

NANOTECHNOLOGY CONTRIBUTION TO INNOVATION-DRIVEN GROWTH: HYPE OR HOPE?

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Abstract

The paper considers the role of nanotechnology as one of the possible general purpose technology (or basic innovation), which would be the core of the next great technological revolution. Authors focus on the numerous troubles with the estimates of the market size of nanotechnology products, as well on the reliability and realism of forecasts made by international research companies for nanotechnology development and its role to spur global economy and new cycle of growth. It appears that the potential of nanotechnology market growth and economic impact of these technologies development may not be so great than anticipated, and its part in the world economy growth is more than modest.

Key words: nanotechnology, economic growth, innovation development, technological revolution, general-purpose technology

INTRODUCTION

Apparently, nanotechnology is an impressive example of much-advertised over-hyped area of new revolutionary technology, which were heralded to take a key position in future economic growth and in the transition to “the next great technology wave”. Indeed, for over a decade, since the beginning of the 2000s and up to 2009 - 2010 years a common view in the economic literature was that nanotechnology will become the nexus of scientific innovation that revolutionizes most industries and indirectly affects the fabric of society comparing the upcoming epoch of nanotechnology with the Industrial Revolution [NSTC 1999; Jurvetson 2004; Eaglesham 2005]. As new emerging technologies they are projected to have significant systemic and long-lasting economic and social impacts, lead to the rapid development of new capabilities, create new opportunities for and challenges to addressing global issues and have the potential to disrupt or create entire industries [Roco & Bainbridge 2001; OECD 2011; Roco, Mirkin & Hersam 2011].

The hyperbole surrounding this new technology came not only from the media but also from scientists who exaggerated the anticipated benefits of nanotechnology to justify research funding. Furthermore, there was a growing body of literature that considered the nanotechnology to be a new driver to spur economic growth worldwide while emphasized its capacities to deliver growth today in order to attract investments [Berube, 2005]. In 2003 - 2005, the years when nanotech euphoria peaked, Lux Capital was publishing the much-anticipated annual "Nanotech Report.", promising nanotechnology Company Nanosys was preparing for an IPO, BusinessWeek had an entire issue devoted to nanotech and finally, US President George W. Bush signed a \$3.7 billion nanotech bill. Since the early 2000s and up to about 2010, many leading research and advisory companies measuring and quantifying success in innovation regularly published very optimistic forecasts of emerging nanotechnology market growth.

Whether these great expectations were realized or disappointed? Did the hopes on “the next great technology wave” come true? What challenges nanotechnology as a new potential basic innovation or general purpose technology will be faced with? This article attempts to probe the figures about the predicted nanotechnology growth. We try to show that the potential of nanotechnology market growth and economic impact of these technologies development may not be so great than anticipated, and its part in the world economy growth is more than modest. This consequently, casts doubt on claim that nanotechnology is the expected new breakthrough basic innovation to give rise to “the next great technology wave” [Youtie, Iacopetta & Graham 2008].

Nanotechnology is an umbrella term for a myriad of technologies spanning multiple industries and it embraces a wide range of technologies and tools with the one thing that all nanotechnologies share that is the tiny dimensions they operate at. Given that criteria of referring products to nanotechnologies are quite confusing, diverse and varied [Drexler 1992; Klaessig, Marrapese & Abe, 2011].

Herein lies another big problem: monitoring, estimation and accounts of the economic impact of the nanotechnology development are initially hampered because of the complexity and vagueness of the object. In view of this problem it is worthwhile and actually proves to be an urgent task to examine thoroughly the validity, reliability and realism of available forecasts and estimates made by research and advisory companies providing strategic advice on emerging technologies.

WHY NOBODY GETS EXCITED ABOUT “NANOTECH” ANYMORE?

First of all, we can conclude that apparently economists and policy makers have recently lost their interest in nanotechnology [Kelleher, 2015]. It is much more difficult now to find publicly available medium-term and especially long-term market forecasts; less attention has been paid to the issue in the media. In order to see how the tendency has changed, it will suffice to consider forecasts and estimates of the value of nanotechnologies, most produced by research companies - experts in nano-enabled products markets. The most authoritative research company in the area is LUX Research¹. Relying on this company forecasts, we will try to assess the development prospects of the nano products market and show that the expectations of its growth are very much overstated.

The first conclusions can be drawn from the primary analysis of publicly available data. Prior to 2008, the company gave a very optimistic market development forecasts. Lux Research's 2007 estimates of the size of the global nanotechnology market assumed a steep growth trajectory to \$2.6 trillion by 2014. This estimate was more than 70% higher than Lux's earlier 2005 report estimate [Berger 2007; Lux Research 2005]. According to Lux Research 2008 estimates, the market value of nanotechnology in 2008 was about \$238 billion and they expect that nanotech will reach \$3.1 trillion worth of products across the value chain in 2015 [Toth, 2009].

However, after the global financial crisis of 2008-2009, the company turned to give far less optimistic predictions. Indeed, the economic downturn since 2008 has caused some downward adjustment in these market forecasts. Lux Research's 2009 global nanotechnology market forecast was decreased to \$2.5 trillion by 2015, 4% less than the 2007 estimates [Lux Research, 2010]. Declines in the automobile and construction industries were also estimated to affect market demand for nanomaterials and composites [Shapira & Youtie, 2012)].

Nevertheless, even these crisis-adjusted projections, proved overly optimistic. LUX Research 2011-2012 estimates based on projected global output for each year, as well as its estimates of nanotechnology penetration rates for products shows that market value of nano-enabled products will reach \$1.48 trillion by 2014 [LUX Research, 2013]. Yet at the end of 2013, this estimate has been revised downwards. According to LUX Research's 2013 estimates which were based on historical output data for 2010-2012, and projected output from 2013-2018, along with its estimates of nanotech penetration rates market value of Nano-enabled products attain to only \$1.37 trillion in 2014 and \$1.79 trillion in 2015 [LUX Research, 2013]. The difference of 2008 and 2013 forecasts respectively is clearly seen in figures 1 and 2.

¹ Lux Research Inc. has collated the indicators most commonly used in analyses. The European Union, United Nations and some countries including Russia refer to their figures, making the Lux Research predictions among the most useful exemplars of the economic value of nanotechnologies.

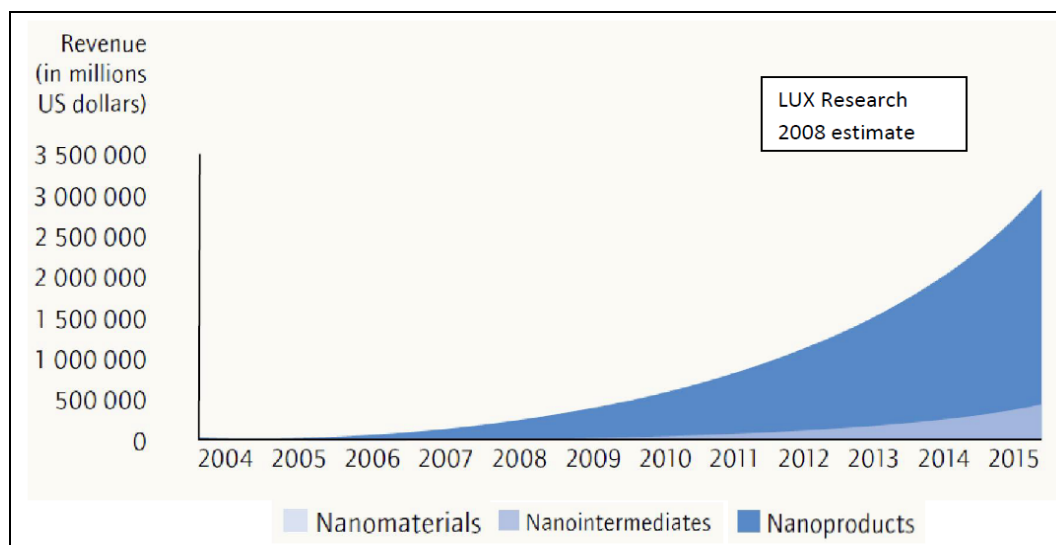


Fig. 1. Value of Nanotech according to Lux Research Inc. in 2008²

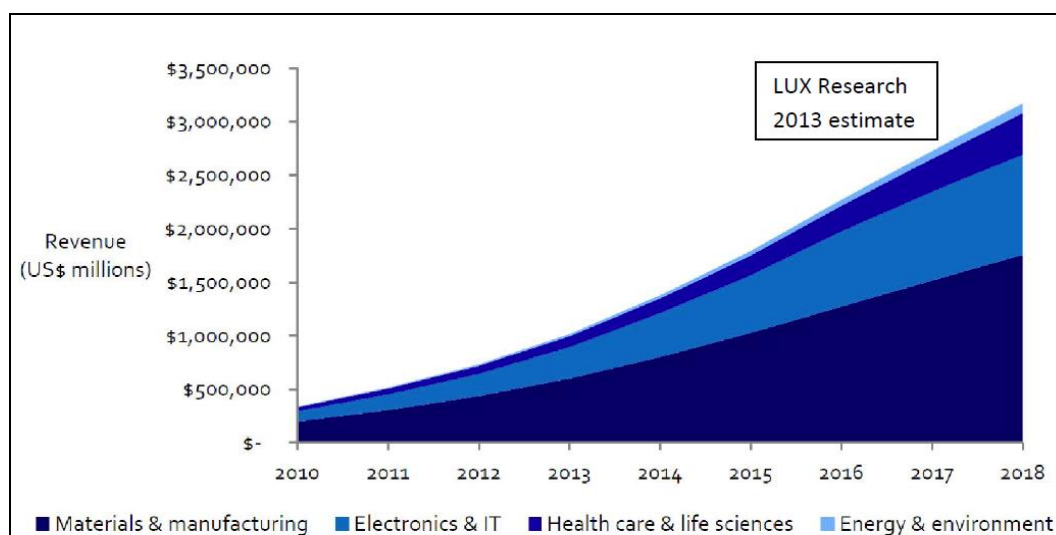


Fig. 2. Value of Nanotech according to Lux Research Inc. in 2013³

As the figures show, 2008 expectations were that by 2015, the total market volume of nano-enabled products would exceed \$3 trillion. However, in 2013 it became clear that this market size will not be reached before 2018. In essence, this tells us that the period of high expectations associated with the rapid development of nanotech market appears to be coming to an end. In the future, growth rates of nano-enabled products will gradually slow down.

It can be confirmed by an analysis of nanotechnology stocks failure. Let us see on Lux Nanotech Index, one of the most representative indices, which was designed to identify a group of companies involved in developing, manufacturing and funding nanotechnology applications. Companies put in list may be involved in one or more stages of Lux's Nanotechnology Value Chain frameworks: nanomaterials, nanointermediates, nano-enabled products and nanotools. The index aims to track the performance of nano companies on all three major branches of the impact of nanotech: materials,

² Source: [LUX Research, 2008]

³ Source: [LUX Research, 2013].

electronics and IT, health and biology. It has been calculated since 2005 and if we trace its evolution, we see that during the 2007-2009 crisis, it experienced a serious fall from which it has not fully recovered. In general, since the beginning of the calculation of the index, its value dropped by 60% (see fig. 3). In comparison: since January 1, 2006 to the present time, S&P index has risen by 71.09%, while LUX Nanotech Index has fallen by 60.85%.⁴ These figures are convincing evidence of the investors' preferences.

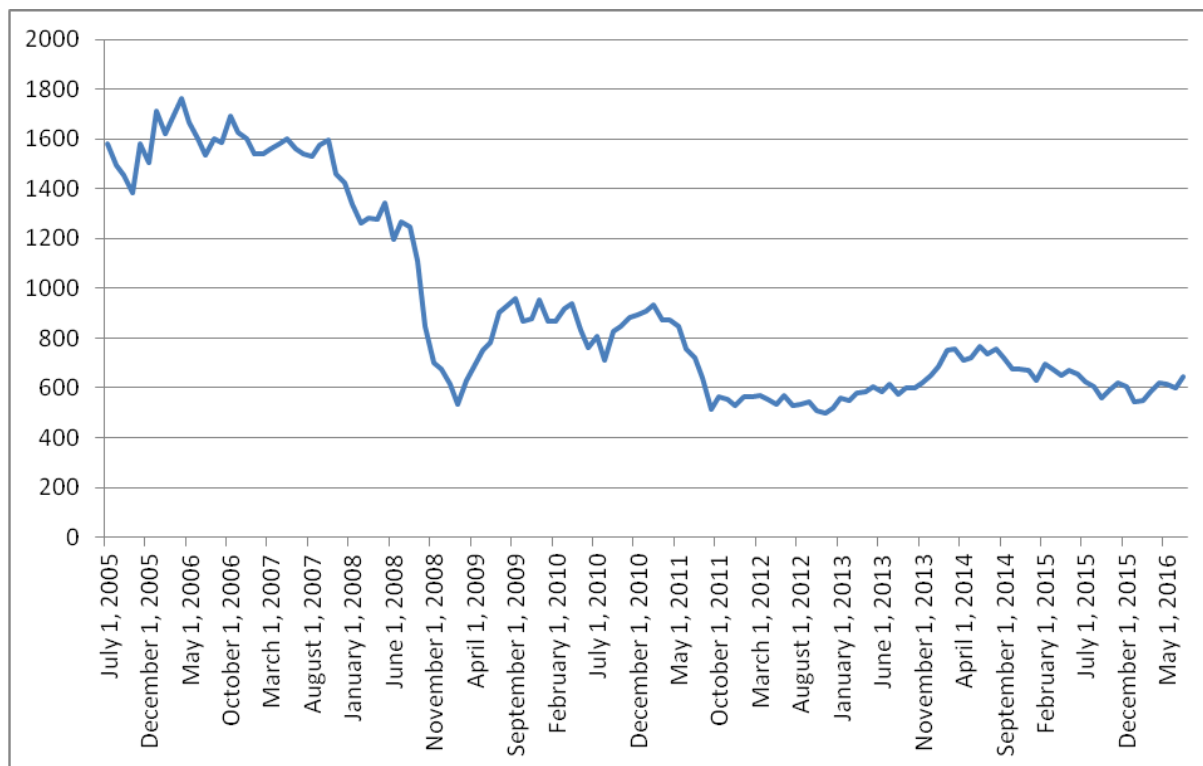


Fig. 3. LUX Nanotech Index⁵

In March of 2004, Merrill Lynch released their “Merill Lynch Nanotech Index” which provided a diversified representation of nanotechnology stocks and ADRs in the United States. That time nanotechnology seemed can offer huge perspectives for investors and many large investment banks took notice. The index is no longer calculated, and no funds or ETFs appear benchmarked to it. In February of 2014 year, PowerShares Capital announced that they would retire the “Lux Nanotech ETF” released in 2006⁶, and it has been discontinued shortly after [StreetAuthority, 2014]. Evidently, it occurred to some extent due to the dismal returns of the ETF over the past 8 years since its launch and a lack of interest from investors. Thus, eleven companies from “Lux Nanotech ETF” of 30 different “nanotechnology companies” in various industries actually had negative returns over the past 10 years. Moreover, an investor in this ETF would have lost half their money, while simply investing in an S&P 500 ETF would have resulted in returns of over 80% over the 2006 -2014 years' time frame

⁴ Calculations based on dynamics of NYSE indices. See <https://www.nyse.com/quote/index/LUXNI>

⁵ Source: <https://www.nyse.com/quote/index/LUXNI>

⁶ The PowerShares Lux Nanotech Portfolio Fund (“Lux Nanotech ETF”) sought to replicate the Lux Nanotech Index, which is designed to identify a group of companies involved in developing, manufacturing and funding nanotechnology applications. Companies may be involved in one or more stages of Lux's Nanotechnology Value Chain frameworks: nanomaterials, nanointermediates, nano-enabled products and nanotools. The modified market-cap portfolio was rebalanced quarterly and reconstituted quarterly.

[Nanalyze, 2014c]. For many investors these two demises signaled the end of the decade-long hype around nanotechnology stocks.

Meanwhile, 5 companies from the “Lux Nanotech ETF” showed superior returns over the past 10 years. However, majority of these companies does not seem like a business that can attribute their growth to the use of nanotechnology. For example, Gentherm (NASDAQ:THRM) manufactures thermal comfort technologies for applications in automotive and other markets but no reference is found in any of the company’s materials about the use of “nanotechnology”. Communications and IT company Harris (NYSE:HRS) may has been looking at using nanotechnology in some fashion in the past. Today nothing about this company seems to lend itself to utilizing nanotechnology. Further, Bidelivery Sciences International (NASDAQ:BDSI) has a pipeline of pharmaceutical products that utilize their BioErodible MucoAdhesive drug delivery technology. However, this company makes no mention of whether or not their drug delivery technology is enabled by “nanotechnology”. Rockwood Holdings (NYSE:ROC) is a developer, manufacturer and marketer of specialty chemicals and advanced materials used for industrial and commercial purposes but as it seems the company does not have a stated goal to utilize nanotechnology as a competitive differentiator in the production of specialty chemicals [Nanalyze, 2014b]. It should be noted that there is lot of others surviving companies, which publicized their nanotech credentials or put “nano” word to their business now describing themselves as materials companies, or semiconductor companies and so on.

Yet, there is German company Aixtron among these 5 companies realized superior returns which manufactures chemical vapor deposition equipment that is used for the production of LEDs, carbon nanostructures such as carbon nanotubes, graphene, organic solar cells, memory chips, and many other applications. However, since 2009 Aixtron has started to lose market share to its market rival Veeco while the “total addressable market” for both of them has fallen sharply by 80% in 2011-2013 years from \$1.7 billion to \$323 million [Nanalyze, 2014a].

It appears that the 2008-2009 global financial crisis and U.S. recession had shifted risk tolerance and caused market stopped acclaiming of nanotechnology as many investors got crushed.

We, therefore, infer that the feeble growth of the nano-enabled products market testifies that other expanding markets restrict its development, most probably, the financial markets. This is where the liquidity is drawn, as the financial markets promise a considerable growth, or due to the fact that the investors are engaged in other markets in the view of its expected growth rates. The drop in the nanotechnologies stock indices due to negative returns and lack of interest from investors indirectly confirm it. In this connection it is worth noting that the counter-crises measures implemented by the leading nations in response to the global crisis of 2008-2009 were mostly aimed at saving the banking and financial sectors, which received huge support first and foremost thanks to the programs of quantitative easing of the FRS, compared to the slowly stagnating real economic sector [Frolov, Koshovets, Ganichev & Tsipko 2011].

WORSE-THAN-ANTICIPATED: ON NANOTECHNOLOGY MARKET FORECASTING

Here we turn to examine the validity of LUX forecasts. According to the most up-to-date and available LUX Research forecast, the volume of nano-enabled product market should amount to \$3,167,706 bln by 2018. However, we claim that this forecast is also most probably over-optimistic and unjustified. To test this hypothesis, we will make a simple model based on a comparison of projected rates of nano-market growth with the global GDP growth rate. As a matter of fact, the growth of the nanotechnologies market is indirectly linked to the increase of the global GDP. The limitation of the GDP growth acts as a limitation of the increase of the entire global added value, which results in the fight of the markets for limited financial resources.

Thus, the expansion of the nano products market must be accompanied by a corresponding increase in the overall scale of the world economy creating demand for products manufactured using nanotechnology. To assess the realism of the LUX forecast for 2018, made in 2013, as well as to make

an approximate estimate of the nano products market volume for the longer term, we will compare this forecast with a forecast of global GDP growth from the IMF⁷.

Figure 4 shows the forecasts for nano-enabled products market until 2018 made by LUX Research at the end of 2013 and recalculated by us in constant prices, taking into account the global GDP deflator along with the global GDP growth rate at constant prices, predicted by the IMF in 2013.

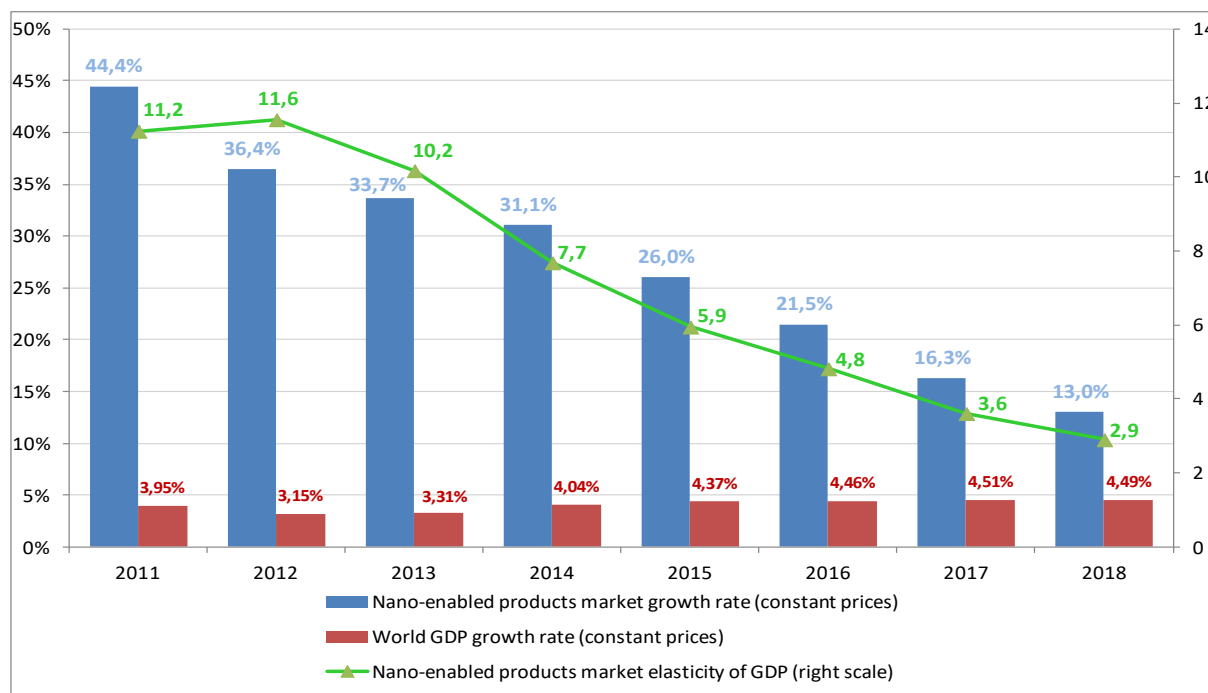


Fig. 4. Nano-enabled products market and world GDP growth rate (constant prices)

From the figure it is clear that prior to 2013, the nano-enabled product market grew approximately 11 times faster than GDP, but LUX Research prediction for 2014-2018 suggests a sharp decline in the coefficient of elasticity between these indicators, which in 2018 should decrease to 2.9 (with an increase in global GDP by 1% the nano-enabled products market will grow by 2.9%). However, since this LUX forecast used the global GDP growth rate calculated by IMF, we can say with reasonable confidence that it is over-optimistic. The fact is that if we compare the figures of the world GDP forecasts, published by the IMF over the years, it is easy to see that the Fund systematically overestimates the global GDP growth rate, and therefore, is obliged to adjust them constantly for a more negative scenario as it approaches the forecast horizon (see table 1).

⁷ In its methodology for evaluating market volume of nano-enabled products and forecasts of sector outputs, LUX Research uses IMF GDP growth estimates as well its own estimates of nanotechnology penetration rates to determine nanotechnology-based revenues.

Table 1. Comparison of forecasts for the rate of global GDP growth made by the IMF for various years⁸

Date of forecast publications	2010	2011	2012	2013	2014	2015	2016	2017	2018
apr.2016	5,431	4,225	3,426	3,308	3,428	3,123	3,56	3,805	3,903
apr.2015	5,379	4,169	3,404	3,408	3,389	3,451	3,759	3,848	3,873
apr.2014	5,176	3,939	3,221	3,005	3,586	3,879	3,95	3,949	3,926
apr.2013	5,221	3,954	3,152	3,308	4,04	4,37	4,461	4,508	4,489
apr.2012	5,265	3,851	3,533	4,073	4,364	4,547	4,623	4,663	
apr.2011	5,01	4,401	4,513	4,54	4,627	4,667	4,732		

- facts at the time of publication of the forecast;
- predicted value at the time of publication of the forecast;

Table 1 shows that when forecasting the next three years, the IMF estimate overstates GDP growth rates by 30-40% in relation to the real growth which occurs in forecasted year. Taking this fact into account, as well as the elasticity coefficient obtained for the nano-enabled products market in 2011-2018, we can recalculate the values of nano-enabled products market growth rate for the period under review to adjust LUX forecast.

As it can be seen below in figure 5, when using a more realistic assessment of global economy growth rate (provided that the GDP growth put in LUX 2013 forecast elasticity of nano-enabled product market remains the same), the volume of the nano-enabled products market in 2018 could be nearly a quarter lower than expected by LUX analysts and will not reach \$3 trillion, which it was supposed to attain to as far back as in 2015, according to the pre-crisis forecast.

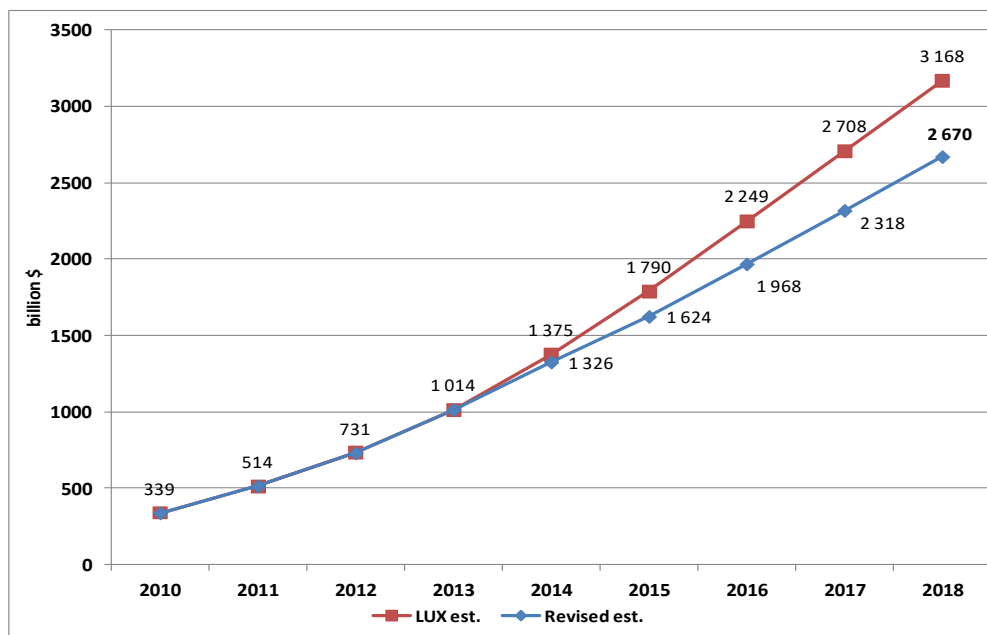


Fig. 5. Revised estimate of nano-enabled products market

⁸ Source: IMF World Economic Outlook Databases 2011- 2016. <http://www.imf.org/external/ns/cs.aspx?id=28>

NO SUCH THING AS A SINGLE NANOMARKET OR WHAT IS CONSIDERED NANOTECHNOLOGY?

In view of its importance some words should be said here about what exactly LUX Research means using term of nano-enabled products?

It is worth emphasizing once again that nanotechnology is an "umbrella" term. In the sense given to it by the Royal Society and the Royal Academy of Engineers it is described as "the design, characterization, production and application of structures, devices and systems by controlling shape and size at nanometre scale" [Royal Society and Royal Academy of Engineering, 2004].

It is generally accepted US National Nanotechnology Initiative's definition according to that "nanotechnology is the understanding and control of matter at dimensions between approximately 1 and 100 nanometers, where unique phenomena enable novel applications. Encompassing nanoscale science, engineering, and technology, nanotechnology involves imaging, measuring, modeling, and manipulating matter at the aforementioned length scale. Unusual physical, chemical, and biological properties can emerge in materials at the nanoscale. These properties may differ in important ways from the properties of bulk materials and single atoms or molecules" [NSTC 2015, p.7].

However, these scientific definitions fit less easily into commercialization characterizations. While nanotechnology has applications across multiple industries, there are no standard classifications of nanotechnology developing or using sectors [Shapira & Youtie, 2011]. The market for nanotechnologies in general does not differentiate between the diverse industries or areas of work covered by the broad term "nanotechnology". To date nanotechnology should be regarded as a means to enhance and improve many industries of the world economy rather than its new sector. In fact, there is no separate "nanotech market" yet, and therefore, more logical to speak about the growing role of nanotechnology in the overall production chain. Nanotechnologies are used to manufacture a variety of materials or substances with certain specified properties that are in demand in a particular manufacturing. Meanwhile, a very small proportion of nanotechnologies allow creating completely novel products.

Thus, the entire nano-enabled products can be notionally divided into two categories: revolutionary novel products developed with the help of nanotechnology, and the products, the consumer properties of which are somehow improved by means of nanotechnology. Some Russian experts believe that the first category may now include not more than 5% from the total market volume of final nano-enabled products, and in the remaining 95%, nanotechnologies really make only a certain share of the final product cost. This can be explained with the fact that these technologies are applied in already developed industries where there are great barriers to enter the market, and they cannot be leapt or broken by mere development of a new technology.

The main share of intermediate products using nanotechnology makes up nanomaterials or nano-coatings for other materials purchased by enterprises. Here, the share of materials in the final cost of products varies from industry to industry. The cost of materials and intermediate products in the automobile industry can reach 60% of the final cost, whereas in the production of clothing and footwear - not more than 20%. According to experts' estimates, the average share of materials and intermediate products in the final cost of goods is about 30%. Given that, nano-enabled products have a very small share in all the amount of materials used; they are mainly coatings, films, powders that are added during the production of materials in order to improve commercial qualities.

This raises the question whether the nano-enabled products market volumes estimations made by LUX Research represent the real impact of nanotechnology on economic development? Figure 6 presents how LUX's methodology forms the cost of nano-enabled products, basing on the identification of three categories of nano-enabled products and their use in the manufacture of other products.

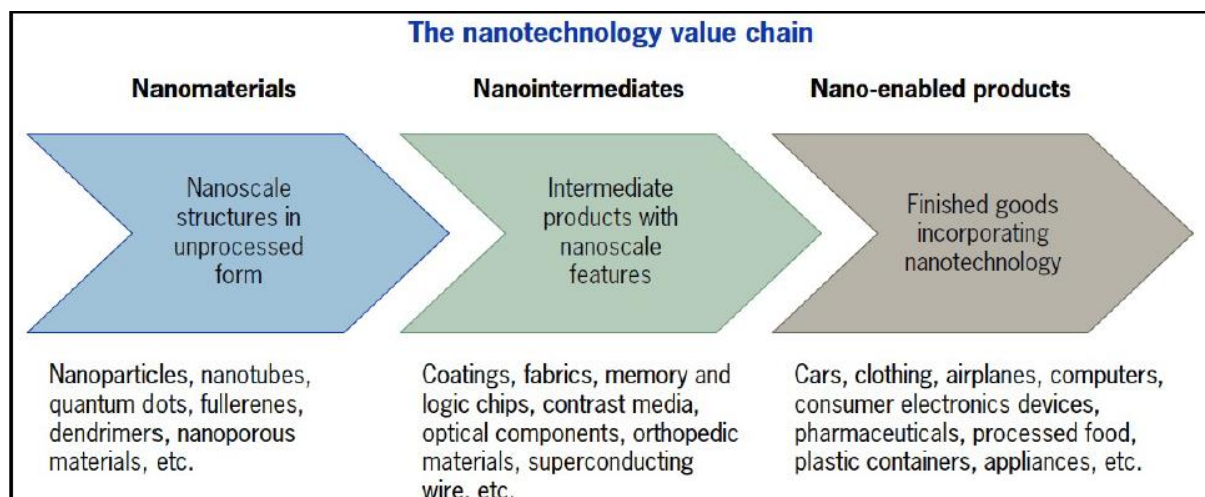


Fig. 6. Nanotechnology is an enabling technology in many industries⁹

As it is seen the nanotechnology value chain consists of three main components: primary nanomaterials, nanointermediates which include products made of nanomaterials, and finished goods, which use nanointermediates. Thus, nanotechnology can be notionally divided into primary (nanomaterials and nanointermediates) and secondary production (finished goods incorporating nanotechnology).

According to LUX, the share of intermediates in the total finished goods incorporating nanotechnologies is very low - about 22% by 2013. It is expected that it will increase up to about 40% by 2018. The share of nanomaterials is even less and amounts to tenths of a percent in the total market of nano-enabled products (see table 2).

Table 2. Volumes of nano-enabled production by categories and the share of primary nanoproduction¹⁰

	2010	2011	2012	2013	2014	2015	2016	2017	2018
Nano-enabled products (bn.\$)	338,5	514,2	730,7	1014,4	1375,2	1790,0	2249,2	2708,5	3167,7
Nano-intermediates (bn.\$)	51,6	86,0	133,3	225,8	350,4	574,9	799,4	1024,0	1248,5
Nanomaterials (bn.\$)	1,065	1,213	1,373	1,567	1,818	2,1312	2,4445	2,7577	3,071
Nano-intermediates share	15,2%	16,7%	18,2%	22,3%	25,5%	32,1%	35,5%	37,8%	39,4%
Nanomaterials share	0,315%	0,236%	0,188%	0,154%	0,132%	0,119%	0,109%	0,102%	0,097%

It is clear that the financial value generated by nanomaterials is minimal compared to that of nano-enabled products. It shows that the high value estimated to be generated by nanotechnology comes mainly from finished goods incorporating nanotechnology, like cars, clothing, plastic containers, aircraft, etc. [Toth, 2009].

⁹ Source: LUX Research.

¹⁰ Source: author's calculations based on the Lux Research data. See [LUX Research, 2013].

To assess the prospects for the development of essential nanotechnologies – i.e. those potentially breakthrough technologies that can form next technological wave and become a new driver for the global economy, we should consider the estimates of the nano-materials and nanointermediates (as it is classified by LUX) growth rates.

Using the obtained values of global GDP elasticity of the nano-enabled products total market, the adjusted IMF forecast of the global GDP growth, as well as the average share of nanointermediates in the total nano-enabled production volume, we made a predictive assessment for the development of the primary nanoproducts market (nano-materials and nanointermediates) till 2020 (see figure 7).

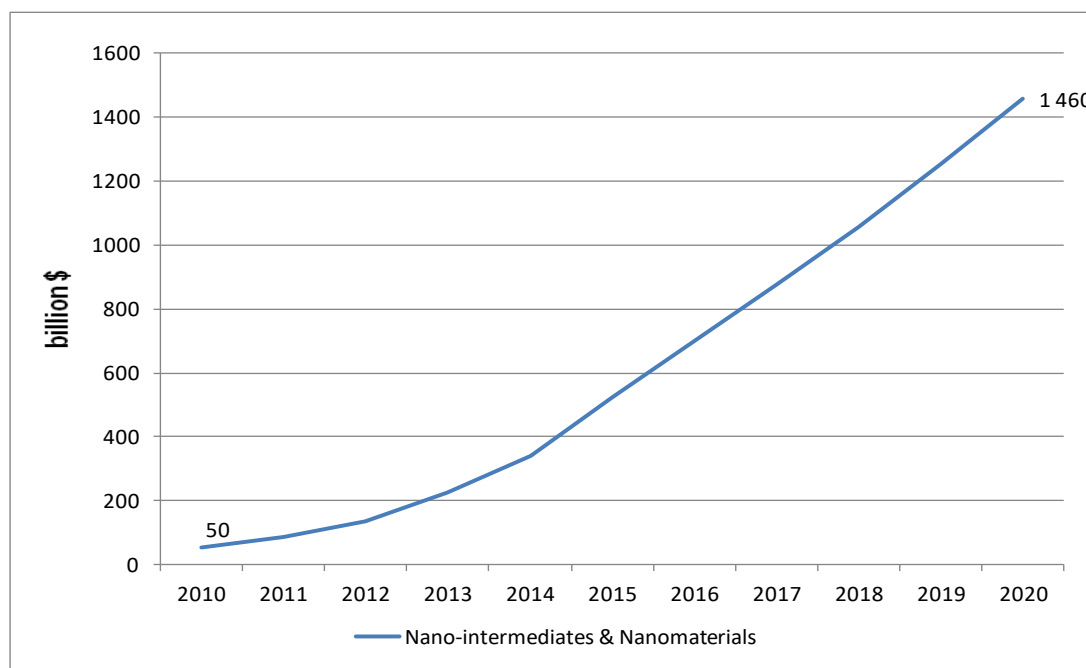


Fig. 7. Evaluation of possible volumes of primary nanoproducts market on the basis of the assumptions made

The figure 7 shows that under the assumptions made, the market volume of primary nano-products that can be attributed to new breakthrough technologies will reach 1 trillion dollars only after 2018. At the same time, the volumes of these products are supposed to increase almost 30 times in 10 years. However, this forecast made on the basis of trends in the global GDP growth and revised LUX estimates may also be too optimistic. This can be demonstrated by assessing the amount of investment required for its implementation.

GETTING SMALL WITH NANOTECHNOLOGY: A FUNDING CHALLENGE

It is worth emphasizing that the sphere of manufacturing nano-materials and nano-intermediates is a science-intensive production. The contemporary global classification of high-tech industries was adopted in the countries-OECD members in the early 1990s. According to this classification, an industry is considered to be high-tech, if the share of R&D expenditures in its production is not less than 4.5-5% [Eurostat, 2008]. Science-intensive productions are those high-tech industries and markets where the share of R&D expenditures is over 10% [National Science Board, 2008].

Therefore, in order to maintain high growth rates assumed in the above-mentioned forecast (fig. 7), it is obviously necessary to keep the investments in nanotechnologies R&D at the level of 10% or, at least, not lower than 5% of production volumes. Thus, to reach the forecasted \$1.46 trillion of primary

nanoproducts market by 2020, it will be necessary to invest no less than approximately \$73 billion in nanotechnologies R&D in 2019 (that is 5% of output in 2020). Accordingly, to amount to the forecasted production volumes of \$1.2 trillion in 2019, about \$62 billion should be invested in R&D in 2018, and so on.

The data on the investment volume in nanotechnology R&D in 2015 are not yet available. Meanwhile, 5% of the total volume of primary nanoproducts output in 2016 supposed in the forecast (see fig. 7) means that investments in the related nanotechnology R&D in 2015 would have made more than \$35 billion. However, analyzing the latest available estimates of the investments volume made in the previous years, we can safely assume that in 2015 they were less than the required amount.

Indeed, according to LUX Research, the volume of investment in nanotechnology R&D in recent years has significantly slowed down. LUX sometimes makes upward retroactive adjustments of the data on the total volume of the nano-enabled products market (like in the report of 2013), but the data on the investment in R&D in the latest LUX reporting, on the contrary, are retroactively revised downwards. For example, in the report published by LUX at the end of 2013, they say that the total investment in R&D related to nanotechnology in 2012 was \$18.5 billion. Meanwhile, the report published at the end of 2015 contained different data. According to this report, in 2012, the worldwide investments in nanotechnology R&D amounted to only \$17.8 billion and had grown by 1.2% in two years, having reached \$18.1 billion in 2014.

Thus, if not the retroactive adjustment of indicators for 2012, they would have recorded a significant reduction in the volume of investment in nanotechnology R&D in the period from 2012 to 2014. However, the adjustments allowed the LUX analysts to keep a positive trend.

It should be noted that the weak positive trend, which was observed in 2012-2014, maintained exclusively due to investments of large corporations (they increased expenditures by 3.5% compared to 2012), while private companies sharply reduced investments in nanotechnology R&D - by 45% - and public spending was frozen at the level of 2012¹¹.

In particular, the trend towards reduction of government spending can be clearly seen in the investment changes in the US National Nanotechnology Initiative program (see. Fig. 8).

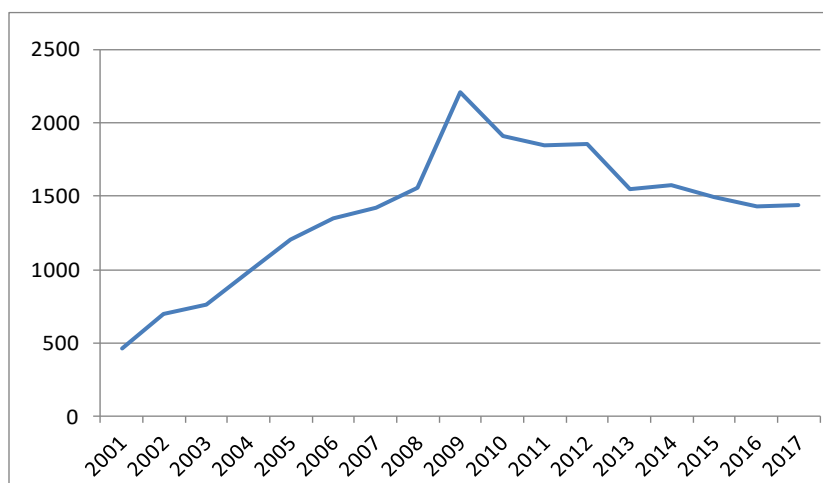


Fig 8. National Nanotechnology Initiative Funding in 2001-2017 (\$ in millions)¹²

¹¹ In 2012 governments and private investors reduced their investments by 5% and 10% respectively to 2010. The United States maintained its lead over all other governments, with \$2.1 billion of federal and state funding in 2012. Europe's collective spending (European Commission and individual country programs) was slightly more than \$2.0 billion in 2012, a decline of 24% from 2010. See: [LUX Research, 2013].

¹² Source: [NSTC, 2016].

The figure shows that the funding of R&D by the National Nanotechnology Initiative will be reduced in the coming years. Whilst the public investment volume in this area was \$2 billion per annum in 2009-2011, in 2016-2017 the budget supplement is planned to be reduced by more than 35% and it will be less than \$1.5 billion per annum.

It is worth noticing that global nanotechnology funding levels had begun to decline in 2010 as many nanotechnology programs began to wind down. Many national programs to support nanotechnology ended just during the last global financial crisis, prior to 2011 and after that many countries decided to cease nanotechnology funding as it had been in the past¹³. From the one hand, this happened due to the fact that nanotechnology has become an integral part of many emerging technologies, and countries have shifted their attention to focus on broader, more market-or application-oriented topic areas for which nanotechnology is an enabling technology. Nevertheless, some countries, such as Germany and Japan, clearly have nanotechnology in mind when allocating funding, while other countries, such as the United Kingdom, take the approach that nanotechnology is not an important part of their decision-making process for funding [LUX Research, 2013]. From the other hand, it appears that the cessation of many national nanotechnology programs or sharp decline in its funding as it occurred with USA (see fig. 8) or with Europe's spending dropped from \$2.7 billion in 2010 to \$2.1 billion in 2012, is the result of the 2008-2009 global financial crisis and extremely sluggish post-crisis development of global economy, especially the developed countries like USA and Europe.

The facts we have considered above enable us to conclude that even if the weak trend of increasing investment in nanotechnology R&D still lasts out in 2014-2015 (and there were no prerequisites for its sharp increase in this period), then in 2015 the global investments in the development of nanotechnology can be at best estimated at \$18-18.5 billion. That is almost two times less than the amount of \$35 billion required for the primary nanoproducts market to reach the growth trajectory outlined above (see fig. 7). Hence, we may infer that without a significant increase of investment in the nanotechnology R&D, which has not been observed in recent years, the share of R&D expenditures in the total output of primary nanoproducts will drop to less than 5%. So the new high-tech industry will not be formed and the production of primary nanoproducts will be much smaller than expected.

As we have noticed the termination of increasing of public investment in nanotechnologies R&D, which is occurred in 2012-2014 was accompanied with the majority of governments were shifting to support more market-oriented topic areas. Some new emerging technologies such as health care technologies, graphene, green energy or NBIC-technologies stole the spotlight. Meanwhile, all these new areas of funding and investment have the same features that were specific for nanotechnology during the boom of the mid-2000s (overestimated statistical database due to including the product final cost along with insignificant application of fundamentally new technologies, mass popularization and over-advertising among investors, etc.).

Such manipulations often aim to produce a certain PR-effect and attract investors in the related industry. Therefore, one can assume that extremely rapid growth of investments in nanotechnology or other potentially promising or breakthrough technologies is largely an effect of a whole set of external factors rather than a real economic result from introduction of these technologies in different industries. What is important is that the factor of the manipulation with statistics and marketing techniques, by which companies involved in the research of promising markets intentionally overstated both current and forecasted growth of the relevant markets, matters.

¹³ Thus, in 2011, global government spending on nanotechnology was \$7.5 billion, a 10% decline from \$8.3 billion in 2010.

CONCLUSIONS FOR FURTHER CONSIDERATION

What essential conclusions can be drawn from the above?

Firstly, nanotechnology has not yet become an industry. It is still a broad interdisciplinary field combining engineering and science on a molecular level to take first steps. Ten years ago the majority of economists and experts seemed to agree that nanotechnologies spanning multiple industries will eventually disrupt these industries over different time frames — but most of them in long-term. To date, some believe that nanotechnology never became an industry itself because the technology behind it just enhanced and improved many different industries [Cientifica, 2009]. So it is enabling a lot of mostly incremental change in older industries and now nanotechnology is advancing this way. Furthermore, at present, the key problem of nanotechnologies is that they have given start to no innovation, like automobiles, electricity or telecommunications that would change the habitual lifestyle and thus create huge consumption markets, while encouraging the development of the corresponding industry. However, nanotechnologies have not yet brought any dramatic change to life. Today they are represented as a very narrow market, like space industries, which is equally costly in terms of investment. Besides, most nanotechnology applications take much longer to find a market.

In our opinion, nanotechnology aiming foremost incremental change in older industries is supposed to be funded for its development by large scale government programs or deep-pocketed, diversified giant corporations. It seems unreasonably to expect that nanotechnology ever had its multibillion dollar blockbuster IPO and thus, cherishes some hopes for venture funds that are the five-to-seven year lifespan while nanotechnology proves to require much longer time to develop.

Secondly, the decade of exaggerated expectations has shown that venture funds and financial markets have not assisted industry development [Shapira & Wang 2010; Shapira & Youtie 2012]. Moreover, the global crisis of 2008-2009 forced most governments to allocate the lion's share of resources to the support of the financial sector and banking, or else to infrastructural projects and demand stimulation. Meanwhile, the previous great technological revolutions and general purpose technologies (or basic innovation) elaborated therein were developed through government funding, mostly in the defense industry. We agree with Vernon Ruttan, who finds that military and defense-related procurement has been a major source of technology development and technological advance of XX century. The current technological landscape would look very different in the absence of military and defense-related contributions to commercial technology development and it would have occurred in the absence of military procurement but significantly slowly [Ruttan, 2006]¹⁴.

It is essential to emphasize that some breakthrough technology, for example, nuclear power would not have developed in the absence of government funding. Ruttan shows that military and defense-related procurement mostly from governments was the crucial factor for nuclear power development [Ruttan, 2006]. Mats Larsson argues that large scale government programs for energy systems transformation will become necessary to drive the development of new energy technologies [Larsson, 2009]. Exactly as the new energy technologies the task of developing and implementing nanotechnology on a large scale appears to be too complex and demanding in terms of resources, for the market to drive this on its own.

Thus, new breakthrough technology enabling to create the next great technological wave demands constantly rising expenditures in R&D. Before they begin to serve as a driver for a new wave of economic growth, they will require considerable time to develop and, most importantly, very large investments to realize. Therefore, in order to ensure the essential financial and technological base to arise for successful development of new basic innovation, it is necessary at first to extend economic growth mechanisms based on the current general-purpose technologies (mostly ICT) as well through financial and managerial innovations.

¹⁴ According to Ruttan, military and defense-related procurement affects R&D of interchangeable parts and mass production, military and commercial aircraft, nuclear energy, computers and semi-conductors, the Internet, the space industries.

Thirdly, we consider that it is necessary to discern between "innovation" as emergence and development of new industries (the definition of Josef Schumpeter – [Schumpeter, 1939]) – term it "innovation 1" - and "innovation" as cycle of capital extended development, which uses new technology as permanent resource for its growing ("innovation 2") [Frolov, 2012]. Obviously, nanotechnology has been developed as "innovation 2". Bottom line, we conclude that current trends in the development of innovative processes indicate decoupling in the types of innovations. In the long term the development of industrial technologies (innovations) will be slow. At the same time, it seems that the priority will take some ways of social sphere capitalization that involves the introduction of new forms of financial and managerial innovations (in sense of "innovation 2"), known as "Impact Investing" [Koshovets & Frolov, 2015]. Thus, summarizing we can infer with the hypothesis putting it for further consideration that technological development or technological advance itself, as a key driver of global economic growth appears to have come to its limits. [Koshovets, 2015].

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