based on the research topic, the MENA region covers the same topics as the rest of the world, so all research topics are addressed in the MENA region. Figure 4 shows the distribution of scientific publications in the micro-nano technologies in the MENA region per country. Egypt and Saudi Arabia are taking the lead, with >50% of the total MENA publications. Algeria, Tunisia, Morocco, Emirate and Jordan constitute the other major contributors in terms of the number of publications and the remaining 10 countries have minor contributions.

When analyzing the scientific output per country, >50% of the publications were made as joint publications with other countries, as shown in Figure 4. This suggests that at this stage of development, partnership is a key parameter for the MENA region to develop in these technologies. France (22%) and the United States (16%) are the main partners in that region, with almost 40% of the total number of publications; they are followed by Germany (7%), the UK (6%), Canada (5%) and then Asian leading countries such as India (5%), Japan (4%), South Korea (3%), China (3%), Malaysia (2%) and Singapore (2%). Based on the number of publications, some of the main notable institutes and universities in the MENA region, which contribute to the field of micro-nano technologies, are shown in Table 2.

3.2 Micro-nano technologies initiatives in the MENA region

Highlights are given on the initiatives that contributed to the development of micro-nano technologies in the MENA region. The aim is to provide the reader with an idea of the different working principles of the initiatives currently used in the MENA region. This is a pre-step in the direction of encompassing and analyzing the effectiveness and impact of those initiatives and how the interaction between them can be better utilized. Such analysis will be undertaken in future work.

3.2.1 Initiatives of international companies – IBM

Working principle: International company experts work with MENA scientists and engineers, who constitute the majority of the workforce, on advanced micro-nano technologies projects. Defined and specific research topics include, for example, photovoltaic and water desalination. Major financial contribution comes from the international company and partly from the host country.

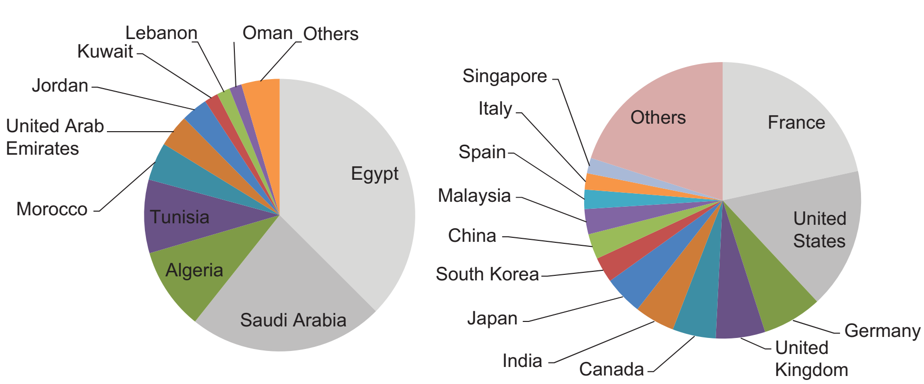

Figure 4 Distribution of scientific publications output in the micro-nano technologies per country. Left is for the Middle East and North Africa (MENA) region and right is for countries who issue a join publication with the MENA region.

Table 2 Notable institutes in the Middle East and North Africa (MENA) region which are active in the field of micro-nano technologies.

Country	Institute
Egypt	**National Research Center, Cairo**
	Ain Shams University
	Central Metallurgical Research and Development Institute, Cairo
	Cairo University
	Suez Canal University
	American University in Cairo
Saudi Arabia	**King Fahd University of Petroleum and Minerals**
	King Saud University
	King Abdulaziz University
	King Abdullah University of Science and Technology
Algeria	University of Sciences and Technology Houari Boumediene
	Université Badji Mokhtar
	Université Mentouri Constantine
Tunisia	University of Monastir
	University of Sfax
	Tunis-El Manar University
Morocco	Faculté des Sciences Semlalia
	Université Mohammed V Agdal
	Al Akhawayn University
United Arab Emirates	United Arab Emirates University
	Masdar Institute of Science and Technology
	The Petroleum Institute, Abu Dhabi
Jordan	Jordan University of Science and Technology
	Hashemite University
	The University of Jordan
Kuwait	Kuwait University
	Kuwait Institute for Scientific Research
Lebanon	American University of Beirut
Oman	Sultan Qaboos University
Bahrain	University of Bahrain

Top five are in bold.

In an attempt to capture the currently underutilized human potential in Egypt, IBM teamed up with the Egyptian Information Technology Industry Development Agency (ITIDA) and the Science and Technology Development Fund (STDF), to create Egypt's first national research laboratory in 2008, the Egypt-IBM Nanotechnology Research Center (EGNC) (www.egnc.gov.eg) [17]. The idea was to have IBM experts working with local scientists and engineers on advanced nanoscience and nanotechnology projects. With $30 million in seed money for the first 3 years, EGNC is focusing on solar energy technology and water desalination. The startup work force of EGNC was about 100 employees, but is expected to grow up to 1000 within the next few years. Current research areas in EGNC include: thin-film silicon photovoltaics, spin-on carbon-based electrodes for thin film photovoltaics, energy recovery from concentrator photovoltaics for desalination, and computational modeling and simulation.

Saudi Arabia's national research and development organization, the King Abdulaziz City for Science and Technology (KACST), established the KACST-IBM nanotechnology center of excellence in 2008 (http://ncekacstibmorg.ipage.com/). This aims at developing long term collaboration in the fields of photovoltaics, water desalination, and bio sensors.

In 2010, IBM announced a plan to build a nanotechnology center in Jordan similar to that in Egypt and Saudi Arabia. In 2010, the Jordan Higher Counsel of Science and Technology approved the establishment of a nanotechnology center at the Jordan University of Science and Technology (JUST) (www.just.edu.jo/Centers/nano/). This center has >30 affiliated faculty members from JUST University, with varied backgrounds, and is currently building their infrastructure and clean room facility.

3.2.2 Initiatives within the MENA region by private endowments – Yousef Jameel

Working principle: A center is established within a local university or an institute and relies on local scientists and engineers who are educated abroad to lead the research projects *in the center. Broad research topics are addressed. Major financial contribution comes from private endowments.*

The first activity in Egypt on the micro-nano research, and establishing a fabrication facility, was started in 2003. This was marked by the establishment of the Yousef Jameel Science and Technology Research Center (YJ-STRC) at the American University in Cairo (AUC) (www.aucegypt.edu/research/jameel/). This center was the fruit of the generous support of $8 million over 5 years from Yousef Jameel, a Saudi businessman and AUC alumnus. So far, the YJ-STRC has secured $13 million in funding and has recruited 17 high profile faculty members with diverse backgrounds. The center consists of six research groups: micro- and nano-systems, nanostructured materials, surface chemistry, biotechnology, environmental science and engineering, and novel diagnostics and therapeutics. Additionally, it is serviced by class 100 clean room and state-of-the-art fabrication and characterization equipment that includes: micro- and nano-systems fabrication, materials synthesis, biotechnology, and surface chemistry. In addition to the research activities, the AUC and the YJ-STRC offer a Master of Science degree in nanotechnology, and a Doctor of Philosophy in applied sciences, with specializations in nanotechnology. This is achieved by the support of eight postdoctoral fellows, 13 doctoral students, 20 master's students, and four technical staff. Another example similar to the Yousef Jameel initiative is the Hamdi Mango Center for Scientific Research (HMCSR) in Jordan, which was established by the grant given by Mr. Ali Mango. Further information about HMCSR activities can be found on the website (http://centers.ju.edu.jo/centers/hmcsr/Home.aspx).

3.2.3 Top-bottom governmental initiatives – The gulf countries

Working principle: New institutes and funding programs are created via top-bottom governmental initiatives to develop micro-nano technologies. Partnerships are made with international and local leading universities and companies. Initiatives rely largely on expertise from other MENA countries and internationally, while at the same time investing on educating many local scientists and engineers abroad, to build their expertise in the field. Broad research topics are addressed. All financial contribution comes from the governments.

The gulf countries are currently investing heavily in scientific education and research [17]. Most of the development activities in these countries are "top-bottom" with large budgets and directed towards building state-of-the-art facilities and infrastructures in micro-nano technologies. The initiatives made in Saudi Arabia to develop micro-nano technologies will be presented here as an example for one of the rich oil countries. Only the names of these initiatives will be given here; further information can be obtained via their websites.

KACST is Saudi's principal agency over research and development and the national policy for science and technology. In 2002, the Council of Ministers approved the National Policy for Science and Technology (NPST), which resulted in The National Nanotechnology Program (NNP), with KASCT being responsible for its implementation (www.kacst.edu.sa). In 2005, the Center of Excellence in Nanotechnology (CENT) at King Fahd University of Petroleum and Minerals was established (http://www2.kfupm.edu.sa/cent/). The Center of Nanotechnology (CNT) at the King Abdul Aziz University was established in 2006 (www.nano-center.kau.edu.sa). In 2009, the Center of Excellence of Nano-manufacturing Applications (CENA) was established at KACST (www.cena-consortium.org). CENA is a research consortium between KACST, Intel, and selected universities in the MENA region. In the same year, King Abdullah University of Science and Technology opened its core facility, the Advanced Nanofabrication, Imaging and Characterization (ANIC) facility (www.anic.kaust.edu.sa). Most recently, the King Abdullah Institute for Nanotechnology (KAIN) was established in 2010 at King Saud University (www.nano.ksu.edu.sa).

3.2.4 Bottom-up educational initiative – Seeds from a Micro Flow Chemistry and Biology (MIFCAB) workshop

Working principle: An event or a series of events are made as an initiative from a group of leading scientists and engineers from the MENA region and other parts of the world. The event aims at educating industrial and academic audiences from the MENA region about micro-nano technologies. Broad research topics are covered by mixed expertise from abroad and the MENA region. Financial contributions come from mixed sources, but mainly from the host organization.

In November 2012, the authors initiated and organized a workshop on MIFCAB in Jordan for 2 days (www.mifcab.org). The workshop aimed at transferring the knowledge of micro process technology, to industrial and academic audiences from the MENA region. The workshop was hosted and sponsored by the Applied Scientific Research Fund from Jordan. The MIFCAB workshop attracted >70 participants from 17 countries and various backgrounds, as can be seen in Figure 5. More than 20 renowned speakers presented the technologies. Profiles for some of those speakers are presented in the Topical Issue of Green Processing and Synthesis – March 2013. The distribution of the topics presented by those speakers is shown in Figure 5. Some speakers covered the topics of microreactors, flow chemistry and novel process windows, and others covered biotechnology, lab on a chip, and sensors. A number of active industrial companies in the field presented their research and services. Additionally, speakers from the MENA region, who were working on neighboring fields, presented their research.

The workshop successfully achieved its aims. As a result, the Nanotechnology Center at JUST University decided to make a division on microfluidics in their center. Moreover, a leading industrial company showed interest in exploring and acquiring micro and nano technologies. Another result of MIFCAB was the initiation of a MENA wide collaborative effort to prepare and publish a review article on nanotechnology development in the Arab World.

3.3 Recommendation – MENA platform and road map of micro-nano technologies

The initiatives mentioned earlier are essential for the development of micro-nano technologies in the MENA region. Despite their importance, these developments are fragmented and do not have a regional framework and a common goal. The MENA region is missing a platform and a road map to provide the ground for the scientific communities, policy makers, industries and nongovernmental organizations to interact with each other toward such a development goal. Such an initiative will spur the development of micro-nano technologies in the MENA region and maximize the utilization of the available resources and infrastructures.

The authors are not on a decision-making level to suggest and realize making such an initiative. Additionally, any analysis made on the development of micro-nano technologies in the MENA region would probably reached a similar suggestion. The authors came across such a prospective position, because they recently organized the MIFCAB workshop and because they participate in producing the review paper about the development of nanotechnology in the Arab world.

The first idea on how to realize the road map is illustrated in Figure 6, which shows a graphical representation of the elements needed in the MENA region. It consists of four elements, as given below:

1. Platform: Exchange of expertise and ideas. Facilitates and maximizes the utilization of the current infrastructures and research facilities in the MENA region.
2. Science – Education: Raises awareness at different organizational levels and demonstrates the societal benefits of micro-nano technologies. For example, organizing workshops and conferences and building expertise and a skilled workforce, by establishing a university or training programs on these technologies.
3. Science – Research: Creates the necessary critical mass of scientists and skilled workforce to serve the demands of these technologies. Identifies the local needs of the technologies and conducts research to demonstrate the ability of providing effective solutions to overcome these local needs.
4. Road map: A plan document to provide the best ways to disseminate the accumulated knowledge to the society, businesses, and industry and to preserve the

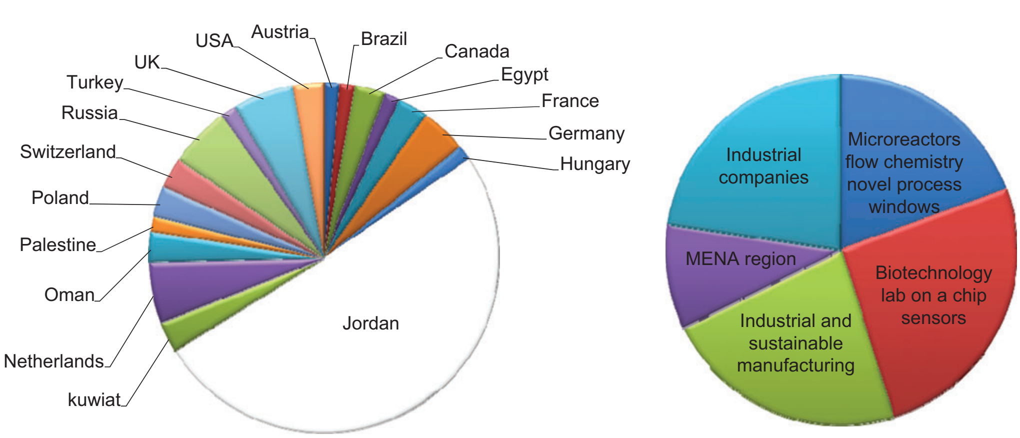

Figure 5 Participants distribution in the Micro Flow Chemistry and Biology (MIFCAB) workshop, which was held in Jordan 7–8 November, 2012. (Left) MIFCAB distribution presented as nation-wise and (right) topic-wise distribution as presented by the speakers.

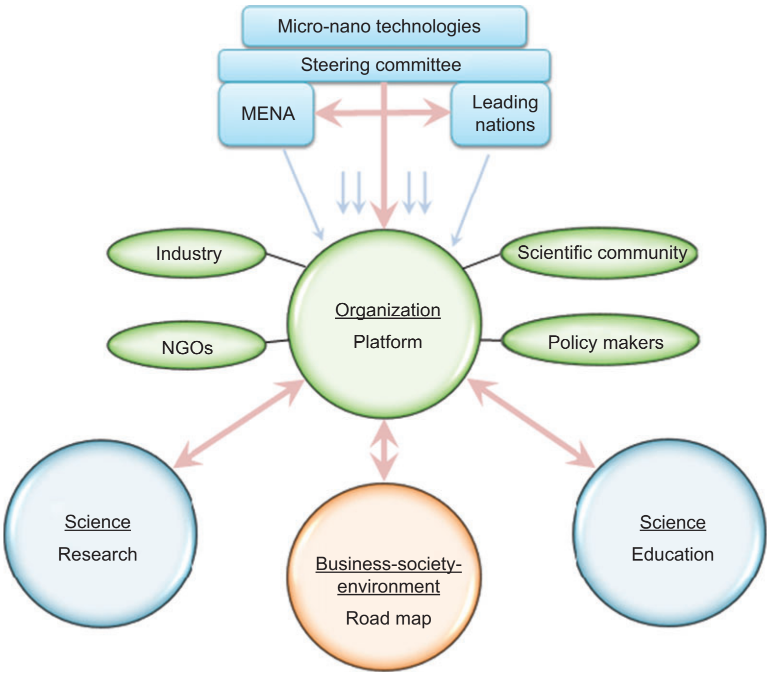

Figure 6 Graphical representation of the suggested recommendation - Middle East and North Africa (MENA) micro-nano technologies platform and road map.

environment. Generate a regional framework and a common goal. Help in unifying priority research topics. Suggest funding programs to support such developments.

The realization of these four elements will require:

1. An institute to develop and implement the road map.
2. A steering committee, which consists of representatives from the MENA region and international experts, to provide guidance to the institute.
3. Committed members.
4. Sources for its financial support.

There are a number of potential entities which could financially support the realization of such an initiative. In the MENA region, the following are some examples of governmental entities which could provide financial support for the above-mentioned road map and platform: League of Arab States, KACST in Saudi Arabia, Qatar foundation in Qatar, Kuwait Foundation for Advancement of Science in Kuwait, STDF in Egypt, Arab Science and Technology Foundation in the UAE, Scientific Research Fund in Jordan, National Center for Scientific and Technological Research in Morocco, Research Council in Oman, and other entities in other countries, along with the private sectors and non-governmental organizations. Additionally, from outside the MENA region, there are organizations which could support such initiatives. For example, the European Union in the FP7 issued a call within the nanosciences, nanotechnologies, materials and new production technologies (NMP) called “Deployment of societally beneficial nano- and/or materials technologies in ICP countries” which could perfectly support the above-mentioned initiative.

4 Conclusion

To date, the scientific contribution of the micro-nano technologies from the MENA region is low compared to industrially advanced nations, but comparable to those of India and Brazil. Data has shown that in the past 4 years, the rate of scientific publications is three to four times more than the average world rate and higher than other developing nations like Brazil, China, and India by three, two and one half times, respectively. Egypt and Saudi Arabia are the leading MENA countries, with >50% of the total MENA publication outcome. This development is partly led by governments as a top-bottom approach, especially in the rich oil states such as Saudi Arabia, and partly because of the involvement of international companies, such as IBM, to set-up institutes on micro-nano technologies in the MENA region. Private endowments from businessmen such as the Yousef Jameel initiative and bottom-up initiatives such as the MIFCAB workshop, are also factors which help boost the development of micro-nano technologies in the MENA region.

The development of a micro-nano technologies platform and a road map would increase the rate of development in the MENA region. The road map will help in providing a regional framework and a common goal. The platform will facilitate and maximize the utilization of the current infrastructures and research facilities in the MENA region.

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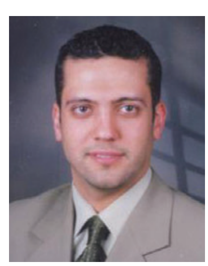

Dr. Bassam Alfeeli, received his BSc degree in Electrical and Computer Engineering from the Florida Institute of Technology, USA, in 2000, his MSc degrees in Electrical Engineering, and Materials Science and Engineering, and his PhD in Electrical Engineering from Virginia Polytechnic Institute and State University, USA, in 2005, 2009, and 2010, respectively. He is currently an Associate Research Scientist in the Nanotechnology and Advanced Material Program, Kuwait Institute for Scientific Research, Kuwait (KISR). His research interests include the development of chemical sensors and sensing related devices.

Dr. Abdel Monem Rawashdeh was born in Jordan in 1970; he earned his PhD from the Missouri University of Science and Technology (MST) in 2003 under the supervision of Professor Chariklia Sotiriou-Leventis. His research is focused on computational chemistry. In 2008, he was awarded the Fulbright scholarship at Cornell University to work with the Nobel laureate Roald Hoffmann. He is currently the CEO of the Applied Scientific Research Fund (ASRF) located in Jordan.

Professor Dr. Volker Hessel, born in 1964 and he studied Chemistry at Mainz University. He obtained a PhD in the field of Organic Chemistry in 1993. The topic of his PhD thesis was structure-property relationships of special supra-molecular structures, micelles and lyotropic liquid crystals, constructed by so-called bi- or multi-polar amphiphiles, with a rigid core unit.

Since 1994 Professor Dr. Hessel has been an employee of the Institut für Mikrotechnik Mainz GmbH and in 1996, he became a group leader for microreaction technology. In 1999, he was appointed Head of the chemical process technology department. His fields of research comprise micro process engineering for mixing, fine chemistry, fuel processing and heterogeneous catalysis. In 2002, he was appointed as a vice director of R&D at IMM and in 2007, as a director of R&D at IMM.

Professor Dr. Hessel is the author or co-author of more than 150 peer-reviewed publications (with 24 extended reviews) and in excess of 180 conference papers with regard to chemical micro process engineering, 15 book chapters, and five books.

In July 2005, Professor Dr. Hessel was appointed as a part-time Professor for the Chair of “Micro Process Engineering” at Eindhoven University of Technology, TU/e. This professorship is under the umbrella of the Chemical Reactor Engineering group of Professor Dr. ir. Jaap Schouten in the Department of Chemical Engineering and Chemistry. Professor Dr. Hessel was appointed as an Honorary Professor at the Technical Chemistry Department at Technical University of Darmstadt and is active in this function within the Cluster of Excellence Smart Interfaces (CSI).

Professor Dr. Hessel received the AIChE award “Excellence in Process Development Research” in 2007. His Hirsch number (scientific impact measure) is 25.

Professor Dr. Hessel was AIChE chair (US) “Microprocess Engineering” (2005–2008); he was elected a board member of the German industrial platform IPmVT; and is a member of the editorial boards of *Catalysis Today*, *Chemical Engineering Journal*, *Chemical Engineering Technology*, *Recent Patents on Chemical Engineering*, and *Current Organic Chemistry*; he holds the Topical chair at AIChE Spring conferences 2006 and 2007 and is an organizing committee member of the symposia held at CHISA-6, ECCE-6 (EPIC), EUChemS and WCCE-8, as well as being the Chair of the program committees of the “Conference on Smart Synthesis and Technologies for Organic Processes” (SynTOP) and the “International Conference on Microreaction Technology 10” (IMRET-10).