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RESEARCH PAPER

# Inventory of nanotechnology companies in Mexico

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**Abstract** This study presents an inventory of 139 nanotechnology companies in Mexico, identifying their geographic distribution, economic sector classification, and position in the nanotechnology value chain. We find that the principal economic sector of nanotechnology-engaged firms involves the manufacture of chemical products, which largely serve as means of production (primary or intermediate materials; instruments and equipment) for industrial processes. The methodology used in this analysis could be replicated in other countries without major modifi cations.

**Keywords** Production networks · Technology · Technological change · Developing countries · Innovation · Nanotechnology · Mexico · Value chain

## Introduction

This study presents the results of research on the nanotechnology value chain in Mexico. We identify 139 companies that work with nanotechnology in Mexico, allocating each firm to an economic sector

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based on its principal product, using the United Nations' International Standard Industrial Classification of All Economic Activities (ISIT). The results of this classification show that most nanotech-related firms are involved in the production of chemical substances and products that occupy an intermediate role in the nanotechnology value chain. We then seek to determine whether the resulting products are intended to be used by industry or as final consumer goods.

In the following discussion, we first provide an inventory of nanotechnology companies and products in different countries and regions, before turning to a brief discussion of the state of nanotechnology in Mexico. We then explain the methodology used in our analysis of Mexican nanotech firms, followed by a presentation of the results. We conclude with a discussion of Mexico's role in this emerging technology.

## Nanotechnology: a global race to be first

The US National Nanotechnology Initiative defines nanotechnology as "the understanding and control of matter at dimensions between approximately 1 and 100 nm (nm), where unique phenomena enable novel applications not feasible when working with bulk materials or even with single atoms or molecules" (US NNI 2015a).[1] It is predicted to be a disruptive technology, with significant changes in computing, medicine, and materials—not to mention jobs and as yet largely unknown risks to health and the environment.

Nanotechnology is also believed to hold great commercial potential, which is why an estimated 60 countries are investing public funds, with the U.S. leading the way.[2] Global government spending between 2000 and 2014 was estimated to reach $100 billion, with private spending more than twice that amount ($150 billion) (Cientifica 2011). Lux Research, a firm that specializes in tracking global investments in nanotechnology, estimated the global market for nanotech-related products at $731 billion in 2012, and—even more bullishly—projected $4.4 trillion by 2018 (Flynn 2014).[3] Yet to date, the results of public investments in nanotechnology have been relatively modest. Among the products that rely nanotechnology for primary or intermediate components are self-cleaning glass, water-resistant coatings, nanoporous filtration, ultra-light (and ultra-strong) carbon-based materials, smart textiles, and controlled drug delivery systems.

The first companies that sold nanotechnology products began to operate in the second half of the 1990s. Zyvex, for example, begin in 1997 in the United States and it specialized in the development of nano-materials for various industrial sectors (Zyvex 2015). Nanotex opened its doors in 1998, manufacturing textiles with chemical-physical properties similar to the skin of some animals, which permitted their products to repel dust and moisture (Nanotex 2015). Nanotechnology's rapid market growth did not begin until the 21st century.

The first public global inventory of nanotechnology products was created in 2005 by the Woodrow Wilson International Center for Scholars (WWICS) in Washington D.C. This inventory, now in its second version, has more than 1800 products registered on a publicly searchable database.[4] The WWICS project partnered with the Institute for Critical Technology and Applied Science at Virginia Polytechnic Institute (ICTAS-VT), enabling it to greatly improve the reliability and functionality of its original database (WWICS 2015).

Nanowerk, based in the U.S and Germany, is another firm that maintains a website disseminating information about the development of nanotechnology.[5] Its databases include a global registry of nanotech companies, classified alphabetically according to the country where they are located in the network (Nanowerk.org 2015). The United States

[1] Lux Research (a private firm that tracks nanotechnology) offers a more succinct definition: "the purposeful engineering of matter at scales of less than 100 nm to achieve size-dependent properties and functions" (Holman et al. 2007, Fig. 1.2). A nanometer is one billionth of a meter. Human hair averages roughly 100,000 nanometers thick, while a DNA molecule is 2–3 nanometers in width.

[2] The 2016 budget request from the U.S. National Nanotechnology Initiative was $1.5 billion, down from a peak of $1.9 billion in 2010, which would bring total U.S. since the inception of the NNI in 2001 to $22 billion (US NNI 2015b).

[3] These figures are cited uncritically in the 2014 report of the U.S. President's Council of Advisors on Science and Technology (PCAST 2014, pp. 23 and 41).

[4] See http://www.nanotechproject.org/cpi/.

[5] See http://www.nanowerk.com/.

leads with 1025 companies, Germany follows with 210, then the United Kingdom with 143, Japan with 54, Switzerland with 46, and all other countries with still fewer companies.

Germany's Federal Ministry of Research and Education also maintains an inventory of institutions involved in the development of nanotechnology in Germany, including research institutions, laboratories, universities, government agencies, non-governmental organizations, museums, and companies. According to the information available on their website, there are 830 medium and small nanotech companies, and 273 large nanotech corporations. The registries are classified according to the sector of application (automotive, chemical/materials, construction, energy, equipment, health, etc.) and the technological disciplines that they complement (biotechnology, optics, chemicals, etc.) (MFIyE 2015).

The government of Canada also maintains a national directory of nanotechnology companies administered by the Ministry of Industry (Industry Canada—IC). This registry is voluntary and functions as a mechanism for connecting interested parties. The directory contains two sub-directories: the first is organized in 3 subdivisions corresponding to users, producers and service provider; the second is subdivided according to the functions of different nanomaterials (IC 2015).

Denmark also maintains a publicly available searchable database of nanotech products. "Nanodatabase" is sponsored by the Danish Consumer Counsel, the Danish Ecological Counsel, and the Department of Environmental Engineering (DTU Environment). Its inventory is based on self-reporting: to register a product a form is filled out online, where the name of the product and the general facts of the company, in addition to a photo of the product is included (Nanodatabase 2015). As of October 2015, 2139 products had been identified.[6]

In Argentina, the Argentinian Nanotechnology Foundation (FAN) maintains a catalog that offers information about companies, equipment, suppliers, and services of the production chain of nanotechnology in the country. The method of incorporating new registries into the catalog is accomplished by filling out a form and sending photos of the products (FAN 2012). The procedure is similar to the one used in Denmark or in Canada. The inventory has more than 40 registrations.

There are also regional and state databases. In Canada, the provinces of Ontario, Quebec, and Alberta have maintained inventories for several years. Nonetheless, the inventory of Alberta is specific to manufacturing entities. The inventory NanoAlberta uses a geo-referenced map to illustrate the location of more than 90 businesses and factories in the province (NanoAlberta 2015).[7] In the United States, there are also state inventories, as in the case of California (Frederick 2014)[8] and Massachusetts (Azonano.com 2014).[9]

## Mexico: nanotech as a national priority

As with the majority of countries, Mexico places nanotechnology as a priority area of development in its plans of Science, Technology, and Innovation (Foladori and Invernizzi 2013). Nonetheless, there does not exist a government organization specific to orienting and programing this field of technology, in contrast with those that occur in many other countries, with the forerunners such as United States, China, Germany, and Japan, or even Brazil and Argentina in Latin America. There have been, however, federal and state investments that show the intention to promote these technologies. Three types of investment have been highlighted: specialized laboratories, research networks, and industrial parks.

*Specialized Laboratories* The Center for the Investigation of Advanced Materials (CIMAV) is the headquarters of the National Laboratory of Nanotechnology (NaNoTeCh). This laboratory opened its doors in 2006 and is financed by the National Counsel of Science and Technology (CONACyT). NaNoTeCh is in Chihuahua and has among its objectives supporting national institutions and corporations in the development of nanotech applications, materials, and research (CIMAV 2015). The National Laboratory of

6 See http://nanodb.dk/.

7 See, for example, http://www.albertatechfutures.ca/nanoAlberta/AlbertaNanoAssetMap/IndustryMap.aspx.

8 See http://californiananoeconomy.org/.

9 See http://www.azonano.com/Industries.aspx.

Research in Nanosciences and Nanotechnology (LINAN), located in the Potosi Institute for Scientific and Technological Investigation (IPI-CyT), has a portfolio of clients that encompass public and private research institutions, as well as national and foreign companies. This laboratory, located in San Luis Potosí, provides services of analysis and characterization of high-quality nano-materials (LINAN 2015). CONACyT's directory of national laboratories also includes the National Laboratory of Nano-Fabrication (NANOFAB), with headquarters in the Center of Nanotechnology and Nanosciences of the National Autonomous University of Mexico (UNAM) in Ensenada, Baja California. NANOFAB was created in August of 2014 and began operations at the beginning of 2015; it is made up of three clean rooms of 200 square meters and has the fundamental objective of developing primarily electronic, medical, automotive, and petroleum applications (NANOFAB 2015).

*Research Networks* The Network of Nanoscience and Nanotechnology, created in 2009, is a network comprised natural science researchers and engineers; it also includes some new companies. It's primary objective is to analyze Mexico's capacity for engaging in cutting-edge nanotech research, linking researchers together to solve specific problems (RNyN 2015). In 2014 CONACyT announced, the creation of the International Network of Bionanotechnology intended to have a significant impact on Biomedicine, Nutrition, and Biosecurity. The institution's headquarters are at UNAM; it is administered by UNAM's Coordination of Scientific Investigation and Center of Nanotechnology and Nanosciences (CONACYT 2014).

*Industrial Parks* The third type of investment has been the creation of scientific-industrial parks specialized in nanotechnology. A key project of the Mexican Government is the Cluster of Nanotechnology of Nuevo Leon (CNNL), which groups together an important number of nano companies. The CNNL functions under the triple helix model, linking academics, companies, and the government to generate competitive advantages (González-Hernández 2011a). The CNNL entered into operations in 2008 and has an incubator specialized in the development of nano-materials for commercialization.

In spite of the investment and development of nanotechnology in diverse institutions, Mexico lacks a nanotech registry that identifies what is being investigated, what is produced, or what is being sold. Nonetheless, as a member of the Organization for Cooperation and Economic Development (OCED), which has launched pilot surveys and nanotech registration initiatives in various countries, Mexico has incorporated into its system of economic statistics surveys some specifics about nanotechnology since 2011.

In 2012, the National Institute of Statistics and Geography (INEGI) presented the results of the first survey on nanotechnology.[10] The sample unit was companies or nonprofits with twenty or more employees dedicated to industrial, mercantile, or provision of services (INEGI 2014). The survey offered general figures, estimating that 188 companies work in nanotechnology in Mexico, which would place the country in eighth place of OCED member countries (OECD 2015). The facts of the sample are confidential, so it is not known which companies were surveyed, nor the productive branch, nor the resulting nanotech product.

In 2012, some of the present researchers developed an inventory based on information derived from web searches (Záyago Lau et al. 2013). This research identified 101 nanotechnology companies in Mexico and classified them according to the economic sector of the nanotechnology product in the market. This investigation constituted the foundation from which we now present a more exhaustive and detailed investigation. We located 38 additional companies as consequence of employing a more precise methodology, a larger research time frame and the tangible dynamism of the nanotechnology sector. Although the topic of nanotechnology development in Mexico has been explored to some extent (Foladori and Záyago Lau 2007; Bernal and Juanico 2009; Záyago Lau and Foladori 2010; Foladori et al. 2012; Záyago Lau and

[10] Encuesta sobre Investigación y Desarrollo Tecnológico y Módulo sobre Actividades de Biotecnología y Nanotecnología (ESIDET).

Foladori 2012; Záyago Lau 2013; Delgado-Ramos 2014; Foladori et al. 2015), no research to date has presented a comprehensive methodology to identify nanotech companies, nor allocated them in a nanotechnology value chain, nor analyzed if the product was an industrial intermediary or a final consumption good.

## Methodology

We applied four different methods through four phases of the present investigation. We began by developing a comprehensive inventory of nanotech companies in Mexico, after which we allocated each company to an economic sector. We then located each company's products in a nanotechnology value chain, and sought to determine whether the products were destined to be intermediates in industrial production or final consumer goods.

### Comprehensive inventory of nanotech companies

The identification of nanotechnology companies required a systematic search and the use of validation criteria for data obtained during the seven-month period September 2014 through March 2015.[11] In the large majority of cases, the companies produced only one product employing nanotechnology. The initial information was compiled from different sources: searches on the Web (the following search words were used: nano + Mexico, producto (product) + Mexico + nano*, empresa (company) + Mexico + nano), scientific articles and releases, presentations and meetings, forums and congresses, interviews with researchers, review of Mexico's principal periodicals (e.g., *La Journada*, *Reforma*, *Milenio*, *El Universal*) and news websites (CNN-español, Unotv, MVS-Noticias, etc.), media advertisements, companies located in specialized parks, and joint projects between researchers and companies (for example, those funded by CONACYT). Once a preliminary list was established that identified the name of the company, the product on the market, the geographic area, the information reference, and the accessory facts, the list was validated according to the following criteria:

- The company explicitly described, on its webpage, the application or use of nanotechnology[12]; and/or
- The product's advertisements clearly described the use of nanotechnology; and/or
- Representatives of the company validated the use of nanotechnology in articles, interviews, or public presentations[13]

The results of this investigation identified 139 companies. The information was ordered in a matrix that included the name of the company, its geographic location (state and city), relationship to foreign firm(s), if appropriate, the size of the company (number of employees),[14] domestic or foreign manufacturing, web reference or publication source, and the date of registry.[15] It is very difficult to know the total number of nanotechnology companies in Mexico at any given moment, so for this reason, the inventory presented here is neither claimed to be exhaustive nor statistically representative.[16] Nonetheless, it signifies the only large and systematic inventory that can give general indicators about the orientation of development of nanotechnology to this date.

Since this inventory was done based on products on the market, it excluded, for instance, companies that do nanotechnology research and development, and may have patents—or have financed a nanotech-related research project—but lack an identifiable

[11] The quantity of products and nanotechnology companies with a presence in the market can change daily; hence it is important to be specific about the time period covered.

[12] Three methods were used to find information on the company's webpage: (1) a Google search using keywords (nanotechnology, nano, nano-particles, nano-material; example nano site: www.(nombre/ruta).com; (2) a search on the website when it was available; and (3) a manual search in the catalogs of products online or from a downloadable format.

[13] There was no technical information concerning the actual nano-particles or nanotechnological components of the products provided in any of the sources available to us for our product inventory. The procedure used to register a product is explained in the "Methodology" section.

[14] The criteria used was based on the number of employees: micro (1–9), small (10–49), medium (50–249) and large (250+).

[15] The source of the information is accessible on the webpage of the Latinoamericana de Nanoteócnología y Sociedad (ReLANS).

[16] For example, the INEGI (2014) study came up with an estimate of 188 firms in 2012.

product on the market.[17] Since our analysis is restricted to companies with an identifiable product on the market, it necessarily results in an underestimation of companies that are doing R&D (and may soon have a product to sell).

## Allocation of company to an economic sector

This was accomplished through a manual classification procedure, utilizing the United Nations ISIC (International Standard Industrial Classification of All Economic Activities[18]), a system used by the majority of countries and international organizations to classify economic sectors (UN 2008). The appropriate four-level classification was determined for the 139 firms we had previously identified, utilizing search categories on United Nations ISIC registry website.[19]

The ISIC classifies firm according to four levels—Section, Division, Group, and Class. The broadest level involves 21 sections and includes both goods and services. Manufacturing (which includes the firms in this study) is designated by Section letter C, and includes activities that result in the physical transformation of materials to obtain a product (ONU 2006, p. 29).[20] To take one illustrative example, a cosmetic product that had nanotechnology-developed inputs would be classified as C2023[21]:

- Section: C—Manufacturing
- Division: 20—Manufacture of chemicals and chemical products
- Group: 202—Manufacture of other chemical products
- Class: 2023—Manufacture of soap and detergents, cleaning and polishing preparations, perfumes and toilet preparations

### *Location in the of nanotechnology value chain*[22]

Building on existing efforts to map nanotech-related firms according to their roles in value chains (Frederick and Stacey 2014; Lux Research 2004), we identified the following stages:

1. Primary nano-materials: particles or structures with one, two, or three nanoscale dimensions
2. Nano-intermediaries: altering the composition, functionality, or otherwise adapting the primary material to make it applicable for other industrial processes or final consumer products
3. Nano-enabled final products: incorporate primary nano materials and/or nano-intermediaries into products that will not undergo new physical–chemical transformation (final products can be destined either as means of production for industrial use, or for the consumer market)
4. Nano-tools, equipment, and machines: for measuring, analyzing, and producing nano-materials and nano-structures, or their application to other productive processes

The concepts shown below in Table 1 were to manually classify nanotechnology products according to their appropriate stage in the value chain, based on the product description that the firm provided:

### *Determination of final product as industrial intermediary or final consumption good*

Final products can be destined either as inputs into new processes for further accumulation of capital (productive consumption)—that is, as means of production; or they can be destined for individual consumption by people. This information is useful to understanding the nature of the revolution in nanotechnology in the process of accumulation of capital. When technology is applied to the means of production it can directly accelerate the development of new

[17] Companies that launch a products could be conducting R&D, but this information was not possible to corroborate.

[18] In Spanish, Clasificación Industrial Internacional Uniforme de todas las actividades económicas (CIIU). See http://unstats.un.org/unsd/cr/registry/regcst.asp?Cl=2&Lg=3.

[19] The search is available online at: http://unstats.un.org/unsd/cr/registry/regs.asp?Lg=1.

[20] Companies engaged in nanotechnology-related research and development, but lacking registered products, were classified as belong to Section M ("professional and scientific activities"). Institutions of education and public labs were not included, only private companies.

[21] This class includes (among many others) beauty and makeup preparations. (http://unstats.un.org/unsd/cr/registry/regcs.asp?Cl=27&Lg=1&Co=2023&qryWords=2023).

[22] As noted previously, in the case of those firms that lacked an identifiable product, we also registered available information on the firm's nanotech R&D, which is useful for understanding the future trajectory of nanotechnology in Mexico.

**Table 1** Key concepts to identify nanotechnology products in the value chain

| R&D | Primary nano-materials | Intermediary nano-materials | Final Nano-enabled products | Measurement and manipulative nano-related instruments |
|---|---|---|---|---|
| Companies that do not sell products but do research on nanotechnology | Nano-particles | Coverings | Sports clothing | Equipment and tools dedicated to the analysis, development, production and application of nano-materials and nano-structured materials |
| Companies with patents | Nano-fibers | Catalyzers | Home goods | |
| Companies with agreements with Universities and Research Centers on R&D on nanotech | Nano-tubes | Sensors and NEMS | Construction products | |
| | Nano-cables | Generators and energy storers | Electronics and computers | |
| | Nano-spherical particles | Pharmaceutical transporters | Personal care products | |
| | Nano-caps | Circuit integrators | Food and agricultural products | |
| | Nano-film | Nano-compounds | Medical products | |

*Source* with the exception of the R&D column, the rest of the information was taken from Stacey Fredrick, California in the Nano-Economy (http://californiananoeconomy.org/)

materials and thereby serve as a lever of economic growth. When nanotechnology is applied for products destined for final consumption, on the other hand, while the consumer may benefit, accelerated economic growth will not result.

The determination of the final destination of a nano-enabled product is not simple, because the same product can serve as a means of production or as a means of consumption. Flour, for example, can be used as a means of production by bakeries and other industrial food producers, thereby creating jobs and generating wealth; it can also be purchased for domestic use at home. While the consumer may benefit, no new jobs or wealth result. In our analysis, products generated during initial stages of the value chain (primary- and intermediary- nano-products) as well as nano-related instruments clearly serve as means of production. The challenge is to classify final products as either destined as means of production or final consumption, particularly when some products can have dual use.

## Results and discussion

Based on the address of the companies' headquarters, the 139 firms tend to be spatially concentrated in Mexico City and its neighboring states, as well as in the northern state of Nuevo Leon (Fig. 1)[23]:

Mexico City, with 66 companies and Nuevo Leon, with 30, make up 69 % of the total. Additionally, the map indicates the presence of nanotechnology firms along the border with the United States, and in central western Mexico. There are various factory companies on the border, and in the state of Jalisco, there is a strong center for research and production of electronics. It is possible this reflects an orientation of these nanotechnology firms toward the electronic industry, which in turn may be export oriented.

The states with industrial development—Nuevo Leon and the State of Mexico, concentrated near Mexico City, and Jalisco—account for 82 % of the nanotechnology companies, along with the main universities and research centers. In contrast, the states that are not involved in manufacturing, which includes the poorest states, not surprisingly also lack companies with nanotechnology manufacturing processes. In the case of Yucatan and Quintana Roo, the only states in the south that appear to have nanotech-related activity, we only find one company in each State, which means that the major portion of the nanotechnology activity is within the center-north of Mexico. This strongly suggests that nanotechnology has only deepened the gap between the more and less developed zones.

Not all of the 139 companies have domestic production. In many cases, it is difficult to determine if the final product embodies nanotechnology that was domestically produced or manufactured overseas, although in some cases the distinction is clear. In slightly more than half of the cases (74 companies), it was possible to establish national production, and in

[23] In some cases, it is possible that the center of production is at a different address that the headquarters; but in general, the principal office coincides with that of production.


**Fig. 1** Geographic distribution of nanotechnology companies in Mexico. *Source* current study

nearly a third nanotech production was manufactured overseas and commercialized in Mexico (Table 2).

The 139 manufacturing companies can be grouped according to their nano-related product(s), as classified by the United Nations ISIC system, previously discussed.[24] The resulting economic distribution covers only six out of 24 ISIC manufacturing divisions. Figure 2 shows the ISIC code (two digits) between parentheses for each manufacturing division, followed by the number of companies represented. The manufacturing of chemical products and substances accounts for by far largest share (60 firms), three times the number of the next-largest category (information, electronic, and optic products, 20 firms). Next are the manufacturing of machines and equipment (14 firms), and the manufacturing of pharmaceutical products, medical chemical substances, and botanic products of pharmaceutical use (21 firms). These four divisions cover more than three-quarters of the total nanotechnology manufacturing industry in Mexico. The distribution suggests that many firms are oriented toward basic science, as represented by the chemical products and in the manufacturing of products of information, electronics, and optics.

Providing a list of Mexican companies is an intricate task, as in many cases, the information about company ownership was not publicly available. This prevented us from establishing the actual nationality of all companies. However, there are some firms in each division where we were able to determine Mexican ownership. In the division "manufacture of chemical products," one example is *COMEX*, which is headquartered in Mexico City and manufactures *Marine Coating AF-53*. The product is a biocide that

[24] It must be emphasized that since the classification was based exclusively on the nanotechnology-related product, the economic classification does not necessarily reflect that of the company itself, since a company may have other products (with different classifications) that are not related to nanotechnology.

**Table 2** Distribution of nanotechnology companies in Mexico

| Manufacturing companies | Number of firms | Percentage |
|---|---|---|
| National | 74 | 53.2 |
| Manufactured overseas and commercialized in Mexico | 44 | 31.7 |
| No information indicating place of production | 21 | 15.1 |
| Total | 139 | 100.0 |

*Source* current study

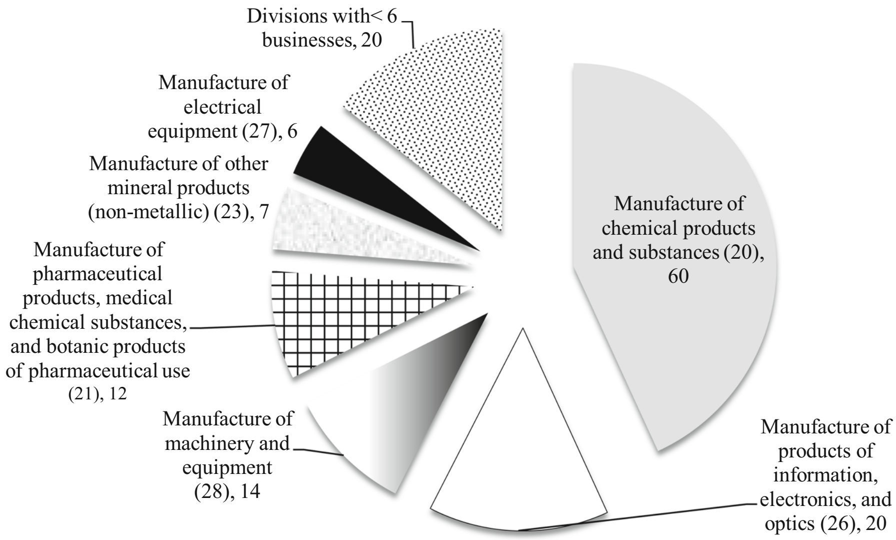


**Fig. 2** Nanotechnology manufacturing companies in Mexico according to ISIC division. *Source* current study

stops biological organisms, such as fungus, from growing in any surface (Comex 2015). In the division "information, electronic and optical products," Vamsa manufactures a vacuum chamber to manipulate a wide array of nano-materials (Vamsa 2015). This product is aimed at the highly specialized scientific market. In the division of "machinery and equipment," *Vago industrial* manufactures a set of mechanical seals with carbon nano-tubes (Vago 2015). *Rubio Pharma*, headquartered in Mexico City, is advancing in the development of nanobiotechnological drugs for human use (RubioPharma 2015). This company is part of a larger conglomerate: *Rubio Coorporativo*, which has presence in a wide array of sectors, from pharmaceuticals to specialized manufacturing (RubioPharma 2015). Fabritek, in the division "other non-metallic mineral products," manufactures a non-porous panel called Alucone for the construction industry; the surface keeps a long-lasting bright and novel appearance, especially after each cleaning session (Fabritek 2015). Another important company, *Condumex*, subsidiary of the *Carso Group* (owned by Carlos Slim, one of the wealthiest men in the world) manufactures cables coated with nano-materials (Castañeda 2009).

The location of products in the nanotechnology value chain of nanotechnologies reflects Mexico's dependence on external imports of primary nano-materials (produced by only 15 % of the Mexican firms) as well as Measurement and Manipulative Nano-Related Instruments (produced by only 4 % of the Mexican firms) (Fig. 3). Slightly more than half (52 %) are final nano-enabled products, many of which most likely incorporate imported primary or intermediary nano-materials.

In Table 3, we provided a more fine-grained analysis of the Mexico's nanotechnology value chain, breaking down primary nano-materials into five subgroups, nano-intermediaries into four groups, and final products into five groups.[25]

[25] This grouping does not indicate a clear inclination toward a determined type of nano-material or of intermediary products and will have to wait for an increase of production with nanotechnology to determine the degree of specialization.

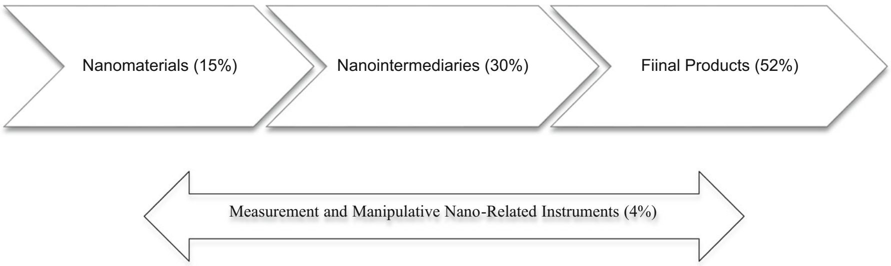


**Fig. 3** Percentage distribution of companies in the nanotechnology value chain. *Source* current study

**Table 3** Nanotechnology companies according to their location in the value chain

| Primary nano-materials | No. | Nano-intermediaries | No. | Final products | No. | Tools and equipment | No. | All companies |
|---|---|---|---|---|---|---|---|---|
| Carbon | 3 | Circuits | 14 | Clothing, sports and home | 17 | Analysis equipment | 5 | |
| Inorganic | 1 | Coverings | 11 | Personal care and food | 17 | | | |
| Metallic | 9 | Composites | 15 | Construction industry | 21 | | | |
| Polymers | 7 | Electronic components | 1 | Health | 9 | | | |
| Semi-metallic | 1 | | | Transport | 8 | | | |
| Total (number) | 21 | | 41 | | 72 | | 5 | 139 |
| Total (%) | 15.1 | | 29.5 | | 51.8 | | 3.6 | 100.0 |

*Source* current study

In the first stage of the value chain, Primary nano-materials/nano-structures, 21 companies were identified. Those that work with metallic nano-materials are the largest group with (9 firms), followed by polymeric structures (7 firms); the remaining groups have 3 or fewer firms each. Principle firms in this stage include Paxair, TCM watches, Tenaris Tamsa, and Dupont; the principal nano-materials identified are titanium dioxide, gold, magnesium hydroxide, and carbon nano-tubes.

41 companies are engaged in the second stage of the nanotechnology value chain, the production of nano-intermediaries. Three nano intermediary products account for all but one firm: composites (15 firms), circuits (14 firms), and coverings (11 firms). (One firm made electronic components.) Comex, for example, makes an anti-vegetative and "self-polishing" paint (Comex 2015). The company Empower Circle Mexico (Trunano) imports a coating that protects against stains, vandalism, and wear-and-tear which is coined "Graffiti Armor" (Empowercircle 2015). More than half of the companies that produce nano-intermediaries manufacture abroad and sell in Mexico. This is the case with Recubritec, Nanodepot, Protec, Altana, Vinssa, Leyvitec, Flextronics, Kodak, Toshiba, Fei y Circuit Check.

There are 72 products in the final stage of the value chain. The majority are in sectors of construction and industry, followed by personal care products, food and agriculture, clothing, spots, and home goods. In the sector of construction and industry, we find various large companies. Cemex, a multinational Mexican corporation, one of the largest in the world to produce products for the construction industry, has its base in Monterrey, produces, and markets a concrete called Fortium ICF which permits economizing in costs of maintenance and energy (Cemex 2015). Vitromex, located in Saltillo, Coahuila, manufactures various nanotechnology products, but most prominently a line of ceramic antibacterial floors with nano-particles of silver and zirconium (Vitromex 2015). Global Provents, based in Monterrey, is a company that makes nano-membranes specialized for filtration of water for residential, commercial or industrial use (Globalproventus 2015). In the sector of personal care, food, and agricultural products, we find Mexican companies

**Table 4** Companies according to producing means of production or final consumer goods

| | Number of firms |
|---|---|
| Produce means of production | |
| Nano-materials | 21 |
| Nano-intermediaries | 41 |
| Final products (construction and industry, transport) | About 29 |
| Tools and equipment | 5 |
| Subtotal | 96 (69 %) |
| Produce consumer goods | |
| Final products (clothing, sporting goods, personal care, food, and health) | About 43 |
| Subtotal | 43 (31 %) |
| Total | 139 |

*Source* current study

like Sigma, Xigns, Gresmex, and Nanonutrition and also companies based abroad such as Avon, Sanki, Vitamist (representative of Mayor Labs), Kellogs and others. Sigma, for examples, uses lighter weight functional containers and nano-particles to package products that deteriorate with contact with oxygen (Clusternano 2010). The company Avon, based in New York City, manufactures cosmetics with different types of nano-particles (Avon 2011). Vitamist, represented in Mexico by the American company Mayor Labs, offers vitamins in nano-spray, with the objective of increasing absorption once they are applied inside the mouth (Vitamist 2015).

We have also registered 21 companies that, while currently lacking products on the market, are doing R&D in nanotechnology based on registered patents or financed research projects. As this information is incomplete, we have not included in the value chain. But some examples are illustrative of the places and topics of research. Nine of the 21 companies that are conducting R&D are concentrated in Nuevo León. Frida Forjados, for example, is a company that investigates nano-materials and applications in the Nuevo León Nanotechnology Cluster (Bárcenas 2010). The company Copamex does research with the task of developing fireproof nano-materials to apply to carton or paper (González-Hernández and Jesús 2011b). Cementos Chihuahua, located in the city of Chihuahua outside of Nuevo León, is studying the physical characteristics of cement enabled by nano-materials (silicon oxide) (Cervantes et al. 2013). There are other companies in R&D located in other states, such as Mezfer, Resymat, Celanese and Casematic, all of which have nanotechnology patents.

Once the companies are distributed on the value chain, it is illustrative to examine the extent to which the final product provides a new (nano-enabled) means of production for future industrial processes, or is destined for the consumer market. As noted previously, some products can be dual use, and so this distinction is not always clear-cut. Nonetheless, the distinction can provide a useful approximation for the extent to which nanotechnology is changing production itself, or mainly contributing to new, nano-enhanced consumer products. Table 4 groups the companies according to whether their products are means of production or final consumer goods.

96 companies create products that contribute to the means of production (69 % of the total), while 43 (31 %) produce final consumer goods. Companies that produce means of production include Viakable, which manufactures nano-coated industrial cables; Polimeros nacionales, a company that produces nano-materials for the industry; Sony, a company that manufactures OLEDS for screens; or Kaltex, among whose products highlights a nano-fiber bacteria that prevents bad orders. Companies that produce consumer goods include 3 M, which markets goods for dental and medical use; Whirpool and Mabe, which manufacture and market white products that contain nano-materials; and Ten Pac, which makes industrial footwear.

## Conclusions

Mexico has been investing in nanotechnology since the 1990s. During the first decade of the twenty-first century, public funds were directed to specialized laboratories, for the establishments of industrial parks, and for the creation of research networks. Yet there is neither an institution nor a public program that establish guidelines for the development of nanotechnology, nor comprehensively compile information on nanotechnology. While some scattered data are available, there is no dataset that permits an estimate of the total investment in nanotechnology. The present research was conducted to gather information on companies that produce and market products with nanotechnology in Mexico, in order to help fill some of these gaps.

The research followed four successive steps. In the first step, we compiled an inventory of 139 nanotechnology companies in Mexico. In the second step, the products with nanotechnology were classified according to the United Nations' International Standard Industrial Classification of All Economic Activities. This revealed that 40 % of the nanotech-related products corresponded to the manufacturing of chemical products and substances, followed by 14 % for the manufacturing of electronic, optic, and information products. In the third step, we located companies according to their role in the nanotechnology value chain, indicating that approximately half of the nanotechnology products on the market are final products, and half are primary nano-materials, intermediary materials, and instruments. The fourth and final step consisted of classifying the products according to whether they primarily lead to new productive processes, or are destined for personal consumption. The results showed that almost four-fifths of the products ended up as consumer goods.

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