https://www.nmb-journal.com

Nano Micro Biosystems

Online ISSN: 2980-8057

Future energy and therapeutic perspectives of green nano-technology: recent advances and challenges

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ARTICLE INFO

Review paper

Article history:
Received: 08 Feb 2023
Revised: 18 Feb 2023
Accepted: 20 Feb 2023
ePublished: 20 Feb 2023

Keywords:
Nanotechnology, Green technology, Green chemistry, Nanomaterials, Sustainability, Therapeutic perspectives

ABSTRACT

World population are struggling with numerous problems related to environmental issues such as pollution, availability of food, as well as the demand and supply of energy. The pollution caused due to the inappropriate management of natural resources is raising grave concerns towards environment safety and sustainability. Certain scientific fields including chemistry and nanotechnology play a fundamental role in the sustainability of environment by promoting green technologies. Recent advances in new and less toxic or nonhazardous materials for industries have been assisting in generating and promoting sources for renewable energy, which is crucial for environmental protection. Considering the demand of energy for all industries and the developmental processes, it is very much necessary to promote the production and consumption of sustainable / green energy. For achieving a green economy, it is necessary to find new ways of producing green energy by using nanosystems and nanoparticles. This review article will focus on the evaluation of the green nanochemistry for sustainable development and will highlight recent advances in the green technology by using nanotechnology-based systems and materials.

DOI: https://doi.org/10.22034/nmbj.2023.385185.1013

1. Introduction

Supply of energy has been playing a key role for mankind particularly since the very beginning of 19th century. Demand for different forms of energy has been increasing with civilization, life quality improvement, and social development. The natural resources of energies are extensively utilized to serve all types of human requirements. However, in the last few decades, it has become very usual to abuse these resources. The conventional sources of energies are different types of fossil fuels including oil, natural gas, and coal. These types of energy leave residues upon usage, which occasionally turn out to be hazardous and / or poisonous for nature and living organisms. Fossil fuels generate around 66% of the required electric energy worldwide [1]. Combustion of the mentioned fuels generates electricity in two segments. Firstly, in heat engines it generates mechanical energy; and secondly, the electrical generators convert this mechanical energy into electrical energy for utilization and / or storage [2, 3]. The increasing rate of green-house gases' generation due to excessive fossil fuel consumption has substantial impacts on human life and especially on the global warming effect. Furthermore, around one-third of CO_2 emission is absorbed by oceans annually, which creates acidic circumstance and has adverse effects on the biodiversity of the marine ecosystem. Nevertheless, it has gradually been realized that for the existence of the future generations of human civilization it is mandatory to adapt to sustainable management of different forms of energy [4].

The concept of sustainability was first announced in the year 1987 by the World Commission on Environment and Development of the United Nations [5], which states that the further existence of future generations of mankind and, the accomplishment of social and monetary requirements of current population can be made possible only if the natural assets are managed appropriately and the connection between economic-growth and compassion towards the environment of the current and upcoming generations is prudently managed, while assessing and managing the long-

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term effects of industrial activities. Environmental pollution is the most life-threatening global issue and is being reflected everywhere in the land, water, and air. As a consequence, new technologies should be developed and promoted to identify, detect and remove all hazardous environmental contaminants [6]. Since 1990 American Chemical Society (ACS) is promoting certain strategies that support sustainable technologies using the principles of green chemistry, and green engineering. Nanotechnologies have proven to have significant effects on creating 'clean' and 'green' methods with substantial environmental advantages. Nanocatalyst-based fuel cells, for instance, have drawn much attention for their potential use as clean and mobile power sources. Graphite nanofiber is a support for platinum to be employed as an electrocatalyst [7].

Nanotechnology offers tools to initiate new industries based on cost-effective strategies, consequently contributing to a sustainable economic growth. Nanotechnology is a wide-range phrase usually applied to explain materials, processes and phenomena at nanoscale and nanodimension. Nanotechnology and green nanotechnology have the potential to diminish the negative impact of energy production, storage, and use [8].

In this manuscript we have discussed and reviewed the main concepts of green energies and their present and future improvements by utilizing nanoscience and nanotechnology. The application of nanotechnology has changed the green energy possibilities in an exceptional way. Presently this application is fully successful at laboratory and research level and very soon it will be dominating in the industry level in a commercially viable way keeping the environment unaffected.

2. Problems with the conventional energy sources

We have been facing increasing number of problems with the conventional energy sources. These include environmental pollution, exhaustible, risky and high cost of energy supply as well as the green-house effects [9]. Air pollution is mainly caused by burning fossil fuels and firewood. Pollution caused by conventional energy sources can take many different forms with varying impacts. Air pollution, greenhouse gases, and acid rain are a few of the more prevailing impacts. Chemicals and particles are discharged into the atmosphere during the burning of fossil fuels. Significant rate of increasing emission of green-house gases, as a result of fossil fuel utilization, has severe impacts on human life and remarkably on the global warming phenomena. A high quantity of these emissions is absorbed by seas and oceans, creating acidic pH values that have devastating effects on the life of the marine organisms. Another issue with the consumption of conventional energy sources, particularly fossil fuels, is that they can run out and deplete. It requires millions of years to regenerate these sources. On the contrary, unconventional sources of energy are renewable and theoretically never run out [10].

3. Sustainability, energy resources and energy utilisation

The current pace of energy consumption is increasing the pressure on natural resources and fossil fuels and it is being expected that with the current pace the annual consumption of energy will get doubled of the current demand up to the year 2050 [11]. Although the demand for energy is fulfilled mostly from fossil fuels which in turn emit toxic gases leading to major natural disasters and climatic changes. To combat this side effect of fossil energy researchers all around the world are trying to find safe and eco-friendly key alternatives to fossil fuels. Solar energy is the plentiful resource which is freely available globally. The challenge is to identify and develop practically efficient technologies to yield and store the solar energy [12]. One such method is the use of solar panels and solar cells for the production, storing and converting the solar energy. It has been established through research that nanotechnology can be used as an alternative to the non-renewable conventional energy resources and is a tool to achieve the vision of Hydrogen economy [13]. Wind energy is used to generate electricity using wind turbines. These turbines use generators for converting mechanical energy into electrical energy. Nanotechnology can play an important role to make these turbines cost-effective and light-weight. Use of carbon nanotubes in turbines makes rotor blades light in weight and increases the conductivity and strength of the blades [14]. Application of nanotechnology in the energy sector leads to the production of more efficient, economically cheaper and environment-friendly energy productions leading to a path of sustainability. The future of energy holds the use of nanosystems and nanostructures to produce low fuel consuming and lightweight hybrid vehicles [15]. Some of the main aspects and issues with renewable energy sources are depicted in Figure 1.

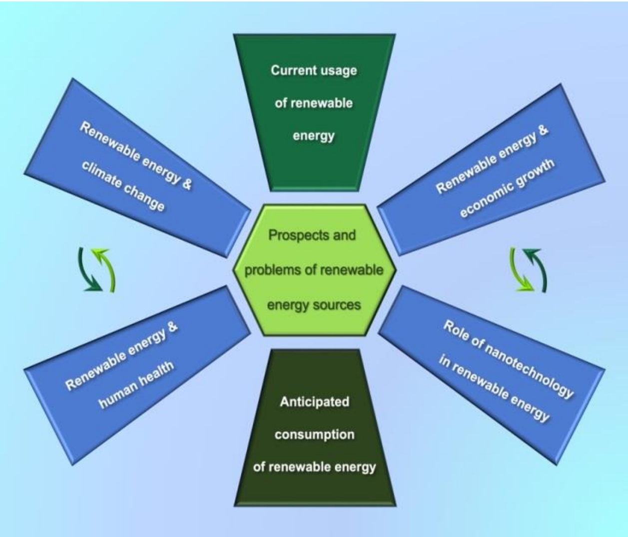

Fig. 1. Some of the main prospects and limitations of sustainability and renewable energy sources [16].

4. Simulation software for in-silico energy analysis

For the in-silico analysis, evaluation and optimization of energy, there are a number of software available. LIMDEP, which is an econometric and statistical software package with a variety of estimation tools, is used to estimate the nested logit model [17]. On the other hand, HOMER is a computer model, which simplifies the task of evaluating design options for both off-grid and grid-connected control systems. It provides a window to designate the latitude and the amount of solar radiation to generate the data for the photovoltaic (PV) array for each hour of the year [18]. To meet the renewable energy system analysis and optimization requirements, HOMER is used for distant, stand-alone, and distributed energy generation applications. The optimization and sensitivity study algorithms of HOMER software enables the user to assess the economic and technical viability of a large number of technology options and to account for uncertainties in technology changes, energy resource availability, and other variables [19].

SCAPS, Labview, and Gaussian software are employed for the assessment and optimization of solar PV systems. SCAPS is a software, which takes into account all the parameters including power conversion efficiency, open circuit voltage, and short circuit current of any solar cell system and aids to fabricate an efficient solar cell by trial and error. Labview, on the other hand, generally helps to interface between computers and characterization devices. Gaussian software is employed to check the highest occupied molecular orbital and lowest unoccupied molecular orbital positions of photoactive materials and optimum design of solar cells [20].

5. Green nanotechnology

In the year 1991 Paul Anastas, under the Environmental Protection Agency (EPA) program of the United States, proposed the term "Green Chemistry" [21]. Since then, green chemistry is playing an important role for improving human life standards and leading to greater protection of health and the environment through the management of chemical compounds [22]. Although it is a broad concept, however, it is most frequently associated with the reduction or elimination of toxic and hazardous substances. United States EPA states that "green chemistry is applied across the life cycle of a chemical compound, including its design, manufacture, application, and ultimate disposal" [23]. The key notion of green chemistry is the concept of fewer hazards and less damage to the environment and health of living organisms. Less hazardous chemicals are being defined as substances that have a less damaging effect on the environment, are less toxic towards organisms, are not persistent in nature, and are safer to use [24]. Green chemistry is the eco-friendly route of producing materials with reduced emission of hazardous substances by employing biodegradable, environmentally-friendly materials. In the year 2014, the United Nations Environment Assembly (UNEA), introduced a new terminology, i.e., "sustainable chemistry" [25]. Green chemistry is well defined and it has been more than 20 years that it has been recognized as a formal sub-discipline of chemistry. “Green

Nanotechnology" is a new area of designing new products that are harmless to human health and environment [26]. Green synthesis through green nanotechnology protocols is potentially transforming the fate of synthesizing nanoparticles and is benefiting the future of nanotechnology. This new concept - along with the basics of green chemistry - is setting new standards for producing safe and sustainable nanomaterials [27]. Scientists have reported different green methods for the synthesis of nanoparticles from plants and microorganisms [28]. Although, green nanotechnology shows a promise of being eco-friendly and safer nanotechnology, it still faces the challenge to deal with the toxic effects of nanoparticles on the environment and health aspects. Nanomaterials from green synthesis have reported to possess vast applications in energy storage, nanosensing and nanomedicine. However, the challenges and issues related to toxicological effects, unclear production and safety guidelines with green nanotechnology need further analysis and assessment. Green nanotechnology is in its emerging phase and still has a long way to go to change the path of conventional procedures towards greener approach and optimization of strategies for its industrial scale-up. Further analysis and more understanding of fundamental reaction mechanisms of green synthesis, along with appropriate and accurate characterization methods will build a concrete ground for environment-friendly, cost-effective and sustainable nanotechnology via green synthesis [29].

6. Role of nanotechnology in energy

Advancements in nanotechnology could offer new procedures to contribute towards global energy-security and energy-supply. As per the report by Rice University (Texas, 2005), several areas were recognized in which nanotechnology can initiate in-expensive, efficient, and environment-friendly technologies [30]. The advantages of nanotechnology are being recognized in various fields including solar-energy, wind-energy, fusion-reactors, clean-coal, fission-reactors, hydrogen-production, fuel cells, storage batteries, shipping and transportation. The major areas where nanotechnology and green nanotech have been influencing are listed in Table 1.

Table 1. The main areas where nanotechnology and green technology have been influencing.

No.	Description	Ref.
1	Improving the storage-capacity and power-efficiency of batteries and super-capacitors.	[31]
2	Commercializing photoconversion of light and water to generate hydrogen along with the photo-catalytic reduction of carbon dioxide to methanol.	[32]
3	Lowering the cost of solar photovoltaic cells and solar cells.	[33]
4	Developing nano-coatings to facilitate cost-effective drilling of geothermal energy.	[34]
5	Manufacturing light-weight materials for hydrogen-storage for reversible chemisorption, liquid hydrogen-vessel and pressure-tanks.	[35]
6	Developing nano-based quantum conductors, super-conductors and power-cables to decrease or remove current-loss and thermal drops and redesigning long-distant transportation of electrical energy.	[36]

While complete achievement of the targets set in Table 1 may take a very long time, however, industry and academic research institutes are putting in their best efforts to explore all the possibilities. Scientists around the world are very optimistic about supply of adequate number of batteries by designing nano-tubes-based ultra-capacitors that are sufficiently powerful to run hybrid electric cars. These ultra-capacitors possess more power-to-weight ratio, have a longer life, can perform well under extreme temperature conditions and can be charged within seconds. Although this technology is in its infancy and most of the achievements are confined to developed countries, yet it is predicted that the global market of ultra-capacitors would increase significantly in the upcoming years [37].

Another area in which nanotechnology is already being recognized significantly is the photovoltaics [38]. Start-ups and spin-off companies from different parts of the world are producing cost-effective photon-harvesting devices as compared to conventional silicon photovoltaic cells. It is observed that the use of nanotechnology-based solar fabric on the top of bridges and buildings would potentially improve their energy-landscape. When mounted on the top of a vehicle such as a bus or a truck, these nano-based solar fabrics may lead to water-splitting through electrolysis and produce hydrogen fuel [39]. It is expected that nanotech will play a fundamental role in improving the key functionalities of existing products and instruments. This can be achieved by utilizing the positive attributes of nanotechnology by including nanoparticles in different items, as well as by using nano-applications and principles in various devices. However, majority of the green nano-based solutions and alternative protocols are still in the early stages of production, feasibility studies and marketing. Further research and studies are required to evaluate the sustainability, capability and applicability of nano-solutions under more rational perspectives [40].

The unique characteristics of nanosystems and nanomaterials make them useful as electrolytes and electrodes in electrochemical sensing, energy harvesting and energy storing devices [41]. In the past few years, the perspective of nanoparticles for generating the innovative and sustainable energy solutions and applications is being explored intensively. Metal-oxide nanomaterials such as ZnO nanomaterials have shown promising potential to be used in piezoelectric devices for converting mechanical energy into electrical energy [42]. Nanowires made up of ZnO nanomaterial are being used for making handwriting enabled nanogenerators (NGs) for the harvesting of electric energy [43]. Some metal oxides such as TiO_2 and Cd-sulfide nano-materials have very strong catalytic property that can be highly useful for fabricating cost-effective photoelectrodes used in the production of hydrogen from water splitting [44, 45]. The nano-size structures in photovoltaic cells increase the area of exposure of conducting surfaces which enhances the collection of solar energy [46]. The use of mesoporous nanostructures including quantum dots, carbon nanotubes and fullerenes in solar cells makes them cheaper, lighter and increases their efficiency, electrical conductivity, mechanical strength, durability, and corrosion resistance [47, 48]. Application of lead-selenide (PbSe) in photovoltaic cells increases their efficiency by increasing the number of electrons released per photon [49]. Nanostructures have potential applications as multifunctional power sources for the manufacture of soft and wearable electronics [50]. The development of NGs creates a possibility for the electronic devices to be operated by the ambient energy harvested from the environment. The current developments in the area of NGs will pave the way for future energy sensing technologies by laying the foundation for autonomous systems. The skin-like triboelectric NG (STENG) [51] and triboelectric NG (TENG) [52] can convert mechanical energy into electrical energy enabling biomechanical energy harvesting. The two main members of the NG family used for harvesting mechanical energy from the environment are piezoelectric NG (PENG) [53, 54] and TENG [52]. Out of these two TENG proved to be very promising for scavenging mechanical energy from wind [55], water [56] and human motion [57]. The profound energy harvesting capabilities of both TENG and PENG have gained global attention from both academia and industries. Additional research and innovations of NGs will mark the development of self-powered systems that will lead to a promising future of energy and sensing technologies. Recently, scientists have successfully produced pyroelectric NG and thermoelectric NG (PyENG and ThENG) for harvesting the widespread thermal energy from the environment [58-60].

7. Nanoscience and nanoparticles for energy conversion and storage

Due to the substantial progress in nanoscience and nanotechnology, energy science has witnessed a surge of interest over the past few years. For the sustainable development of human beings, extensive research has been dedicated to renewable energy, its conversion and storage, owing to the increasing concerns about climate change and the growing demand for energy. It has been established that, downsizing functional materials to the nanoscale can manifest intriguing properties and performances compared to their bulk structures [61, 62]. For instance, nanoparticles and nanomaterials improve the performance of solar cells by providing unique optical and / or electrical properties arising from their special structural properties. These optical or electrical characteristics are employed to either increase the optical absorption of the solar cells, or improve the electron transport in the solar cell films. On the other hand, nanostructures provide higher surface area, easier access of electrolyte to the active material, and shorter diffusion distances, leading to improved energy storage and performance in supercapacitors [63].

Formulating nanostructured materials with custom-made characteristics is at the fore-front of scientific and technological exploration. Currently available strategies such as size / facet control, atomic regulation, structural engineering, vacancy engineering, and construction of nanocomposites alter the physicochemical properties (e.g., optical, electronic, band and textural) of the active sites [64]. Consequently, this gives rise to a considerable improvement in the performance of nanomaterials towards energy conversion and storage. Research in this energy realm necessitates an interdisciplinary approach with synergistic collaboration from all related disciplines such as chemistry, engineering, nanotechnology, as well as computation. Equally important is industrial thinking and scale up measures to achieve high-performance energy systems. Majority of the next-generation solar-powered batteries employed for converting solar energy into mechanical, chemical, or electrical energy are based on nanostructured materials such as quantum dot cells, nanowires, and mesoscopic nano-structures [65]. The larger surface area and compact dimensions of nanomaterials improve the storage and release of energy. Furthermore, it provides stability to the electrodes against the damage induces by ion intake and offers adequate fracture resistance and strain relaxation to the electronic devices and improves the rate of electron flow by improving the electrode – electrolyte contact. Nanotechnology can play an efficient role in the development of new and innovative storage techniques for electrical energy such as nanostructure-based redox super capacitors [66].

8. Therapeutic perspectives of green synthesized nanomaterials

Different types of nanomaterials and nanoparticles have been explored extensively due to their unique properties such as antimicrobial, anticancer and catalytic activity, as well as their optical and magnetic characteristics. The most important attribute of nanoparticles is their large surface area to volume ratio which increases their interaction with other molecules. Due to these remarkable and intriguing characteristics, nanoparticles are gaining significant attention in a diverse range of applications including biochemical sensors, tumour-imaging, catalysts, electronic equipment, bio-assay, drug encapsulation and delivery, as well as pharmaceutical treatment protocols [67].

With the development of nanotechnology and nanobiotechnology, novel approaches have been invented for manufacturing different nanoparticles for biomedical and environmental applications. Nanotheragnostics is a promising field of science with incredible prospects for the improvement of diagnosis and treatment of various diseases particularly drug-resistant infections and cancers. It is worth noting that overcoming multidrug-resistant mechanisms is the main challenge in bacterial infections and cancer therapy [68, 69]. Nevertheless, development of efficient and biocompatible carrier systems, for the controlled release of the therapeutic agents, still remains a challenge. Green synthesis methodology of nanoparticles with reduced environmental pollution and enhanced biocompatibility and stability is a novel platform, with many advantages compared to chemical or physical nanoparticle synthesis methods [70]. The conventional techniques employed to synthesize the nanomaterials (e.g., physical and chemical methods) involve application of hazardous reaction conditions and potentially toxic chemicals hence posing a risk to human health and the environment. These problems are solved by the biological methods that involve green nanotechnology which integrates green chemistry and engineering principles to formulate harmless and eco-friendly nanomaterials to address the problems affecting human health and the environment. These biological methods use phytochemicals found in plants and plants parts as well as microorganisms for the bioreduction of metal ions to their corresponding nanomaterials. The plants and the microorganisms are readily available, cost-effective, and biocompatible, therefore, offering sustainable methods for nanomaterial manufacture [71, 72]. The green-synthesized nanomaterials can exist in different shapes and arrangements including nanorods, nanotubes, nanowires and nanoconjugates (Figure 2) [73].

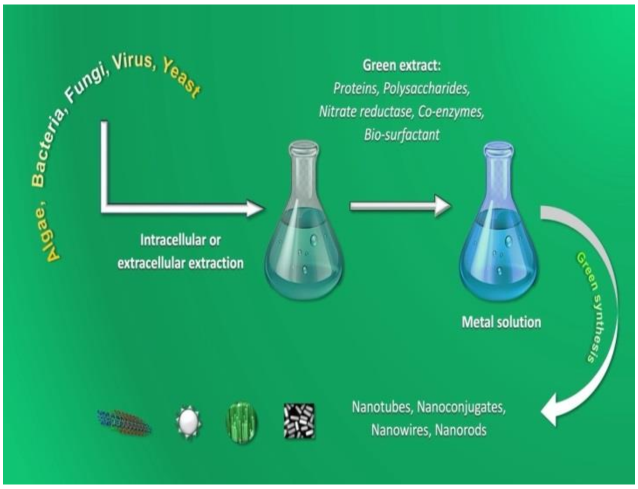

Fig. 2. Schematic representation of the biosynthesis of different types of nanoparticles employing green technology [73].

9. Conclusions

Green nano-technology can assist to improve key sustainability concerns in areas such as climate change, water purification, disease and medicine, food production, natural resources and renewable energy. As explained throughout this manuscript, nanostructured materials have proven to be effective in enhancing the performance of different devices and processes including lithium-ion batteries, solar cells, supercapacitors, and hydrogen storage. This is due to the novel geometrical characteristics and unique optical and electronic properties of nanoparticles and nano-sized material. In summary, nanostructures benefit the mentioned devices and processes by: (*i*) providing a large surface area to enhance the electrochemical reaction or molecular adsorption occurring at the solid–gas and / or solid–liquid interface; (*ii*) giving rise to high crystallinity and / or porous structure to facilitate both electron and ion transport and electrolyte diffusion, in order to ensure the electrochemical process occurring with high efficiency; (*iii*) generating optical effects that improve the optical absorption in solar cells; and (*iv*) delivering new mechanisms, for instance, the quantum confinement effect, that lead to nanomaterials achieving energy conversion and storage more efficiently.

As discussed in this article, majority of the mentioned nanoparticles and nanomaterial can be manufactured through green synthesis. In fact, green synthesis incorporates principles of green chemistry and engineering to formulate harmless and eco-friendly nanomaterials to address the problems affecting human health and ecosystem. Nevertheless, while the advantages of nanostructured substances have been well documented, there are still several aspects of nanomaterials that need to be addressed. These include some toxicological concerns and cost effectiveness of the manufacturing processes which demand further research and development to be fully addressed.

Study Highlights

- Nanostructured materials have proven to be effective in enhancing the performance of different devices and processes including lithium-ion batteries, solar cells, supercapacitors, and hydrogen storage.
- Majority of the mentioned nanoparticles and nanomaterial can be manufactured through green synthesis.
- Green synthesis incorporates principles of green chemistry and engineering to formulate harmless and eco-friendly nanomaterials to address the problems affecting human health and ecosystem.
- There are still several disadvantages of nanomaterials particularly toxicological concerns and cost effectiveness of the manufacturing processes that need to be addressed in future studies.

Abbreviations

ACS: American Chemical Society
EPA: Environmental Protection Agency
NGs: Nanogenerators

PENG: Piezoelectric nanogenerator
PyENG: Pyroelectric nanogenerator
STENG: Skin-like triboelectric nanogenerator
TENG: Triboelectric nanogenerator
ThENG: Thermoelectric nanogenerator
UNEA: United Nations Environment Assembly

Funding
This work was not supported by any institutes.

Conflict of interest
The authors declare that they have no conflict of interest.

Ethical approval
This article does not contain any studies with animals or human participants performed by any of the authors.

Authors' contribution
All authors: conceptualization, preparing the first drafting, and revising the manuscript.

Acknowledgements
Declared none.

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HOW TO CITE THIS ARTICLE:
Dehkharghani FM, Ghahremanlou M, Zandi Z, Jalili M, Mozafari MR, Mardani P. Future energy and therapeutic perspectives of green nano-technology: recent advances and challenges. Nano Micro Biosystems. 2023;2(1):11-21.doi: https://doi.org/10.22034/nmbj.2023.385185.1013