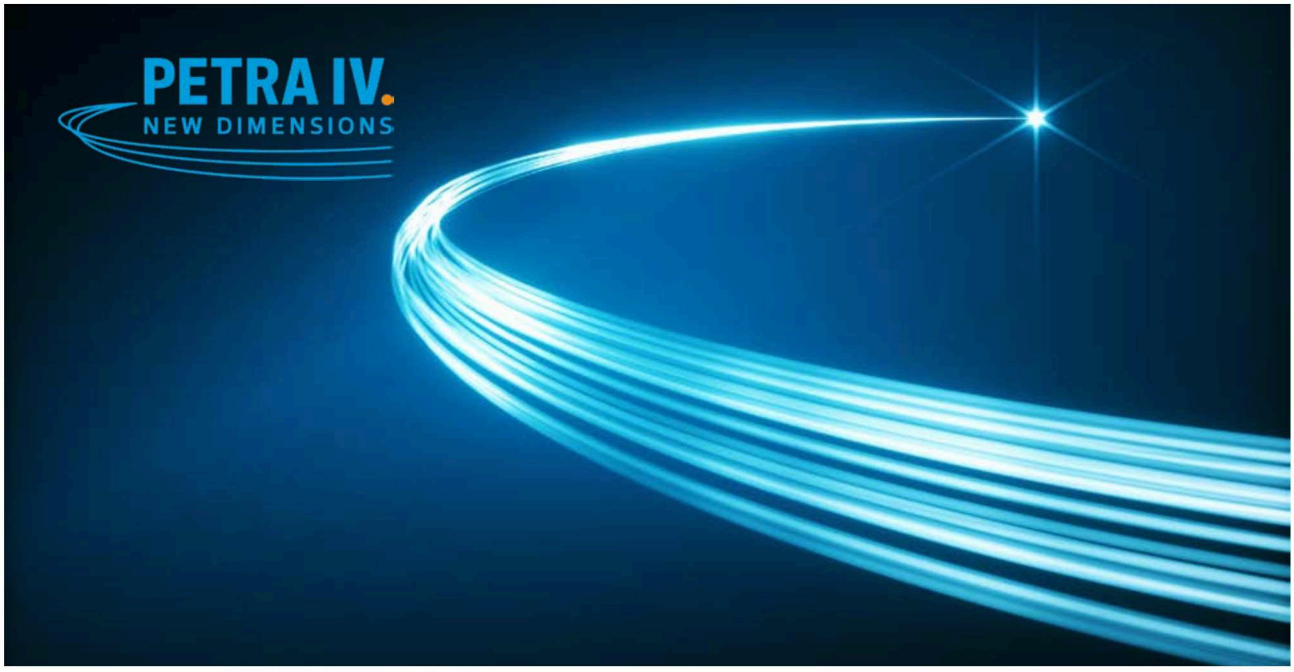
EFISCENTRE

INNOVATION & TECHNOLOGY TRANSFER

DESY.

TECHNOLOGY TREND STUDY FOR DESY (PETRA IV).



FINAL REPORT

Meta-analysis of societal & technological challenges

Authors:
Dr. Matias Barberis Rami, Dr. Richard Wade,
MA. Mariam Yeghyan, Dr. Erika Vaiginiene, Dr. Jelena Angelis

| NBrussels, 15 February 2022

TABLE OF CONTENTS

INTRODUCTION

DESY has been successfully designing, building, commissioning, and exploiting a number of research and user facilities within the last six decades and seeks to maintain its pioneering scientific position by looking its strategy for the next 10-15 years. With this intention, DESY came up with its 4th generation synchrotron radiation source project PETRA IV (an upgrade of PETRA III, 3rd generation synchrotron radiation source), which looks to be a user facility serving the international photon science community across different scientific domains. Since PETRA IV project is still in its development phase, there is a **need to provide solid argumentations for its relevance and contribution to addressing grand societal challenges and technological trends for the next 10-15 years** by vividly showcasing its beamline portfolio to all interested and potential stakeholders at national and international levels, such as national and European Union policy makers, industry, international research, and user community.

Therefore, this study aims to identify and assess the grand societal and technological challenges for the coming 10-15 years in the 5 major fields of interest for PETRA IV potential application areas: energy, life and health, earth and environment, transport, and quantum materials for information technology (or new technologies).

METHODOLOGICAL APPROACH

The study had three distinct stages:

- desk research analysing relevant documents on societal challenges and technological trends.
- experts' assessment via FIBRES platform, ranking and commenting on different technological trends.
- reporting and mapping key societal challenges and technological trends of interest for PETRA IV.

LITERATURE REVIEW

The first stage was designed to provide a comprehensive overview of the current societal and technological challenges at the EU and global levels referring to multiple sources of information. Our approach was based on the investigation and analysis of the literature from three major stakeholder groups: 1) policy makers, 2) industrial or commercial sector and 3) academia.

The targeted stakeholder groups are viewed as key players in triggering, managing or influencing grand societal challenges, related technology trends and associated solutions, taking into account their financial, material and intellectual capacities, often determining the pace and overall direction of the societal and technological developments. This assumption allowed us to balance between the published materials by different stakeholders, as an initial indication whether a trend or challenge is progressing rapidly, is a frontrunner in the field, or has a potential to be materialised in the next 10-15 years.

Regarding the **policy makers** perspective, we have explored a large number of policy, strategy and guideline papers published by influential and authoritative international organisations, such as EU, NATO, WHO, UN, OECD, as well as future oriented foresight studies prepared by specialised research centres, consultancies and think tanks. The insights of the **business community** have been covered by publications of professional market research and consultancies, such as Deloitte, KPMG, McKinsey, CBI, etc., as well as some insights provided by field leading industrial firms and their associations. The **scientific** angle was considered by screening articles published in peer-reviewed scientific journals, and open access data repositories.

Overall, more than 175 academic publications, policy documents and business reports published in the last three years (in some cases, exceptionally five years) were collected and analysed. At the first stage of the study, we did not apply any classification or prioritisation of trends, attaching the results to the frequency of references on the screened material.

Each area of interest is presented by considering the following descriptive criteria:

AREA

Related SDG / Societal Challenge

Main trends and topics

Application domains

Research challenges

Market overview

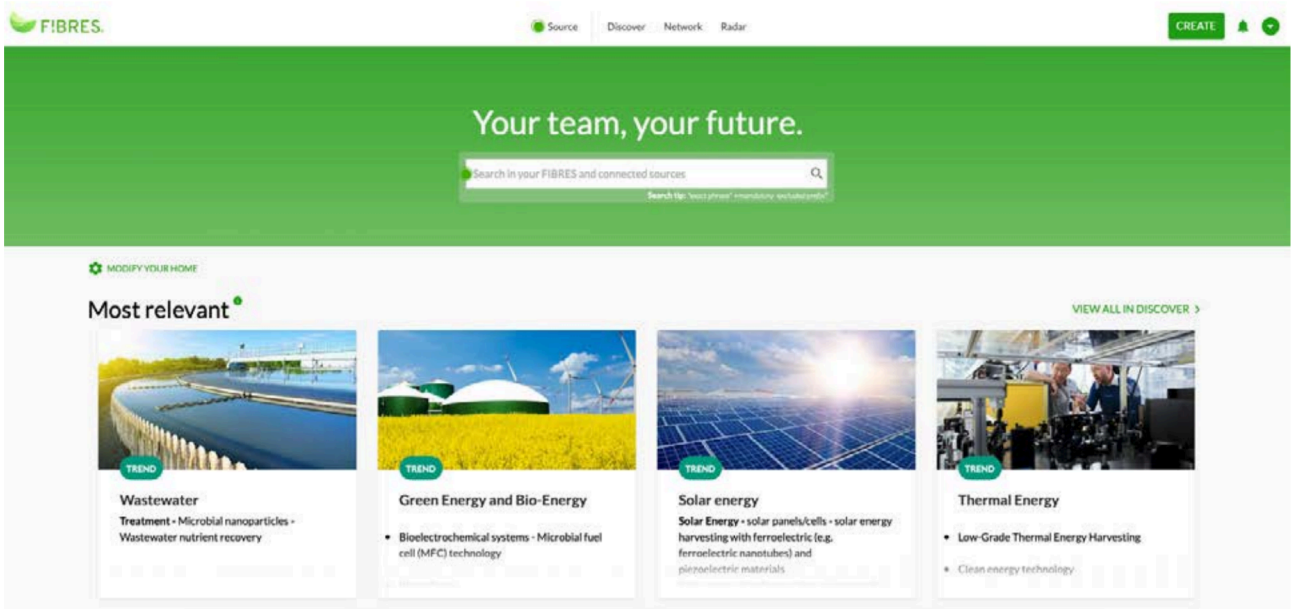
MAPPING OF TECHNOLOGY TRENDS

The second step aimed to map the technology trends through an online assessment with experts of the five areas of interest of PETRA IV plus an extra selection of experts working on cross-cutting issues. The main output of this phase is a map of technology trends (in a radar style graphic) that allows to clearly foresee how trends will potentially materialise in the next decade according to experts' review.

This task was coordinated with DESY's Interdivisional Department ITT to reach a larger number of experts, who assessed societal challenges and technological trends against defined evaluation criteria. Experts were invited to log into FIBRES platform and validate the results of the identified technological trends sharing their individual views based on experience and expertise. They were given a period of approximately 10-14 days to complete the task, receiving a direct registration link, a short guide to navigate the platform and a set of indications coming directly from the DESY's Project Officer, including some qualitative evaluation questions.

The trends included in the FIBRES platform came from the literature review phase and experts had the possibility of adding new trends, commenting on the existing ones and adding further sources of information related to the technology trend under review.

The following figure shows the interface of the FIBRES platform, used by experts to assess and classify trends.



The criteria used for the evaluation included:

1. **Position on the radar:**
    - Time to impact: When will this phenomenon begin to have impact as its expected strength?
    - Impact strength: How strong will be the impact of this phenomenon?
    - Area domain: What is the primary domain of this phenomenon?
2. **Classification:**
    - Phenomenon certainty: How likely is it for this phenomenon to have impact as its expected strength?
    - Trend label:
        - Emerging: those technological solutions and trends that are expected to reach technological maturity in the period 2021-2035.
        - Disruptive: those technological solutions and trends that may have a major, revolutionary impact in a specific field or a number of fields in the period 2021-2035.
        - Convergent: a combination of technologies that are combined in a novel manner to create a disruptive effect.
    - Scientific background: this scale assesses the research intensity level behind a specific trend or technology, i.e., how much research has been done to date to investigate the trend/technology and its different aspects
    - Technological maturity
    - Market uptake potential
    - Underlying political and legal environment: what is the underlying political and legal environment at the European level in a 10-year perspective
        - neutral/absent (i.e., not focusing on a given trend/technology in policy documents, work programmes, etc.),
        - supporting (i.e., addressing the trend/technology in some political agendas),
        - conducive (i.e., promoting the development and materialization of the trend/technology via available political tools & channels, such as funding mechanisms, work programs, legal & regulatory frameworks, etc.)
    - Relevance and impact in addressing a societal challenge
    - Potential economic impact in a 10-year perspective

Additionally, experts were also asked to provide – on a voluntary basis – further answers to the following questions:

1. **What trends and challenges do you see in your business/research area that have not been mentioned here yet? Is there any trend mentioned here that you think shouldn't be?**
2. **What are the crucial technical and research challenges in your field that need to be solved in the coming years?**
3. **Could you outline which specific scientific tools, instruments, measurement techniques you would need in the coming years to cover your research gaps?**
4. **Do you know any colleagues who could share further insights with us on the technology trends? How could we reach him or her?**

Due to a limited access capacity to the platform, we have invited the experts in three waves based on a prioritisation process done in collaboration with DESY's Project Officer. A total of 35 experts out of 72 pre-identified were connected to the platform and performed the assignment. Selected experts came from different kind of institutions including academia, think tanks, research institutes, enterprises and business sector from different countries, mainly in Europe. In total 20% of participants were female in senior and leading positions. The following table shows the distribution of experts by PETRA IV areas of interest:

Area of Interest	Number of Experts
Cross-cutting trends	12
Life and health	6
Transport	6
Earth and environment	5
Energy	4
Quantum materials	2

ANALYSIS

The last stage consisted of a presentation of the main findings based on the outputs of the literature review and the experts' assessment. In the last section of the report, we present arguments and identify trends opportunities for PETRA IV to integrate with the existing design, considering the linkages of the possible applications with addressing sustainable development goals and societal challenges.

The study itself presents a number of limitations, that should be considered when reading the results:

- Regarding the literature review, two main difficulties were encountered: first, different words for common trends were used in multiple sources; second, the existence of convergent or cross-cutting trends dispersed over different sectors (for instance, technologies which are multidisciplinary by nature such as AI, nanotechnologies, bioinformatics, etc. and can be projected to a wide range of scientific fields and applications). Added to a limited timeframe to process the information of the multiple sources, the wording and the convergence of trends could lead to trends classified under one area of interest but probably also applicable to others.

- Furthermore, we have identified a considerable number of publications made by specialised research and policy consultancies, which have done similar trends mapping by applying very concrete indicators, such as TRL level, trademark, patent analytics and publications as main reference points when determining the likelihood of a certain trend to occur and materialise in the future. We intentionally have not focused on this kind of studies in order to avoid bias during the data analysis phase.

- Due to data availability regarding a specific technology trend, technique, narrowing research topics and application areas also presented a degree of difficulty, leading to a lack of information particularly in the application domains for specific technologies or their market size and leaders.

- Regarding the expert assessment, some new trends were added by experts joining in the second or third waves of invitations. This means that some trends are not evaluated by the whole group of experts, but by a limited number. It should also be noted that not all experts have assessed the whole set of trends loaded in the FIBRES platform, but only those close to their areas of expertise.

LITERATURE REVIEW

The scope of the review includes five main sectors (Energy, Life and Health, Transport, Earth & Environment and Quantum Materials for Information Technologies) identified as the main science and technology drivers in the PETRA IV conceptual design report (CDR). Additionally, we have identified and grouped separately some cross-cutting or convergent technologies which are applicable to several fields and topics. An initial analysis connected the technology trends to respective societal challenges and UN Sustainable Development Goals (SDGs).

A key finding reveals that there is a direct connection and transformative impact between the grand societal challenges and emerging or breakthrough technologies. For example, ageing population, which is a global concern, has provoked sub-challenges such as the fight against cancer, genetic and infectious diseases, diabetes, which in their turn have triggered the development of newly emerging technologies and know-how in life and health sciences, like gene and cell therapy, biosensing technologies, novel technologies for drug delivery, etc.

The analysis of the reviewed publications at European and international levels shows that climate change, digital transformation, ageing population and urbanisation triggered key emerging societal challenges such as environmental protection (calling for efficient, secure, clean and renewable energy approaches, reduction of CO2 and greenhouse gas emissions, etc.), fight against the most deadliest diseases (e.g. Ischemic heart disease, stroke, cancer, Alzheimer's disease, diabetes, etc.), need for a smarter, socially inclusive cities and communities with advanced (intelligence-based) infrastructures and environmentally friendly ecosystem, big data storage, management and sharing issues, with a particular emphasis on data security aspects, etc.

To cope with the abovementioned grand challenges, governments, intergovernmental organisations and some industrial corporations are promoting (by means of funding, legislative incentives, tax privileges) responsible research and innovation approaches and pushing forward across a large number of research and innovation programmes, research infrastructures and commercial research and development (R&D). For instance, in a recent document, the European Commission (EC) states: "achieving the existing 2030 climate and energy targets will require EUR 260 billions of additional investment in the energy system annually in 2021-2030. The European Investment Bank (EIB) Group will become Europe's climate bank by doubling its climate target to 50%. Under the upcoming Just Transition Mechanism, the Commission is also

working with the European Investment Bank (EIB) Group towards mobilizing significant investments for regions that will need to be particularly assisted in the environmental and climate transition during the period of the next Multiannual Financial Framework (MFF). Europe also needs to remain technologically sovereign by investing in innovative technologies like block-chain, high-performance and quantum computing, algorithms and tools to allow data sharing and data usage. Data and Artificial Intelligence (AI) are major drivers for innovation that can help us to find solutions to societal challenges, from health to farming and food production, from security to manufacturing"[1].

Market insights provided by different consultancies and commercial forecasting companies also indicate that most of the currently emerging and promising technologies fall into the wider fields of energy, environment, life and health, transport, big data, AI, communications, etc. There is a visible alignment of market perspectives with governmental approaches. Of particular relevance is the topic of standardisation, which is at the core of the single European Union market and key for the sustainable development agenda, in particular for topics such as data science, AI, Quantum technologies, among others linked to the digital transition.

Furthermore, COVID-19 pandemic keeps accelerating the impact on some technology trends linked to urbanisation, mostly in the field of robotics, mobility and communications[2]. It has also triggered new challenges and research applications in the medical research sphere, putting more demand on deeper investigation of infectious diseases, viruses and vaccines. In addition to a number of past, and ongoing, research actions related to coronaviruses and outbreaks, the Commission launched several special actions in 2020 for COVID-19 research. These actions address epidemiology, preparedness and response to outbreaks, the development of diagnostics, treatments and vaccines, as well as the infrastructures and resources that enable this research. Horizon Europe, the EU research and innovation framework programme for 2021-2027, will continue to invest in research and innovation to tackle infectious diseases including poverty-related and neglected diseases. The Commission and national ministries have also agreed on the first ERAvsCorona action plan which lays out ten priority short-term coordinated actions to tackle coronavirus, including clinical trials, data access, uses of research infrastructures and further investment for COVID-19 research and innovation[3].

---

1 Enabling Technologies for Industry 5.0. Results of a workshop with Europe's technology leaders. European Commission. Directorate-General for Research and Innovation, 2020, Prosperity

2 Loke, Seng & Rakotonirainy, A. (2021). An Overview of Technology Trends Towards Smarter Cities. 10.1007/978-3-030-82318-4_1.

3 1. ERAvsCORONA Action Plan: Working Document and First Results.

Overall, the research results show that the five identified fields assumed to be potentially impacted by or benefited from PETRA IV capabilities are on the academic, policy and industrial agendas for at least the upcoming decade, evidenced in the following summary from the reviewed documents.

PRELIMINARY TREND ANALYSIS

This section provides an initial analysis connecting the identified technology trends to respective societal challenges and UN Sustainable Development Goals (SDGs) in the key areas of interest of PETRA IV. All trends and main topics have been collated and summarised from the desk research, combining multiple sources as previously mentioned in the methodological section.

ENERGY:

This area of in terest is mainly linked to the societal challenges of switching to renewable, cleaner, secure and efficient energy as well as circular economy. The literature reveals some of key research challenges within the area of interest will be oriented towards the clarification of mechanisms behind the deterioration of materials that occurs during the conversion of kinetic energy into electric energy, clarification of the degradation mechanisms of thermoelectric materials, combination of different materials for increased efficiency, scale-up possibilities; economic aspects, such as cost reduction, logistic issues, investment decisions, etc.

MAIN TRENDS	MAIN TOPICS
Solar Energy, Green Energy, Bioenergy, Thermal Energy, Wind Energy, Water Energy, Batteries, Thermoelectrical energy harvesting, Lead-based and lead-free ferroelectric ceramic capacitors for electrical energy storage	Energy Harvesting, Energy Conversion, Energy Storage

EARTH & ENVIRONMENT:

This area of interest is mainly connected to the societal challenges of decarbonisation, reduction of greenhouse gas (GHG) emissions, emissions reduction from Emissions Trading Systems (ETS) sectors, reduction of primary energy demand, effective waste management and water quality.

MAIN TRENDS	MAIN TOPICS
Wastewater Treatment, microbial nanoparticles, wastewater nutrient recovery, splitting carbon dioxide (CO2), arsenic removal, underwater living, underwater sensor networking, water quality	Water, Air, Soil, Underwater living, Pollution

TRANSPORT:

This area of interest responds to the following societal challenges: safer, cleaner, secure alternative fuels, tackling with urbanization and faster delivery.

MAIN TRENDS	MAIN TOPICS
Intelligent Transport Systems (ITS), ITS-technologies: Vehicle-to-Infrastructure (V2I), Infrastructure-to-Vehicle (I2V) and Vehicle-to-Vehicle (V2V); Electric-Drive Vehicles, hybrid electrical vehicles (incl. aviation), wide bandgap semiconductors; drones; hydrogen fuel cell technology	Reduction of CO2 emissions through optimization of combustion engines, the electrification of propulsion systems or the development of new battery technologies, Autonomous Vehicles, CAV (connected automated vehicles), Hydrogen fuel cell technology, Intelligent Transport Systems (ITS)

LIFE AND HEALTH:

By 2024, an ageing population increase means the workforce in eleven EU Member States is estimated to fall by more than 3% compared to today. By 2060, the EU's workforce is estimated to decline by 12% . Facing this perspective, key societal challenges of this area of interest are decreasing labour force, cancer treatment, Alzheimer's disease, cardiovascular disease, diabetes, infectious diseases and vaccines..

MAIN TRENDS	MAIN TOPICS
Cell-therapy (e.g., CAR-T), Gene-therapy (e.g. Genome Editing Technologies, CRISPR Gene Editing), Engineered Living Materials (ELMs), Biosensing technologies, Stem-cell-based tissue engineering, Drug delivery, Biodegradable sensors, Lab-on-a-chip, Antibiotic Susceptibility Testing, Bio-Printing (of human parts)	Labour forces, various diseases, health applied methodologies, intervention materials

[4] More information: Communication from the Commission to the European Parliament, The Council, The European Central Bank, The European Economic and Social Committee, The Committee of the Regions and the European Investment Bank Annual Sustainable Growth Strategy 2020; Brussels.

QUANTUM MATERIALS FOR INFORMATION TECHNOLOGIES (NEW TECHNOLOGIES):

This area is mainly addressing societal challenges such as digital transformation, security (incl. data security), social inclusion, environmental protection, tackling with climate change (e.g., floods).

MAIN TRENDS	MAIN TOPICS
Multilayers, e.g., Ferromagnetic thin films, Ferroelectrics as a means of computer storage	Data Storage & Transfer /Spintronics, Neuromorphic chips, Artificial Intelligence, Additive Manufacturing

Further to the five areas of interests, some **cross cutting or convergent trends** emerged from the literature review:

- Graphene-based technologies, lack of standardisation, great application potential in automotive and transportation, aerospace, electronics, military and defence
- Carbon nanotubes
- Nanotechnologies (Agriculture, Medicine, Energy, Food, Fuel cells, Batteries, Better air quality, Chemical sensors, Fabric, Solar cells)
- 3D/4D Printing
- Synthetic Biology
- Bioinformatics
- Hyperspectral imaging

EXAMPLES OF TECHNOLOGY TRENDS

SOLAR ENERGY

Including solar panels/cells, solar energy harvesting with ferroelectric (e.g., ferroelectric nanotubes) and piezoelectric materials

Application Domain	Civil engineering, Heating, Cooling, Industrial applications, Electricity.
Scientific Disciplines	Electrical engineering, thin films physics
Market Overview	Solar installations in the USA are forecasted to quadruple from current levels by 2030, as more and more homeowners are learning that it's possible to reduce their environmental impact while offsetting their energy bills with solar panels.[5]

GREEN OR BIOENERGY APPROACHES

Including bioelectrochemical systems, microbial fuel cell (MFC) technology, biomethane, biohythane, biohydrogen, green hydrogen production, ultra-green hydrogen production with graphene coating

Application Domain	Reducing GHG emissions, waste management, improving air quality, alternative fuels, alternative energy sources
Scientific Disciplines	Environmental science, Biotechnologies, Chemistry, Molecular Physics
Market Overview	In the last few years, trends of using bioenergy have become quite popular with many new projects and initiatives being given the green light across the globe. This has shown a positive impact on national, regional, and local levels. More business and residential buildings are converting waste-to-energy systems, thereby supporting this market, worldwide.[6]

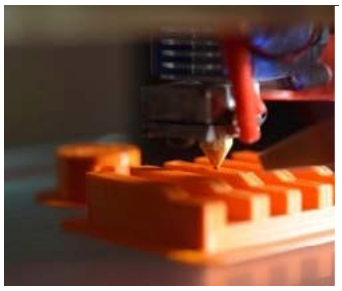
[5] More information: Top Solar Companies: 8 Best Solar Energy Companies of 2021 - EcoWatch, 10 Biggest Solar Companies

[6] More information: Top 10 Bioenergy Companies in the global market by 2021

THERMAL ENERGY

Including thermal energy storage as well as development and application of advanced thermodynamic methods for optimizing thermal systems for, e.g., power production, refrigeration, heat pumps, internal combustion engines, and biomass utilisation.

Application Domain	Low-Grade Thermal Energy Harvesting, Clean energy technology
Scientific Disciplines	Physics, Chemistry, Mechanical Engineering, Molecular Physics
Market Overview	Thermal Energy Storage Market to surpass USD 374 Million by 2030 from USD 190 Million in terms of value growing at a CAGR of 14.2% throughout the forecast period, i.e., 2020-30.[7]



ADDITIVE MANUFACTURING

3D/4D Printing, defined as a method that enables fabrication of metallic and non-metallic parts directly from the CAD (computer-aided design) file)

Application Domain	Energy storage, Structural applications, Structural elements, insolation. Questions for research: whether the system can be scaled up sufficiently and whether transmission across the long distances of cislunar space and through Earth's atmosphere is safe and practical.
Scientific Disciplines	Chemistry, Mechanical engineering, Physics, Materials Science
Market Overview	The Global Additive Manufacturing Market size is expected to reach USD 23.75 billion by 2027.[8]

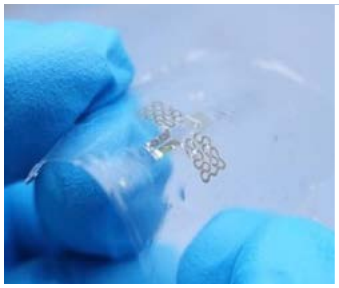
[7] More information: Global Thermal Energy Storage Market Forecast up to 2030

[8] More information: Additive Manufacturing Market Analysis By Material Type, By Metal Type, By Polymer Type, By Ceramics Type, By Process, By End-use, And Segment Forecasts To 2027, Additive Manufacturing with Metal Powders Market Statistics

ARTIFICIAL INTELLIGENCE

Including any type of software or hardware component supporting machine learning, computer vision, natural language understanding (NLU) and natural language processing (NLP).

Application Domain	e-commerce, automotive industry, education, robotics, healthcare,
Scientific Disciplines	Economics, Engineering, Computing, Physics
Market Overview	The global Artificial Intelligence market is projected to grow from $47.47 billion in 2021 to $360.36 billion in 2028. [9]



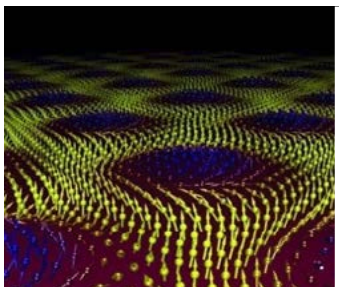
BIODEGRADABLE SENSORS

Mainly sensors fully biodegradable (and implantable) including power source, circuitry, and wireless technologies.

Application Domain	Health, food monitoring
Scientific Disciplines	Molecular Biology, Chemistry, Microbiology
Market Overview	Biosensors is estimated the largest product type in the global Disposable Medical Sensors market in 2019, demand for which is anticipated to register 2019-2026 CAGR of 9.9% and reach a projected US$7.1 billion by 2026.[10]

[9] More information: Global Artificial Intelligence Market | 2021 - 26 | Industry Share, Size, Growth - Mordor Intelligence, Artificial Intelligence Market Size & Share | AI Industry Growth by 2025, Artificial Intelligence Market Size, Share | AI Industry Growth, 2028

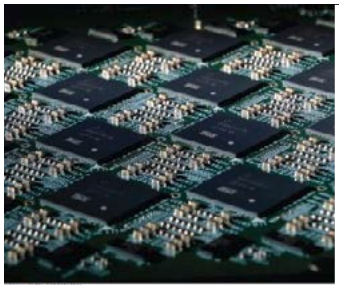
[10] More information: Global Disposable Medical Sensors Industry to 2026 - Key Business Trends Focusing on Product Innovations/Developments, Mergers & Acquisitions, and Joint Ventures



SPINTRONIC

Study of the intrinsic spin of the electrons and its associated magnetic moment, in addition to fundamental electronic charge in solid-state devices

Application Domain	Electric vehicles, industrial motors, data storage, magnetic random-access memory, semiconductor lasers, spintronics couplers, magnetic sensing
Scientific Disciplines	Physics, Engineering, Computing
Market Overview	The spintronics market is estimated to reach USD 967.8 million by 2026. [11]



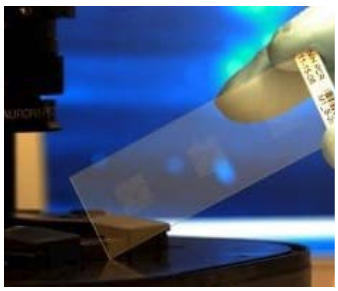
NEUROMORPHIC CHIP

Specific brain-inspired ASIC that implements the Spiked Neural Networks.

Application Domain	Environment, medicine, automotive industry, digital transition
Scientific Disciplines	Computing, Bioengineering, Electrical Engineering
Market Overview	The Neuromorphic Chip Market was valued at USD 22.5 million in 2020, and it is projected to be worth USD 333.6 million by 2026.[12]

[11] More information: Spintronics Market Size, Share, Growth Forecast 2027

[12] The Neuromorphic Chip Market was valued at USD 22.5 million in 2020, and it is projected to be worth USD 333.6 million by 2026. More information: Neuromorphic Chip Market | 2021 - 26 | Industry Share, Size, Growth - Mordor Intelligence



LAB-ON-A-CHIP

Miniaturized device that integrates into a single chip one or several analyses, which are usually done in a laboratory (e.g., DNA sequencing or biochemical detection).

Application Domain	Nucleic acid biotechnology and analysis (DNA and RNA sequencing, genotyping, gene manipulation), protein analysis (proteomics and metabolomics for targeted and untargeted analysis), medical diagnostics, medical devices and treatments (including implantable and wireless), drug development (screening and delivery), cells, tissues, organs on chip and integrated tissue engineering, 3D cell culture, single cell analysis, cell and organism motility and interactions, systems and synthetic biology and medicine, Energy, biofuels, environmental and food monitoring.
Scientific Disciplines	Molecular Biology, Chemistry, Microbiology, Medicine, Physics
Market Overview	The global lab on a chip market is expected to reach US$9.06 billion by 2026. [13]

CELL & GENE THERAPY

Including chimeric antigen receptor T-cell (CAR-T), engineered living materials, biosensing technologies, Stem-cell based tissue-engineering and genome editing technologies.

Application Domain	Treating cancer, cystic fibrosis, heart disease, diabetes, haemophilia and AIDS
Scientific Disciplines	Molecular Biology, Genetics, Chemistry, Microbiology, Medicine
Market Overview	Cell and gene therapy market is expected to grow from $4,390.3 million in 2020 to $15,482.3 million in 2025 at a rate of 28.7%. The market is then expected to grow at a CAGR of 17.3% from 2025 and reach $34,317.9 million in 2030.[14]

[13] More information: Lab On a Chip Market Size, Trends & Growth | 2021 to 2026 (marketdataforecast.com), Top Lab-on-chip companies

[14] More information: Gene Therapy Market Size, Share, Trends & Growth | 2021 to 2026, Global Cell and Gene Therapy Market Report 2021-2030: Growing Investments and Manufacturing Facility Expansion & Increasing Number Of Pipeline Studies and Drug Development, Cell Therapy Technologies Market - Global Forecast to 2025, Cell Therapy Market Size Worth $23.0 Billion By 2028

BATTERIES

Including Graphene Batteries and Li-Ion Batteries.

Application Domain	Transport & mobility (marine, aerospace, aviation, electrical vehicles), defence, stationary energy storage. Key research topics: Battery systems, battery management, digital twins for battery system design, manufacturing and management, methods and tools for assessment of battery, performance and safety
Scientific Disciplines	Chemistry, Electrical Engineering, Physics
Market Overview	The global lithium-ion battery market size is projected to grow from USD 41.1 billion in 2021 to USD 116.6 billion by 2030. The global graphene battery market size is projected to grow from USD 168 million in 2024 to USD 609 million by 2030. [15]

[15] More information: The Worldwide Lithium-Ion Battery Industry to 2030 is Expected to Reach $116.6 Billion by 2030; Graphene Battery Market by Type, End-Use Industry, Region - Global Forecast to 2030

ASSESSMENT BY EXPERTS

The second stage of the study consisted of an expert assessment, where experts were invited to rank and comment on the identified societal challenges and technological trends via the online platform FIBRES. The identification and potential impact assessment of a particular trend requires consideration of the threat environment (current and future), legal and policy constraints, political factors, investment decisions, as well as estimating the potential for organizational uptake (e.g., entrepreneurial drive and risk tolerance). Some of these factors have been used in the experts' assessment as categorisation criteria, as previously described in the methodological section.

Experts were presented with a series of trends on the FIBRES platform and after selecting the technologies closer to their field of expertise, they could classify the trends in terms of the time to impact, strength and main area of domain. This exercise allowed a comparison with the results of the literature review and a better understanding whether a trend is perceived as belonging to one specific area or if it tends to be a convergent issue, possibly tackling multiple societal challenges.

The trends were classified into different areas by the experts as follows:

ENERGY

- Additive Manufacturing for renewable energy
- Batteries
- Solar energy
- Thermal Energy
- Green Energy and Bio-Energy
- Other trends in energy harvesting

EARTH AND ENVIRONMENT

- Biodiversity / species extinction
- Underwater living
- Wastewater
- Water quantity and scarcity
- Splitting Carbon dioxide (CO2)

TRANSPORT

- Drones
- Intelligent Transport Systems (ITS)
- Electric-Drive Vehicles
- Hydrogen fuel cell technology

LIFE AND HEALTH

- soil/land degradation
- Biodegradable sensors
- Water quality
- Cell (e.g. CAR-T) & Gene-therapy (e.g. Genome Editing Technologies)
- Lab-on-a-chip

QUANTUM MATERIALS

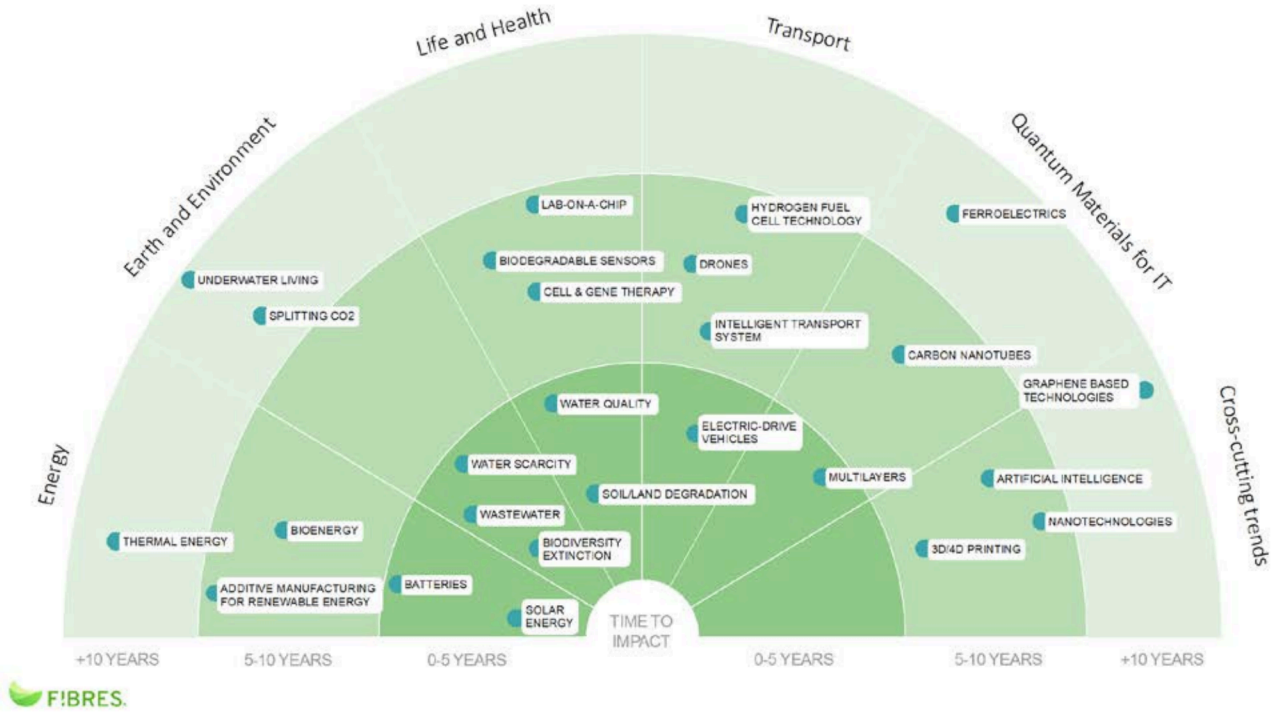
- Ferroelectrics as a means of computer storage
- Carbon nano-tubes
- Multilayers, e.g. Ferrimagnetic thin films

CROSS-CUTTING

- 3D & 4D printing
- Artificial Intelligence
- Graphene-based technologies
- Nanotechnologies

Further to this classification, the main output of this exercise is an assessment of trends by their likelihood to happen in a certain timeframe. The following figure represents the timeframe categorisation made by the group of experts.

Radar of technology trends, by area of interest for DESY PETRA IV



Finally, the third categorisation made by the experts was related to the impact of the technology trend. Trends were classified by low, medium or high impact, as follows:

- Biodiversity / species extinction
- Artificial Intelligence
- Wastewater
- Water quantity and scarcity
- Additive Manufacturing for renewable energy
- Batteries
- soil/land degradation
- Water quality
- Multilayers, e.g. Ferrimagnetic thin films
- Electric-Drive Vehicles
- Other trends in energy harvesting
- Carbon nano-tubes
- Intelligent Transport Systems (ITS)

- Nanotechnologies
- Splitting Carbon dioxide (CO2)
- Solar energy
- Green Energy and Bio-Energy
- Biodegradable sensors
- Drones
- 3D & 4D printing
- Lab-on-a-chip
- Hydrogen fuel cell technology

- Underwater living
- Thermal Energy
- Ferroelectrics as a means of computer storage

The following table summarises the main results of the categorisation of trends by the defined criteria. Annex 1 presents a detailed overview of values received by each individual trend, comparing time to impact and impact strength, along with other categories used for categorisation, as well as a comprehensive view of the assessment of all trends and criteria during the second phase of the study.

ASSESSMENT CRITERIA	MAIN RESULTS
Phenomenon Certainty	In terms of certainty, six technology trends were assessed more frequently with a likelihood to happen: batteries, solar energy, artificial intelligence, wastewater and electric-drive vehicles, and biodiversity extinction. The lower level of certainty goes to underwater living and hydrogen fuel cell technology.
Trend label (emerging, disruptive or convergent)	Batteries, 3D/4D printing and solar energy have been identified more frequently as emerging technologies; artificial intelligence, wastewater, biodiversity extinction and harvesting energy were identified as disruptive technologies; artificial intelligence and carbon nanotubes were more frequently classified as convergent technologies.
Technological maturity	Experts assessed batteries and solar energy as possessing the higher TRL (8-9) with solutions fully deployed in market; electric-drive vehicles and nanotechnology were identified with an intermediate TRL (6-7); artificial intelligence and wastewater presents a lower TRL level, but already on study/testing phases (3-5); while underwater living and Ferroelectrics as a means of computer storage presents the lowest TRL according to the assessment (1-2).
Scientific background	Batteries, artificial intelligence, nanotechnologies, solar energy and electric-drive vehicles were classified with high and very high scientific background, while underwater living was tagged as the trend with less scientific developments.

ASSESSMENT CRITERIA	MAIN RESULTS
Market uptake potential	Batteries, artificial intelligence and solar energy were classified as the trends with better uptake potential; carbon nanotubes, electric-drive vehicles and wastewater also presents a high potential; 3D & 4D printing, graphene-based technologies and underwater living present the lowest uptake potential, as per the classification of experts.
Underlying political and legal environment	Experts identified batteries and artificial intelligence as the trends with a conducive political and legal environment. Solar energy, carbon nanotubes, wastewater, electric-Drive Vehicles and hydrogen fuel cell technology were identified as trends with a supportive political and legal framework. Experts assessed that nanotechnologies as well as 3D and 4D printing have either a neutral or absent political and legal environment.
Relevance and impact in addressing a societal challenge	Experts evaluated that batteries and artificial intelligence present a higher relevance and impact in addressing societal challenges, followed by solar energy and electric-drive vehicles. Trends such as 3D & 4D printing and carbon nanotubes have a moderate relevance and impact.
Potential economic impact in a 10-year perspective	Biodiversity extinction, batteries, artificial intelligence, and electric-drive vehicles were among the most voted trends having a potential economic impact in the next decade, followed by solar energy. Meanwhile, graphene-based technologies and 3D/4D printing would present a moderate impact.

Additionally, an internal group of experts from DESY rated further trends, considering their matching potential for PETRA IV:

Relevant trends	Potentially relevant trends
• Small pores, big impact • Living Materials • 2D magnets • Materials from Mars • Functional polymer coatings • Predictive maintenance • Green building materials • Bioplastics • Gradient materials • Biofuel cells, energy harvesting from natural substrates • Direct solar hydrogen production • Metal lenses • Highly efficient solar cells • Customized 4D printing	• Bio-additives for sustainable plastics • Artificial Photosynthesis • DNA data storage • Polymer materials for battery technologies • Bio-inspired underwater adhesives • 5G • Internet of Things (IoT) from Space • Ionic Liquids • Superamphiphobic surfaces • Energy storage systems of the future change colour • Bioprinting • Atmospheric water generation • Machine learning • Kinetic energy for portable electricity consumers • Industry 4.0 • genome editing • Augmented Sensing • Lidar-on-a-Chip

The assessment by the experts provides insights in terms of the technologies that will prevail in the next decade, not only supported by legal environment but also perceived as the ones contributing to address societal challenges and create a potential economic impact. The expected impact corresponds to a certain extent to the findings of the literature review. While a first reading leads to clearly identify batteries, solar energy and artificial intelligence, there are a number of trends that remain at an intermediate level in terms of identified economic impact and evidenced political and legal support, but that are growingly being developed in the scientific arena.

MAIN FINDINGS

The analysis reveals that the areas of interest identified by DESY (Energy, Life and Health, Earth and Environment, Transport and Quantum Materials for Information Technology) are well aligned with, and relevant to globally accepted societal challenges and the UN Sustainable Development Goals (SDGs). We estimate, for example, that DESY's areas of interest are relevant to at least 10 of the 17 UN SDGs. These societal challenges give rise to a wide range of technology challenges that are represented by the trends appearing in our literature study that have been reviewed and augmented by a range of experts.

While a significant number of the technology trends identified in this study are potentially suitable targets for study with PETRA IV, the relevance of many of the trends is harder to discern. This is inevitable given that the methodology was set up to identify trends in particular areas of interest and the output has not been filtered to match the capabilities of PETRA IV at this stage.

However, it is possible to link the technology trends identified in this study to the Science Highlights and Science and Technology Drivers described in the PETRA IV Conceptual Design Report. For example, in the area of Energy the trends relating to battery development and solar energy, which are two of the most prominent trends identified in the whole study, the links to the highlights and drivers in the Conceptual Design Report are very clear. Regarding the Life and Health area, the connections with the Conceptual Design Report focussing on the ability of PETRA IV to better understand biological systems and functions from the whole organism level down to the molecular level were deemed relevant during the literature review. Improved understanding, diagnosis and treatment of diseases such as cancer, diabetes, neurodegenerative disease and cardiovascular disease are important targets for PETRA IV and should be further taken into consideration in next steps of analysis such as dedicated workshops with experts.

There are further topics that represents an opportunity in terms of their relevance to PETRA IV and should be target of analysis in next phases of the study:

- Catalysts, which will be increasingly relevant in the fields of energy, the environment and transport. Catalysis is becoming ever more important in improving the efficiency of chemical processes in a range of applications including the production of chemicals and the reduction of pollution.
- Hydrogen Economy is an important trend in energy and transport. Hydrogen fuel cells appear as a trend under transport, but hydrogen production and storage as well as use of alternative fuels such as ammonia and methane should be further explored.
- Smart Materials (self-healing materials) have applications in energy, transport and life and health.
- Durable, low friction materials have applications in energy and transport as well as the environment and health in terms of reducing pollution.

Addressing the identified challenges requires a range of tools based on 3rd Generation synchrotron sources, free electron lasers (e.g., FLASH and the European XFEL), lasers (such as those provided by the European Extreme Light Infrastructure, ELI) as well as neutron sources such as the ESS. These complementary facilities enable studies at different spatial and temporal scales of structures and processes at atomic and molecular scales. PETRA IV, with its ability to examine phenomena at the diffraction limit for hard X-rays will be a unique and important addition to the toolbox providing capabilities not available at other current or proposed facilities in Germany or the rest of Europe.

Matching particular technology challenges to the proposed portfolio of beamline capabilities of PETRA IV is beyond the scope of the current work and will require expert input from beamline scientists and users to develop examples of pathways from technology challenge to experiments with PETRA IV to the application of data and measurements to the solution to challenges.

REFERENCES

ACADEMIC LITERATURE

1. Husain, I. & Ozpineci, Burak & Islam, Md Sariful & Gurpinar, Emre & Su, Gui-Jia & Yu, Wensong & Chowdhury, Shajjad & Xue, Lincoln & Rahman, Dhrubo & Sahu, Raj. (2021). Electric Drive Technology Trends, Challenges, and Opportunities for Future Electric Vehicles. Proceedings of the IEEE. PP. 10.1109/JPROC.2020.3046112.
2. Annamalai J, Ummalyma SB, Pandey A, Bhaskar T. Recent trends in microbial nanoparticle synthesis and potential application in environmental technology: a comprehensive review. Environ Sci Pollut Res Int. 2021 Sep;28(36):49362-49382. doi: 10.1007/s11356-021-15680-x. Epub 2021 Jul 30. PMID: 34331227.
3. Alka, Sadiya & Shahir, Shafinaz & Ibrahim, Norahim & Ndejiko, Mohammed & Vo, Dai-Viet & Abd Manan, Fazilah. (2020). Arsenic Removal Technologies And Future Trends: A Mini Review. Journal of Cleaner Production. 278. 123805. 10.1016/j.jclepro.2020.123805.
4. Bai, Yang & Jantunen, Heli & Juuti, Jari. (2019). Ferroelectric Oxides for Solar Energy Conversion, Multi-Source Energy Harvesting/Sensing, and Opto-Ferroelectric Applications. ChemSusChem. 12. 10.1002/cssc.201900671.
5. Crisp, Jake & Ellison, Joanna & Fischer, Andrew. (2020). Current Trends and Future Directions in Quantitative Geodiversity Assessment. Progress in Physical Geography. 45. 10.1177/0309133320967219.
6. Achkari Begdouri, Oussama & Fadar, A. (2019). Latest developments on TES and CSP technologies – Energy and environmental issues, applications and research trends. Applied Thermal Engineering. 167. 114806. 10.1016/j.applthermaleng.2019.114806.
7. Loke, Seng & Rakotonirainy, A. (2021). An Overview of Technology Trends Towards Smarter Cities. 10.1007/978-3-030-82318-4_1.
8. Kumar, Gopalakrishnan & Lay, Chyi-How & Kim, Sang-Hyoun & Ponnusamy, Vinoth Kumar. (2020). Recent developments on alternative fuels, energy and environment for sustainability. Bioresource Technology. 317. 124010. 10.1016/j.biortech.2020.124010.
9. Garzaniti, Nicola & Tekic, Zeljko & Kukolj, Dragan & Golkar, Alessandro. (2021). Review of technology trends in new space missions using a patent analytics approach. Progress in Aerospace Sciences. 125. 100727. 10.1016/j.paerosci.2021.100727.
10. Gupta, Shashaank. (2021). Introduction to ferroelectrics and related materials. 10.1016/B978-0-08-102802-5.00001-7.
11. Kumar, Abhishek & Mukherjee, Somdutta & Roy, Amritendu. (2020). Solar energy harvesting with ferroelectric materials. 10.1016/B978-0-08-102802-5.00002-9.
12. Kishore, Ravi. (2021). Harvesting thermal energy with ferroelectric materials. 10.1016/B978-0-08-102802-5.00003-0.
13. Moura, Adriane & Erturk, Alper. (2021). Leveraging size effects in flexoelectric-piezoelectric vibration energy harvesting. 10.1016/B978-0-08-102802-5.00004-2.

14. Meesala, Vamsi & Hajj, Muhammad R.. (2020). Modeling and identification of nonlinear piezoelectric material properties for energy harvesting. 10.1016/B978-0-08-102802-5.00005-4.

15. Sirohi, Jayant. (2021). Wind energy harvesting using piezoelectric materials. 10.1016/B978-0-08-102802-5.00006-6.

16. Gupta, Shashikant & Fatma, Bushara & Bhunia, Ritamay & Prajapati, Prateek & Gupta, Raju & Garg, Ashish. (2021). Biomechanical energy harvesting with piezoelectric materials. 10.1016/B978-0-08-102802-5.00007-8.

17. Baraskar, Bharat & Darvade, Tulshidas & Kambale, Rahul & Ryu, Jungho & Venkateswarlu, Annapureddy. (2021). Harvesting stray magnetic field for powering wireless sensors. 10.1016/B978-0-08-102802-5.00008-X.

18. Palneedi, Haribabu & Peddigari, Mahesh & Upadhyay, Ashutosh & Silva, José P. B. & Hwang, Geon & Ryu, Jungho. (2021). Lead-based and lead-free ferroelectric ceramic capacitors for electrical energy storage. 10.1016/B978-0-08-102802-5.00009-1.

19. Jia, Tingting & Kimura, Hideo & Cheng, Z. & Zhao, Hongyang. (2019). Domain switching in bismuth layer-structured multiferroic films. 10.1016/B978-0-12-814499-2.00001-3.

20. Cheng, Z. & Hong, Fang & Jia, Tingting & Zhao, Hongyang & Wang, Zengmei & Ozawa, Kiyoshi & Kimura, Hideo. (2019). Strain tuning effects in perovskites. 10.1016/B978-0-12-814499-2.00002-5.

21. Zhao, Hongyang & Cai, Kang & Wang, Huan & Hu, Zhao & Zhang, Xiaodan & Li, Huadong & Cheng, Z. & Jia, Tingting & Kimura, Hideo. (2019). Aurivillius layer-structured multiferroic materials. 10.1016/B978-0-12-814499-2.00003-7.

22. Fujii, Ichiro & Wada, Takahiro. (2019). Fabrication of (K, Na)NbO3 films by pulsed laser deposition and their domain observation. 10.1016/B978-0-12-814499-2.00004-9.

23. Yamaguchi, Masaki & Watanabe, Kazuki & Masuda, Yoichiro. (2019). Microscale materials design using focused proton-beam writing. 10.1016/B978-0-12-814499-2.00005-0.

24. Nishida, Takashi. (2019). Thin film fabrication using nanoscale flat substrates. 10.1016/B978-0-12-814499-2.00006-2.

25. Matsumoto, Takao. (2019). Ferroic domain observation using transmission electron microscope. 10.1016/B978-0-12-814499-2.00007-4.

26. Moriwake, Hiroki & Fisher, Craig & Kuwabara, Akihide & Fu, Desheng. (2012). A First-Principles Study of the Ferroelectric Phase of AgNbO3. Japanese Journal of Applied Physics. 51. 09LE02-1. 10.1143/JJAP.51.09LE02.

27. Umegaki, Toshihito & Kanno, Isaku. (2019). Structural optimization of piezoelectric thin-film vibration energy harvesters based on electric equivalent circuit model. 10.1016/B978-0-12-814499-2.00009-8.

28. 2Zhu, Ruijian & Wang, Zengmei & Cheng, Z. & Kimura, Hideo. (2019). Ferroelectric nanofibers and their application in energy harvesting. 10.1016/B978-0-12-814499-2.00010-4.

29. Yoshimura, Takeshi. (2019). Microenergy harvesting using BiFeO3 films. 10.1016/B978-0-12-814499-2.00011-6.

30. Maiwa, Hiroshi. (2019). Thermal energy harvesting of PLZT and BaTiO3 ceramics using pyroelectric effects. 10.1016/B978-0-12-814499-2.00012-8.

31. Matthijs J. Janssen, Jonas Torrens, Joeri H. Wesseling, Iris Wanzenböck, The promises and premises of mission-oriented innovation policy—A reflection and ways forward, Science and Public Policy, Volume 48, Issue 3, June 2021, Pages 438–444, https://doi.org/10.1093/scipol/scaa072

32. Boon, Wouter & Edler, Jakob. (2018). Demand, challenges, and innovation. Making sense of new trends in innovation policy. Science and Public Policy. 45. 435-447. 10.1093/scipol/scy014.

33. Kohli, T. AI's contribution to the global economy will bypass that of China and India by 2030, to reach $15.7 trillion (2019). URL https://www.weforum.org/agenda/2019/09/artificial-intelligence-meets-biotechnology/.

34. Melchiorri M F, Freire A J, Schiavina S, Kemper M, Kemper M and Unveiling T 2018 25 years of planetary urbanization with remote sensing: perspectives from the global human settlement layer Remote Sens. 10 768

35. Malik B, Pirzadah T, Kumar M, Rehman A (2017) Biosynthesis of nanoparticles and their application in pharmaceutical industry. In: Prasad R, Kumar V, Kumar M (eds) Nanotechnology. Springer, Singapore, pp 235–252m

36. Singh M, Srivastava M, Kumar A, Pandey K (2019) Role of plant growth promoting microorganisms in sustainable agriculture and nanotechnology. Elsevier, Amsterdam

37. Sharma D, Kanchi S, Bisetty K (2019) Biogenic synthesis of nanoparticles: a review. Arab J Chem 12:3576–3600

38. Evandro B. da Silva, Wendy A. Mussoline, Ann C. Wilkie, Lena Q. Ma, Anaerobic digestion to reduce biomass and remove arsenic from As-hyperaccumulator Pteris vittata, Environmental Pollution, Volume 250, 2019, Pages 23-28, ISSN 0269-7491, https://doi.org/10.1016/j.envpol.2019.03.117. (https://www.sciencedirect.com/science/article/pii/S0269749119301964)

39. For more detailed discussion of a range of COVID-19 technologies, see Gasser, U., Ienca, M., Scheibner, J., Sleigh, J., & Vayena, E. (2020). Digital tools against covid-19: taxonomy, ethical challenges, and navigation aid. The Lancet Digital Health

40. Sako, M. (2020). Artificial intelligence and the future of professional work. Communications of the ACM, 63(4), 25–27., Kuniavsky, M. (2010). Smart Things: Ubiquitous Computing User Experience Design: Ubiquitous Computing User Experience Design. San Francisco, CA, USA: Morgan Kaufmann Publishers Inc.

41. Dillirani Nagarajan, Duu-Jong Lee, Chun-Yen Chen, Jo-Shu Chang, Resource recovery from wastewaters using microalgae-based approaches: A circular bioeconomy perspective, Bioresource Technology, Volume 302, 2020, 122817, ISSN 0960-8524, https://doi.org/10.1016/j.biortech.2020.122817. (https://www.sciencedirect.com/science/article/pii/S0960852420300869)

42. K. Chandrasekhar, Sunil Kumar, Byung-Don Lee, Sang-Hyoun Kim,Waste based hydrogen production for circular bioeconomy: Current status and future directions, Bioresource Technology, Volume 302, 2020, 122920, ISSN 0960-8524, https://doi.org/10.1016/j.biortech.2020.122920. (https://www.sciencedirect.com/science/article/pii/S0960852420301899)

43. O'Hanlon, M. Forecasting change in military technology, 2020-2040. Tech. Rep., Foreign Policy at Brookings Institution, Washington, D.C. (2018). URL https://www.brookings.edu/wp-content/uploads/2018/09/FP_20181218_defense_advances_pt2.pdf

44. New Applications for Energy Harvesting, By John Donovan, Mouser Electronics https://www.mouser.be/applications/energy-harvesting-new-applications/

45. Ling-Chin, Janie & Bao, Huashan & Ma, Zhiwei & Taylor, Wendy & Roskilly, Tony. (2019). State-of-the-Art Technologies on Low-Grade Heat Recovery and Utilization in Industry. 10.5772/intechopen.78701.

46. Yan Zhang, Pham Thi Thuy Phuong, Eleanor Roake, Hamideh Khanbareh, Yaqiong Wang, Steve Dunn, Chris Bowen, Thermal Energy Harvesting Using Pyroelectric-Electrochemical Coupling in Ferroelectric Materials, Joule, Volume 4, Issue 2, 2020, Pages 301-309, ISSN 2542-4351, https://doi.org/10.1016/j.joule.2019.12.019. (https://www.sciencedirect.com/science/article/pii/S2542435119306348)

47. Achkari Begdouri, Oussama & Fadar, A.. (2019). Latest developments on TES and CSP technologies – Energy and environmental issues, applications and research trends. Applied Thermal Engineering. 167. 114806.

48. Anna Laura Pisello, Antonella D'Alessandro, Claudia Fabiani, Alessandro Pio Fiorelli, Filippo Ubertini, Luisa F. Cabeza, Annibale Luigi Materazzi, Franco Cotana, Multifunctional Analysis of Innovative PCM-filled Concretes, Energy Procedia, Volume 111, 2017, Pages 81-90, ISSN 1876-6102, https://doi.org/10.1016/j.egypro.2017.03.010.

49. Additive Manufacturing Poised to Remake Renewable Energy, by R.P. Siegel Feb 18, 2021

50. Tran, LG., Cha, HK. & Park, WT. RF power harvesting: a review on designing methodologies and applications. Micro and Nano Syst Lett 5, 14 (2017). https://doi.org/10.1186/s40486-017-0051-0,

51. W.A. Serdijn, A.L.R. Mansano, M. Stoopman, Chapter 4.2 - Introduction to RF Energy Harvesting, Editor(s): Edward Sazonov, Michael R. Neuman, Wearable Sensors, Academic Press, 2014, Pages 299-322, ISBN 9780124186620, https://doi.org/10.1016/B978-0-12-418662-0.00019-2. (https://www.sciencedirect.com/science/article/pii/B9780124186620000192),

52. Nechibvute, Action & CHAWANDA, Albert & Taruvinga, Nicholas & LUHANGA, Pearson. (2017). Radio Frequency Energy Harvesting Sources. Acta Electrotechnica et Informatica. 17. 19-27. 10.15546/aeei-2017-0030.

53. Chongfeng Wei, Xingjian Jing, A comprehensive review on vibration energy harvesting: Modelling and realization, Renewable and Sustainable Energy Reviews, Volume 74, 2017, Pages 1-18, ISSN 1364-0321, https://doi.org/10.1016/j.rser.2017.01.073.

54. Chongfeng Wei, Xingjian Jing, A comprehensive review on vibration energy harvesting: Modelling and realization, Renewable and Sustainable Energy Reviews, Volume 74, 2017, Pages 1-18, ISSN 1364-0321, https://doi.org/10.1016/j.rser.2017.01.073.

55. Vibration energy harvesting: A review, Anwesa Mohanty, Suraj Parida, Rabindra Kumar Behera and Tarapada Roy https://doi.org/10.1142/S2010135X19300019, Journal of Advanced Dielectrics Vol. 09, No. 04, 1930001 (2019),

56. Moura, Adriane & Erturk, Alper. (2021). Leveraging size effects in flexoelectric-piezoelectric vibration energy harvesting. 10.1016/B978-0-08-102802-5.00004-2.

57. Yang, H., Bao, W., Lu, Z., Li, L., Ji, H., Huang, Y., . . . Wang, D. (2020). High-energy storage performance in BaTiO3-based lead-free multilayer ceramic capacitors. Journal of Materials Research, 1-10. doi:10.1557/jmr.2020.286,

58. Palneedi, Haribabu & Peddigari, Mahesh & Upadhyay, Ashutosh & Silva, José P. B. & Hwang, Geon & Ryu, Jungho. (2021). Lead-based and lead-free ferroelectric ceramic capacitors for electrical energy storage. 10.1016/B978-0-08-102802-5.00009-1.,

59. Wang, G., Lu, Z., Li, J. et al. (9 more authors) (2020) Lead-free (Ba,Sr)TiO3 – BiFeO3 based multilayer ceramic capacitors with high energy density. Journal of the European Ceramic Society, 40 (4). pp. 1779-1783. ISSN 0955-2219 https://doi.org/10.1016/j.jeurceramsoc.2019.12.009

60. Chayambuka, Kudakwashe & Mulder, Grietus & Danilov, Dmitri & Notten, Peter. (2020). From Li-Ion Batteries toward Na-Ion Chemistries: Challenges and Opportunities. Advanced Energy Materials. 10. 2001310. 10.1002/aenm.202001310.,

61. Dr.Shubhadra Rajpoot, Devang Pratap Singh and Prakarsh Kaushik, "Recent Advances of Nano technology in Bio Medical & Energy Sector- A Review", International Journal for Modern Trends in Science and Technology, Vol. 07, Issue 01, January 2021, pp.- 102-106.,

62. Grasso G, Zane D, Dragone R. Microbial Nanotechnology: Challenges and Prospects for Green Biocatalytic Synthesis of Nanoscale Materials for Sensoristic and Biomedical Applications. Nanomaterials (Basel). 2019;10(1):11. Published 2019 Dec 18. doi:10.3390/nano10010011

63. Haribabu Palneedi, Mahesh Peddigari, Ashutosh Upadhyay, José P.B. Silva, Geon-Tae Hwang, Jungho Ryu, Lead-based and lead-free ferroelectric ceramic capacitors for electrical energy storage, Editor(s): Deepam Maurya, Abhijit Pramanick, Dwight Viehland, In Woodhead Publishing Series in Electronic and Optical Materials, Ferroelectric Materials for Energy Harvesting and Storage, Woodhead Publishing, 2021, Pages 279-356, ISBN 9780081028025, https://doi.org/10.1016/B978-0-08-102802-5.00009-1. (https://www.sciencedirect.com/science/article/pii/B9780081028025000091)

64. González, J.A.; Andrés, J.P.; López Antón, R. Applied Trends in Magnetic Rare Earth/Transition Metal Alloys and Multilayers. Sensors 2021, 21, 5615. https://doi.org/ 10.3390/s21165615

65. Armah, Edward & Chetty, Maggie & Adedeji, Jeremiah & Kukwa, Donald & Mutsvene, Boldwin & Shabangu, Khaya & Bakare, Babatunde. (2020). Emerging Trends in Wastewater Treatment Technologies: The Current Perspective. 10.5772/intechopen.93898.

66. Annamalai J, Ummalyma SB, Pandey A, Bhaskar T. Recent trends in microbial nanoparticle synthesis and potential application in environmental technology: a comprehensive review. Environ Sci Pollut Res Int. 2021 Sep;28(36):49362-49382. doi: 10.1007/s11356-021-15680-x. Epub 2021 Jul 30. PMID: 34331227., Mandeep , Shukla Pratyoosh, Microbial Nanotechnology for Bioremediation of Industrial Wastewater, Frontiers in Microbiology, Volume 11, 2020, pages 2411, https://www.frontiersin.org/article/10.3389/fmicb.2020.590631 DOI=10.3389/fmicb.2020.590631, ISSN=1664-302X

67. Yuanyao Ye, Huu Hao Ngo, Wenshan Guo, Soon Woong Chang, Dinh Duc Nguyen, Xinbo Zhang, Jian Zhang, Shuang Liang, Nutrient recovery from wastewater: From technology to economy, Bioresource Technology Reports, Volume 11, 2020, 100425, ISSN 2589-014X, https://doi.org/10.1016/j.biteb.2020.100425. (https://www.sciencedirect.com/science/article/pii/S2589014X20300463

a. Jeffery B. Greenblatt, Daniel J. Miller, Joel W. Ager, Frances A. Houle, Ian D. Sharp, The Technical and Energetic Challenges of Separating (Photo)Electrochemical Carbon Dioxide Reduction Products, Joule, Volume 2, Issue 3, 2018, Pages 381-420, ISSN 2542-4351, https://doi.org/10.1016/j.joule.2018.01.014.

b. (https://www.sciencedirect.com/science/article/pii/S2542435118300424),

68. Bogaerts Annemie, Centi Gabriele, Plasma Technology for CO2 Conversion: A Personal Perspective on Prospects and Gaps, Frontiers in Energy Research, Volume 8, 2020, https://www.frontiersin.org/article/10.3389/fenrg.2020.00111 DOI=10.3389/fenrg.2020.00111, ISSN=2296-598X

69. Sadiya Alka, Shafinaz Shahir, Norahim Ibrahim, Mohammed Jibrin Ndejiko, Dai-Viet N. Vo, Fazilah Abd Manan, Arsenic removal technologies and future trends: A mini review, Journal of Cleaner Production, Volume 278, 2021, 123805, ISSN 0959-6526, https://doi.org/10.1016/j.jclepro.2020.123805. (https://www.sciencedirect.com/science/article/pii/S0959652620338506)

70. Rogers, A.D., Brierley, A., Croot, P., Cunha, M.R., Danovaro, R., Devey, C., Hoel, A.H., Ruhl, H.A., Sarradin, P-M., Trevisanut, S., van den Hove, S., Vieira, H., Visbeck, M. (2015) Delving Deeper: Critical challenges for 21st century deep-sea research. Larkin, K.E., Donaldson, K. and McDonough, N. (Eds.) Position Paper 22 of the European Marine Board, Ostend, Belgium. 224 pp. ISBN 978-94-920431-1-5

71. Heidemann, John & Ye, Wei & Wills, Jack & Syed, Affan & li, Yuan. (2006). Research Challenges and Applications for Underwater Sensor Networking. IEEE Wireless Communications and Networking Conference, WCNC. 1. 228 - 235. 10.1109/WCNC.2006.1683469.

72. Obilonu, A.N. & Chijioke, C. & Igwegbe, W.E. & Ibearugbulem, Ogedi & Abubakar, Y.F.. (2013). Water Quality Challenges and Impact. International Letters of Natural Sciences. 4. 44-53. 10.18052/www.scipress.com/ILNS.4.44

73. González, J.A.; Andrés, J.P.; López Antón, R. Applied Trends in Magnetic Rare Earth/Transition M 35.

74. Hoorens, Stijn, Benoit Guerin, Jeremy Ghez, Daniel Schweppenstedde, Tess Hellgren, Veronika Horvath, Marlon Graf, Barbara Janta, Samuel Drabble, and Svitlana Kobzar, Europe's Societal Challenges: An analysis of global societal trends to 2030 and their impact on the EU, Santa Monica, Calif.: RAND Corporation, RR-479-EC, 2013. As of October 18, 2021: https://www.rand.org/pubs/research_reports/RR479.htmletal Alloys and Multilayers. Sensors 2021, 21, 5615. https://doi.org/ 10.3390/s21165615

75. WilV. Srubar, Engineered Living Materials: Taxonomies and Emerging Trends, Trends in Biotechnology, Volume 39, Issue 6, 2021, Pages 574-583, ISSN 0167-7799, https://doi.org/10.1016/j.tibtech.2020.10.009. (https://www.sciencedirect.com/science/article/pii/S0167779920302730)

76. Shafiee, A., Ghadiri, E., Kassis, J. et al. Biosensing Technologies for Medical Applications, Manufacturing, and Regenerative Medicine. Curr Stem Cell Rep 4, 105–115 (2018). https://doi.org/10.1007/s40778-018-0123-y

77. Kwon, S.G., Kwon, Y.W., Lee, T.W. et al. Recent advances in stem cell therapeutics and tissue engineering strategies. Biomater Res 22, 36 (2018). https://doi.org/10.1186/s40824-018-0148-4,

78. Edward H. Ntege, Hiroshi Sunami, Yusuke Shimizu, Advances in regenerative therapy: A review of the literature and future directions,

79. Regenerative Therapy, Volume 14, 2020, Pages 136-153, ISSN 2352-3204, https://doi.org/10.1016/j.reth.2020.01.004.(https://www.sciencedirect.com/science/article/pii/S2352320420300043),

80. Liu, D., Zheng, W., Pan, S. et al. Concise review: current trends on applications of stem cells in diabetic nephropathy. Cell Death Dis 11, 1000 (2020). https://doi.org/10.1038/s41419-020-03206-1

81. Gonçalves, Giulliana & Paiva, Raquel. (2017). Gene therapy: advances, challenges and perspectives. Einstein (SÃ£o Paulo. 15. 369-375. 10.1590/s1679-45082017rb4024.

82. ACS Appl. Bio Mater. 2021, 4, 1, 122–139 Publication Date:August 7, 2020 https://doi.org/10.1021/acsabm.0c00859 ,

83. Ashammakhi, N., Hernandez, A. L., Unluturk, B. D., Quintero, S. A., de, N. R., Hoque, E., Bin, A., Ostrovidov, S., Li, J., Contag, C., Gomes, A. S., Holgado 2104149, M., Biodegradable Implantable Sensors: Materials Design, Fabrication, and Applications. Adv. Funct. Mater. 2021, 2104149. https://doi.org/10.1002/adfm.202104149,

84. Wing Li, Miaowen Jiang, Yuan Gao, Yufeng Zheng, Zhi Liu, Chen Zhou, Tao Huang, Xuenan Gu, Ang Li, Jiancheng Fang, Xunming Ji, Current status and outlook of biodegradable metals in neuroscience and their potential applications as cerebral vascular stent materials, Bioactive Materials, 2021, ISSN 2452-199X, https://doi.org/10.1016/j.bioactmat.2021.09.025. (https://www.sciencedirect.com/science/article/pii/S2452199X21004436)

85. Wang Hee Lee, Gi Doo Cha, Dae-Hyeong Kim, Flexible and biodegradable electronic implants for diagnosis and treatment of brain diseases, Current Opinion in Biotechnology, Volume 72, 2021, Pages 13-21, ISSN 0958-1669, https://doi.org/10.1016/j.copbio.2021.07.027. (https://www.sciencedirect.com/science/article/pii/S0958166921001440)

86. Melika Haji Mohammadi, Sterre Mulder, Patricia Khashayar, Alireza Kalbasi, Mostafa Azimzadeh, Amir Reza Aref, Saliva Lab-on-a-chip biosensors: Recent novel ideas and applications in disease detection, Microchemical Journal, Volume 168, 2021, 106506,ISSN 0026-265X, https://doi.org/10.1016/j.microc.2021.106506. (https://www.sciencedirect.com/science/article/pii/S0026265X21005907)

87. Aarathi Pradeep, Jeethu Raveendran, T.G. Satheesh Babu, Design, fabrication and assembly of lab-on-a-chip and its uses, Progress in Molecular Biology and Translational Science, Academic Press, 2021, ISSN 1877-1173, https://doi.org/10.1016/bs.pmbts.2021.07.021. (https://www.sciencedirect.com/science/article/pii/S1877117321001617)

88. Lab on a Chip (rsc.org)

89. Introduction to lab-on-a-chip 2020: review, history and future - Elveflow

90. Hoppe, Merja & Trachsel, Thomas. (2018). Emerging trends in transport technologies: The potential for transformation towards sustainable mobility.

91. Christine Gschwendtner, Simon R. Sinsel, Annegret Stephan, Vehicle-to-X (V2X) implementation: An overview of predominate trial configurations and technical, social and regulatory challenges, Renewable and Sustainable Energy Reviews, Volume 145, 2021, 110977, ISSN 1364-0321, https://doi.org/10.1016/j.rser.2021.110977. (https://www.sciencedirect.com/science/article/pii/S1364032121002690)

92. Akshay Ajagekar, Fengqi You, Quantum computing based hybrid deep learning for fault diagnosis in electrical power systems, Applied Energy, Volume 303, 2021, 117628, ISSN 0306-2619, https://doi.org/10.1016/j.apenergy.2021.117628. (https://www.sciencedirect.com/science/article/pii/S030626192100996X)

93. Savisha Mahalingam, Abreeza Manap, Azimah Omar, Foo Wah Low, N.F. Afandi, Chin Hua Chia, Nasrudin Abd Rahim, Functionalized graphene quantum dots for dye-sensitized solar cell: Key challenges, recent developments and future prospects, Renewable and Sustainable Energy Reviews, Volume 144, 2021, 110999, ISSN 1364-0321, https://doi.org/10.1016/j.rser.2021.110999. (https://www.sciencedirect.com/science/article/pii/S1364032121002896)

94. Dieny, B., Prejbeanu, I.L., Garello, K. et al. Opportunities and challenges for spintronics in the microelectronics industry. Nat Electron 3, 446–459 (2020). https://doi.org/10.1038/s41928-020-0461-5

95. Olivier Bethoux, 2020. „Hydrogen Fuel Cell Road Vehicles and Their Infrastructure: An Option towards an Environmentally Friendly Energy Transition," Energies, MDPI, Open Access Journal, vol. 13(22), pages 1-27, November. https://ideas.repec.org/a/gam/jeners/v13y2020i22p6132-d449464.html

96. Kellermann, Robin & Biehle, Tobias & Fischer, Liliann. (2020). Drones for parcel and passenger transportation: A literature review. 4. 100088. 10.1016/j.trip.2019.100088.https://www.researchgate.net/publication/338767975_Drones_for_parcel_and_passenger_transportation_A_literature_review

97. Grüne, Matthias & Ganz, Walter & Hermann, Sibylle & Ardilio, Antonino & Schletz, Alexander & Schirrmeister, Elna & Meissner, Svetlana & Maloca, Spomenka & Moller, Björn & Jovanović, Miloš & Schulte, Anna & Bantes, René & Welz, Juliane & Riemer, Annamaria & Döbel, Inga. (2019). Foresight Fraunhofer – Zukunftsthemen für die angewandte Forschung.

98. James A. Vedda and Karen L. Jones, Space-based solar power: a near-term investment decision, Center for Space Policy and Strategy, Space Agenda 2021, October 2020

99. Vladimir Matyushok, Vera Krasavina, Andrey Berezin & Javier Sendra García (2021) The global economy in technological transformation conditions: A review of modern trends, Economic Research-Ekonomska Istraživanja, 34:1, 1471-1497, DOI: 10.1080/1331677X.2020.1844030

100. Johnson, W. & Dahlburg, Keith & Bartolo, Bob & Dorsey, W. & Gubser, Donald & Jenkins, Phillip & Smith, Nathan & Boncyk, Wayne & Brown, Michael & Huber, David & Jaffe, Paul. (2009). Space-based Solar Power: Possible Defense Applications and Opportunities for NRL Contributions.

101. Lai, Chao-Sung & Kao, Shao-Ku. (2021). Quantum Computing Looking Forward [Highlights]. IEEE Nanotechnology Magazine. 15. 3-6. 10.1109/MNANO.2021.3063397.

102. From Li-Ion Batteries toward Na-Ion Chemistries: Challenges and Opportunities, Kudakwashe Chayambuka, Grietus Mulder, Dmitri L. Danilov and Peter H. L. Notten, Advanced Energy Materials 10 (38) 2001310 (2020), DOI: 10.1002/aenm.202001310

103. Zhao, Nan & Zhang, Shun & Yu, F. & Chen, Yunfei & Nallanathan, Arumugam. (2017). Exploiting Interference for Energy Harvesting: A Survey, Research Issues and Challenges. IEEE Access. 5. 10403-10421. 10.1109/ACCESS.2017.2705638.

104. González, Juan & Andrés, Juan & Lopez Anton, Ricardo. (2021). Applied Trends in Magnetic Rare Earth/Transition Metal Alloys and Multilayers. Sensors. 21. 5615. 10.3390/s21165615.

105. Bludyan, N. (2021). Main trends in digital transformation of passenger automobile transport. IOP Conference Series: Materials Science and Engineering. 1159. 012062. 10.1088/1757-899X/1159/1/012062.

106. Hiroyuki Akinaga 2020 Jpn. J. Appl. Phys. 59 110201, Recent advances and future prospects in energy harvesting technologies.

107. Gibson I., Rosen D., Stucker B., Khorasani M. Additive Manufacturing Technologies, 2021, ISBN : 978-3-030-56126-0

108. Chayambuka, Kudakwashe & Mulder, Grietus & Danilov, Dmitri & Notten, Peter. (2020). From Li-Ion Batteries toward Na-Ion Chemistries: Challenges and Opportunities. Advanced Energy Materials. 10. 2001310. 10.1002/aenm.202001310, 34.

109. Emerging trends in transport technologies: The potential for transformation towards sustainable mobility https://www.researchgate.net/publication/329103605_Emerging_trends_in_transport_technologies_The_potential_for_transformation_towards_sustainable_mobility

110. Christine Gschwendtner, Simon R.Sinsel, Annegret Stephan, Vehicle-to-X (V2X) implementation: An overview of predominate trial configurations and technical, social and regulatory challenges https://www.sciencedirect.com/science/article/pii/S1364032121002690

111. Pieter Vermaas, 2017, The societal impact of the emerging quantum technologies: a renewed urgency to make quantum theory understandable https://link.springer.com/article/10.1007/s10676-017-9429-1

112. Daniil Drozd, Huiyan Zhang, Irina Goryacheva, Sarah De Saeger, Natalia V. Beloglazova, Silanization of quantum dots: Challenges and perspectives, Talanta, Volume 205, 2019, 120164, ISSN 0039-9140, https://doi.org/10.1016/j.talanta.2019.120164.

113. Shinya Koshihara, Tadahiko Ishikawa, Yoichi Okimoto, Ken Onda, Ryo Fukaya, Masaki Hada, Yasuhiko Hayashi, Sumio Ishihara, Tadeusz Luty, Challenges for developing photo-induced phase transition (PIPT) systems: From classical (incoherent) to quantum (coherent) control of PIPT dynamics, Physics Reports, 2021, ISSN 0370-1573, https://doi.org/10.1016/j.physrep.2021.10.003

114. Jeong, Hoon & Lee, Eunsongyi & An, Soo-Chan & Lim, Yeonsoo & Jun, Young (2020). 3D and 4D printing for optics and metaphotonics. Nanophotonics. 9. 10.1515/nanoph-2019-0483. https://www.researchgate.net/publication/339031119_3D_and_4D_printing_for_optics_and_metaphotonics

FORESIGHT STUDIES & BUSINESS REPORTS

115. Ulrich Schmoch, Bernd Beckert, Thomas Reiß, Peter Neuhäusler, Oliver Rothengatter, Identifizierung und Bewertung von Zukunftstechnologien für Deutschland, Endbericht an die KfW Fraunhofer ISI Breslauer Str. 48 76139 Karlsruhe Karlsruhe, Dezember 2020

116. Hainsch, Karlo & Löffler, Konstantin & Burandt, Thorsten & Auer, Hans & Crespo Del Granado, Pedro & Pisciella, Paolo & Zwickl-Bernhard, Sebastian. (2021). Energy Transition Scenarios: What policies, societal attitudes, and technology developments will realize the EU Green Deal?. Energy. 239. 122067. 10.1016/j.energy.2021.122067.

117. Reid, Alasdair & Tuytens, Pieter & Miedzinski, Michal. (2013). A framework for analysing global trends and drivers in the context of designing smart specialisation strategies. 10.13140/RG.2.2.10852.17282.

118. Science & Technology Trends 2020-2040; Exploring the S&T Edge; NATO Science & Technology Organization; Copyright © NATO Science & Technology Organization, 2020 First published, March 2020 https://www.nato.int/nato_static_fl2014/assets/pdf/2020/4/pdf/190422-ST_Tech_Trends_Report_2020-2040.pdf

119. Hoorens, Stijn, Benoit Guerin, Jeremy Ghez, Daniel Schweppenstedde, Tess Hellgren, Veronika Horvath, Marlon Graf, Barbara Janta, Samuel Drabble, and Svitlana Kobzar, Europe's Societal Challenges: An analysis of global societal trends to 2030 and their impact on the EU, Santa Monica, Calif.: RAND Corporation, RR-479-EC, 2013. As of October 18, 2021: https://www.rand.org/pubs/research_reports/RR479.html

120. United Nations Industrial Development Organization, 2019. Nature-like and Convergent Technologies Driving the Fourth Industrial Revolution. Vienna. https://www.unido.org/sites/default/files/files/2020-01/Convergent%20technologies.pdf

121. Technology and Innovation Report 2021, Catching Technological Waves - Innovation With Equity, 2021-04-08; ISBN: 9789211130126. https://unctad.org/webflyer/technology-and-innovation-report-2021

122. O'Hanlon, M. Forecasting change in military technology, 2020-2040. Tech. Rep., Foreign Policy at Brookings Institution, Washington, D.C. (2018). URL https://www.brookings.edu/wp-content/uploads/2018/09/FP_20181218_defense_advances_pt2.pdf

123. United Nations 2017 General assembly resolution 71/256, New Urban Agenda A/RES/71/256 (available at: undocs.org/ en/A/RES/71/256)

124. European Commission 2018 Atlas of the human planet 2018—a world of cities EUR 29497 EN (Luxembourg: Joint Research Centre, European Commission) p JRC114316

125. Esch T et al 2017 Breaking new ground in mapping human settlements from space—The Global Urban Footprint ISPRS J. Photogramm. Remote Sens. 134 30–42

126. https://www.un.org/development/desa/en/news/population/2018-revision-of-worldurbanization-prospects.html

127. EPRS|European Parliamentary Research Service Global Trends Unit PE 627.126 -November 2018, Global Trends to 2035, DOI:10.2861/19165, batteries_europe_strategic_research_agenda_december_2020__1.pdf (europa.eu)

128. Tech Trends 2020, Deloitte Insights, Copyright © 2020 Deloitte Development LLC. All rights reserved. www.deloitte.com/insights/tech-trends

129. Roland Berger, Trend Compendium 2030, Megatrend 5 Dynamic technology & innovation October 2017; https://www.rolandberger.com/publications/publication_pdf/roland_berger_trend_compendium_2030___trend_5_dynamic_technology_and_innovation.pdf

130. Robert A. Manning, Global Trends 2030: Challenges and Opportunities for Europe The Atlantic Council, July 9, 2013. https://www.atlanticcouncil.org/wp-content/uploads/2013/07/global_trends_2030_challenge_opportunities.pdf

131. State of the IoT 2018: Number of IoT devices now at 7B – Market accelerating (iot-analytics.com)

132. https://www.iea.org/reports/world-energy-outlook-2021, Visualization RIBRI (isi-project.eu),

133. https://assets.kpmg/content/dam/kpmg/au/pdf/2021/kpmg-30-voices-on-the-future-of-energy.pdf

134. GE Renewable Energy is experimenting with 3D-printed turbine bases for taller towers By WPED Staff | June 17, 2020 (https://www.windpowerengineering.com/ge-renewable-energy-is-experimenting-with-3d-printed-turbine-bases-for-taller-towers/)

135. https://oxisenergy.com/

136. Fueling the Future of Mobility; Hydrogen and fuel cell solutions for transportation https://www2.deloitte.com/content/dam/Deloitte/cn/Documents/finance/deloitte-cn-fueling-the-future-of-mobility-en-200101.pdf

137. TechTrends2020, Deloitte Insights

    a. global_trends_2030_challenge_opportunities.pdf (atlanticcouncil.org)

138. United Nations Industrial Development Organization, 2019 United Nations Industrial Development Organization, 2019. Nature-like and Convergent Technologies Driving the Fourth Industrial Revolution. Vienna. https://www.unido.org/sites/default/files/files/2020-01/Convergent%20technologies.pdf

139. Roland Berger Trend Compendium 2050 Trend Compendium 2050: Megatrends shaping the coming decades | Roland Berger, 12 Tech Trends To Watch Closely In 2021 - CB Insights Research

140. Fore advantages, market & GMG And BOSCH sign collaboration agreement for graphene aluminium-ion battery manufacturing plant | Graphene-Info, Graphene companies: the comprehensive list | Graphene-Info

141. Graphene Market Size, Share | Industry Growth & Forecast, 2027 (alliedmarketresearch.com),

142. https://www.marketsandmarkets.com/Market-Reports/graphene-market-83933068.html

143. Full stack ahead: Pioneering quantum hardware allows for controlling up to thousands of qubits at cryogenic temperatures - Microsoft Research

144. https://www.forbes.com/sites/bernardmarr/2020/04/20/these-25-technology-trends-will-define-the-next-decade/?sh=3b08a4f929e3

145. Enabling Technologies for Industry 5.0. Results of a workshop with Europe's technology leaders.

European Commission. Directorate-General for Research and Innovation, 2020, Prosperity

146. 21st Century Trends in Space-Based Solar Power Generation and Storage, Report submitted for NASA Research Announcement: NNA15ZBP0001N-B1, Economic Research for Space Development

147. Batteries Europe Strategic Research Agenda, The European Technology and Innovation Platform on Batteries (ETIP Batteries, Batteries Europe), 3 December 2020

148. Kaushik, Dr.Shubhadra. (2021). Recent Advances of Nano technology in Bio Medical & Energy Sector- A Review. International Journal for Modern Trends in Science and Technology. 7. 102-106. 10.46501/IJMTST070124.

149. Fueling the Future of Mobility; Hydrogen and fuel cell solutions for transportation, https://www2.deloitte.com/content/dam/Deloitte/cn/Documents/finance/deloitte-cn-fueling-the-future-of-mobility-en-200101.pdf

150. Fraunhofer Trends Report, 2021. https://www.int.fraunhofer.de/de/geschaeftsfelder/corporate-technology-foresight/trend-news.html

POLICY PAPERS

151. COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN CENTRAL BANK, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE, THE COMMITTEE OF THE REGIONS AND THE EUROPEAN INVESTMENT BANK, Annual Sustainable Growth Strategy 2020; Brussels, 17.12.2019 https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2019:0650:FIN

152. Open innovation, open science, open to the world - a vision for Europe, Directorate-General for Research and Innovation (European Commission), 2016-05-17, Print: ISBN978-92-79-57345-3, doi:10.2777/552370 https://op.europa.eu/en/publication-detail/-/publication/3213b335-1cbc-11e6-ba9a-01aa75ed71a1/language-en/format-PDF/source-238485340

153. COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS, An SME Strategy for a sustainable and digital Europe, Brussels, 10.3.2020, COM(2020), 103 final, https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1593507563224&uri=CELEX:52020DC0103

154. Orientations towards the first Strategic Plan for Horizon Europe; 2019, https://www.era-learn.eu/documents/orientation_strategicplan_horizon/@@download/file/ec_rtd_orientations-he-strategic-plan_122019.pdf

155. Science, research and innovation performance of the EU, 2020,Published: 2021-03-19, Corporate author(s): Directorate-General for Research and Innovation (European Commission)https://op.europa.eu/s/tuHt

156. The Economy of Wellbeing - Draft Council Conclusions

157. Framing innovation policy for transformative change: innovation policy 3.0 Johan Schot, W. Edward Steinmuell

158. Multi-annual Action Plan 2021-2026 , June 2021"Science Europe Strategy Plan 2021-2026"

159. EUA STATEMENT The future of innovation ecosystems: recommendations from the European Smart Specialisation Workshop (https://eua.eu/resources/publications/801:the-future-of-innovation-ecosystems-recommendations-from-the-european-smart-specialisation-workshop.html)

160. COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE EUROPEAN COUNCIL, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS The European Green Deal

161. The 2018 Ageing Report, https://ec.europa.eu/info/sites/info/files/economy-finance/ip079_en.pdf

162. IEA (2021), World Energy Outlook 2021, IEA, Paris, https://www.iea.org/reports/world-energy-outlook-2021

163. batteries_europe_strategic_research_agenda_december_2020__1.pdf (europa.eu)

164. Graphene research, innovation and collaboration | Graphene Flagship (graphene-flagship.eu), http://www.timesnano.com/en/product.php?prt=3,36,63,

165. https://ribri.isi-project.eu/

166. The global water quality challenge & SDGs (unesco.org)

167. Orientations towards the first Strategic Plan for Horizon Europe; 2019, https://www.era-learn.eu/documents/orientation_strategicplan_horizon/@@download/file/ec_rtd_orientations-he-strategic-plan_122019.pdf

168. Enabling Technologies for Industry 5.0 , Results of a workshop with Europe's technology leaders, EC 2020, https://op.europa.eu/en/publication-detail/-/publication/8e5de100-2a1c-11eb-9d7e-01aa75ed71a1

169. EIC Work Programme 2021.pdf (europa.eu), page 56, United Nations Industrial Development Organization, 2019. Nature-like and Convergent Technologies Driving the Fourth Industrial Revolution. Vienna.

170. Vladimir Matyushok, Vera Krasavina, Andrey Berezin & Javier Sendra García (2021) The global economy in technological transformation conditions: A review of modern trends, Economic Research-Ekonomska Istraživanja, 34:1, 1471-1497, DOI: 10.1080/1331677X.2020.1844030

171. Wide Bandgap Technology Enhances Performance of Electric-Drive Vehicles https://www.nrel.gov/transportation/wide-bandgap-technology.html

172. Communication from the Commission to the European Parliament, The Council, The European Central Bank, The European Economic And Social Committee, The Committee of the Regions and the European Investment Bank Annual Sustainable Growth Strategy 2020; Brussels, 17.12.2019 https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2019:0650:FIN

173. EPRS | European Parliamentary Research Service. Global Trends Unit. PE 627.126 - November 2018. Global Trends to 2035. Economy and Society

174. Warnke, Philine & Cuhls, Kerstin & Schmoch, Ulrich & Daniel, Lea & Andreescu, Liviu & Dragomir, Bianca & Gheorghiu, Radu & Baboschi, Catalina & Curaj, Adrian & Parkkinen, Marjukka & Kuusi, Osmo. (2019). 100 Radical Innovation Breakthroughs for the future. 10.2777/24537.

175. ERAvsCORONA Action Plan: Working Document and First Results, available at: https://ec.europa.eu/info/files/eravscorona-action-plan-first-results_en

176. Science & Technology Trends 2020-2040; Exploring the S&T Edge; NATO Science & Technology Organization NATO Science & Technology Organization, 2020 First published, March 2020 https://www.nato.int/nato_static_fl2014/assets/pdf/2020/4/pdf/190422-ST_Tech_Trends_Report_2020-2040.pdf

177. Orientations towards the first Strategic Plan for Horizon Europe; 2019, https://www.era-learn.eu/documents/orientation_strategicplan_horizon/@@download/file/ec_rtd_orientations-he-strategic-plan_122019.pdf

178. Wide Bandgap Technology Enhances Performance of Electric-Drive Vehicles https://www.nrel.gov/transportation/wide-bandgap-technology.html

ANNEX 1. TRENDS ASSESSMENT BY EXPERTS

ENERGY

Trend

FIBRES.

Solar energy

Expert's comments:
It will impact especially energy sector, but also others e.g. manufacturing sector which requires a lot of energy

Sources:
Why the EU supports solar energy rese...
https://www.seia.org/
https://www.globalsolarcouncil.org/
Achkari Begdouri, Oussama & Fadar, A....

Impact Assessment

Time to impact	Area Domamain	Impact Strenght
■ 0-5 years	■ Energy	Low
5-10 years	Earth and Environment	■ Medium
10+ years	Life and Health	High
	Transport	
	Quantum Materials for IT	
	Cross-cuting trend	

Trend

FIBRES.

Batteries

Experts' comments:
- Classical material science most crucial in battery research - far more important than system evaluation or digital twins. Potentially impacted economic sector: most importantly mobility (cars) and, potentially, large-scale energy storage. scientific areas: electrochemistry & material science.
- There will be some convergence between engineering and material science when it comes to

Sources:
Science & Technology Trends 2020-2040
Chayambuka, Kudakwashe & Mulder, Grie...
GMG And BOSCH sign collaboration agre...
https://oxisenergy.com/

Impact Assessment

Time to impact	Area Domamain	Impact Strenght
■ 0-5 years	■ Energy	Low
5-10 years	Earth and Environment	Medium
10+ years	Life and Health	■ High
	Transport	
	Quantum Materials for IT	
	Cross-cuting trend	

Trend

FIBRES.

Green Energy and Bio-Energy

Sources:
100 RADICAL INNOVATION BREAKTHROUGHS ...
Kumar, Gopalakrishnan & Lay, Chyi-How...
EIC Work Programme 2021
Sparc Technologies to develop an ultr...

Impact Assessment

Time to impact	Area Domamain	Impact Strenght
0-5 years	■ Energy	Low
■ 5-10 years	Earth and Environment	■ Medium
10+ years	Life and Health	High
	Transport	
	Quantum Materials for IT	
	Cross-cuting trend	

Trend

FIBRES.

Additive Manufacturing for renewable energy

Sources:
https://www.sculpteo.com/en/3d-learni...
GE Renewable Energy is experimenting ...
Multifunctional Analysis of Innovativ...
Gibson I., Rosen D., Stucker B., Khor...

Impact Assessment

Time to impact
- [ ] 0-5 years
- [x] 5-10 years
- [ ] 10+ years

Area Domamain
- [x] Energy
- [ ] Earth and Environment
- [ ] Life and Health
- [ ] Transport
- [ ] Quantum Materials for IT
- [ ] Cross-cuting trend

Impact Strenght
- [ ] Low
- [ ] Medium
- [x] High

Trend

FIBRES.

Thermal Energy

Sources:
https://www.german-energy-solutions.d...
Ling-Chin, Janie & Bao, Huashan & Ma,...
World Energy Outlook 2021
Maiwa, Hiroshi. (2019). Thermal energ...

Impact Assessment

Time to impact
- [ ] 0-5 years
- [ ] 5-10 years
- [x] 10+ years

Area Domamain
- [x] Energy
- [ ] Earth and Environment
- [ ] Life and Health
- [ ] Transport
- [ ] Quantum Materials for IT
- [ ] Cross-cuting trend

Impact Strenght
- [x] Low
- [ ] Medium
- [ ] High

Trend

FIBRES.

Other trends in energy harvesting

Sources:
Kishore, Ravi. (2021). Harvesting th...
Tran, LG., Cha, HK. & Park, WT. RF po...
Sirohi, Jayant. (2021). Wind energy h...
Chongfeng Wei, Xingjian Jing, A compr...

Impact Assessment

Time to impact
- [x] 0-5 years
- [ ] 5-10 years
- [ ] 10+ years

Area Domamain
- [x] Energy
- [ ] Earth and Environment
- [ ] Life and Health
- [ ] Transport
- [ ] Quantum Materials for IT
- [ ] Cross-cuting trend

Impact Strenght
- [ ] Low
- [ ] Medium
- [x] High

Trend

FIBRES.

Biodiversity / species extinction

Experts' comments:

The greatest force next to climate change shaping humanities future

Sources:
https://www.nature.org/en-us/newsroom...

Impact Assessment

Time to impact	Area Domamain	Impact Strenght
■ 0-5 years	Energy	Low
5-10 years	■ Earth and Environment	Medium
10+ years	Life and Health	■ High
	Transport	
	Quantum Materials for IT	
	Cross-cuting trend	

Trend

FIBRES.

Wastewater

Experts' comments:

- Water will be an even more important resource in a few years. Not only clean water, but also harvesting water ingredients, like phosphates or rare metals. Water purification and filtering ingredients most efficiently works with membranes. Thus, this field is highly important.
- Megatrend: desalination, wastewater treatment, low-cost water treatment, removal of bioactive molecules in low conc., water table management

Sources:
100 Radical Innovation Breakthroughs ...
Annamalai J, Ummalyma SB, Pandey A, B...
Yuanyao Ye, Huu Hao Ngo, Wenshan Guo,...
Real-scale chlorination at pH4 of BW3...

Impact Assessment

Time to impact	Area Domamain	Impact Strenght
■ 0-5 years	Energy	Low
5-10 years	■ Earth and Environment	Medium
10+ years	Life and Health	■ High
	Transport	
	Quantum Materials for IT	
	Cross-cuting trend	

Trend

FIBRES.

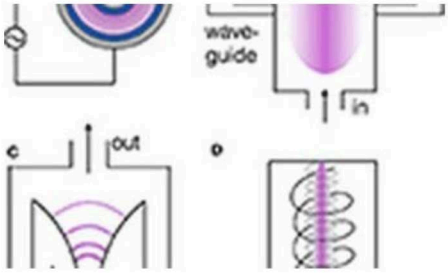
Water quantity and scarcity

Urban Transformation - Blue infrastructure - natural water balance - intelligent irrigation (KI-Big Data etc.) The amount of available water will change in the future. This is due on the one hand to climate change, but also to increasing demands for a green hydrogen economy and the production of food.

Sources:
Green hydrogen
If we don't change our habits now, gl...

Impact Assessment

Time to impact	Area Domamain	Impact Strenght
■ 0-5 years	Energy	Low
5-10 years	■ Earth and Environment	Medium
10+ years	Life and Health	■ High
	Transport	
	Quantum Materials for IT	
	Cross-cuting trend	



Trend

FIBRES.

Splitting Carbon dioxide (CO2)

Sources:
Plasma Technology for CO2 Conversion:...
The Technical and Energetic Challenge...
100 radical innovation breakthroughs ...

Impact Assessment

Time to impact	Area Domamain	Impact Strenght
0-5 years	Energy	Low
5-10 years	**Earth and Environment**	**Medium**
10+ years	Life and Health	High
	Transport	
	Quantum Materials for IT	
	Cross-cuting trend	

Trend

FIBRES.

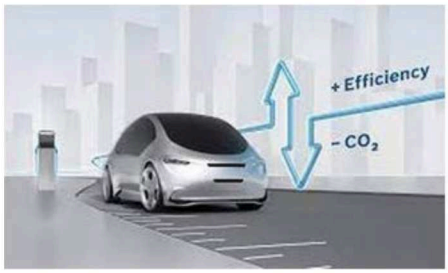
Underwater living

Sources:
100 radical innovation breakthroughs ...
Rogers, A.D., Brierley, A., Croot, P....
Heidemann, John & Ye, Wei & Wills, Ja...

Impact Assessment

Time to impact	Area Domamain	Impact Strenght
0-5 years	Energy	**Low**
5-10 years	**Earth and Environment**	Medium
10+ years	Life and Health	High
	Transport	
	Quantum Materials for IT	
	Cross-cuting trend	

TRANSPORT



Trend

FIBRES.

Electric-Drive Vehicles

Experts' comments:
The most empacted economic sectors: OEM and supplier; transport of any kind (logistics, public passenger, ...); energy providers

Sources:
Wide Bandgap Technology Enhances Perf...

Impact Assessment

Time to impact	Area Domamain	Impact Strenght
0-5 years	Energy	Low
5-10 years	Earth and Environment	Medium
10+ years	Life and Health	**High**
	Transport	
	Quantum Materials for IT	
	Cross-cuting trend	

Trend

Intelligent Transport Systems (ITS)

Sources:
Vehicle-to-X (V2X) implementation: An...

Impact Assessment

Time to impact	Area Domamain	Impact Strenght
0-5 years	Energy	Low
5-10 years	Earth and Environment	Medium
10+ years	Life and Health	High
	Transport	
	Quantum Materials for IT	
	Cross-cuting trend	

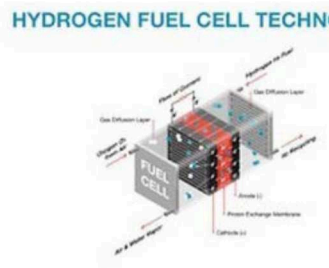
Trend

Drones

Sources:
100 Radical Innovation Breakthroughs ...
Drones for parcel and passenger trans...

Impact Assessment

Time to impact	Area Domamain	Impact Strenght
0-5 years	Energy	Low
5-10 years	Earth and Environment	Medium
10+ years	Life and Health	High
	Transport	
	Quantum Materials for IT	
	Cross-cuting trend	



Trend

Hydrogen fuel cell technology

Experts' comments:

- All manufacturing companies thinking about new ways of how to provide the energy resources

Sources:
100 radical innovation breakthroughs ...
Hydrogen Fuel Cell Road Vehicles and ...

Impact Assessment

Time to impact	Area Domamain	Impact Strenght
0-5 years	Energy	Low
5-10 years	Earth and Environment	Medium
10+ years	Life and Health	High
	Transport	
	Quantum Materials for IT	
	Cross-cuting trend	

LIFE AND HEALTH

Trend

FIBRES.

Soil / land degradation

erosion, desertification,

Impact Assessment

Time to impact	Area Domamain	Impact Strenght
■ 0-5 years	Energy	Low
5-10 years	Earth and Environment	Medium
10+ years	■ Life and Health	■ High
	Transport	
	Quantum Materials for IT	
	Cross-cuting trend	

Trend

FIBRES.

Water quality

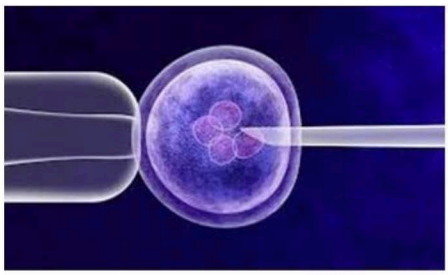
Sources:

Obilonu, A.N. & Chijioke, C. & Igwegb...

Thin film composite membrane compacti...

Impact Assessment

Time to impact	Area Domamain	Impact Strenght
■ 0-5 years	Energy	Low
5-10 years	Earth and Environment	Medium
10+ years	■ Life and Health	■ High
	Transport	
	Quantum Materials for IT	
	Cross-cuting trend	



Trend

FIBRES.

Cell (e.g. CAR-T) & Gene-therapy (e.g. Genome Editing Technologies)

Sources:

Nature-like and Convergent Technologi...

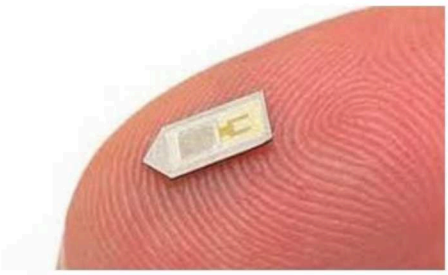
100 Radical Innovation Breakthroughs ...

Engineered Living Materials: Taxonomi...

Biosensing Technologies for Medical A...

Impact Assessment

Time to impact	Area Domamain	Impact Strenght
0-5 years	Energy	Low
■ 5-10 years	Earth and Environment	■ Medium
10+ years	■ Life and Health	High
	Transport	
	Quantum Materials for IT	
	Cross-cuting trend	



Trend

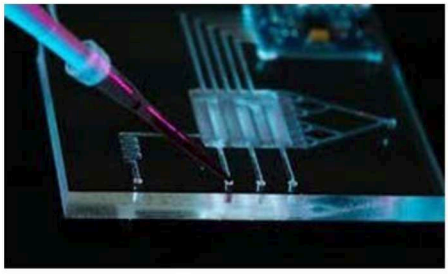
Biodegradable sensors

FIBRES.

Sources:
100 Radical Innovation Breakthroughs ...
Wearable and Biodegradable Sensors fo...
Biodegradable Implantable Sensors: Ma...
Current status and outlook of biodegr...

Impact Assessment

Time to impact	Area Domamain	Impact Strenght
0-5 years	Energy	Low
5-10 years	Earth and Environment	Medium
10+ years	Life and Health	High
	Transport	
	Quantum Materials for IT	
	Cross-cuting trend	



Trend

Lab-on-a-chip

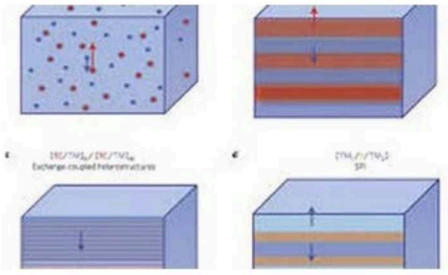
FIBRES.

Sources:
Introduction to lab-on-a-chip 2020: r...
Saliva Lab-on-a-chip biosensors: Rece...
Design, fabrication and assembly of l...
Lab on a Chip

Impact Assessment

Time to impact	Area Domamain	Impact Strenght
0-5 years	Energy	Low
5-10 years	Earth and Environment	Medium
10+ years	Life and Health	High
	Transport	
	Quantum Materials for IT	
	Cross-cuting trend	

QUANTUM MATERIALS



Trend

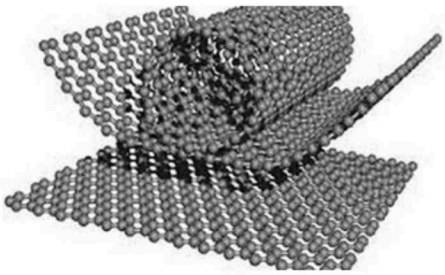
Multilayers, e.g., Ferrimagnetic thin films

FIBRES.

Sources:
Narrow-band tunable terahertz emissio...

Impact Assessment

Time to impact	Area Domamain	Impact Strenght
0-5 years	Energy	Low
5-10 years	Earth and Environment	Medium
10+ years	Life and Health	High
	Transport	
	Quantum Materials for IT	
	Cross-cuting trend	



Trend

FIBRES.

Carbon nano-tubes

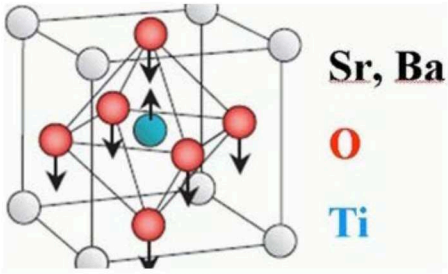
Experts' comments:

- Possibly the electronics market could benefit, very difficult to see a marketable application currently.

Sources:
http://www.timesnano.com/en/product.p...
Conical Nanotubes Synthesized by Atom...

Impact Assessment

Time to impact	Area Domamain	Impact Strenght
0-5 years	Energy	Low
■ 5-10 years	Earth and Environment	Medium
10+ years	Life and Health	■ High
	Transport	
	■ Quantum Materials for IT	
	Cross-cuting trend	



Trend

FIBRES.

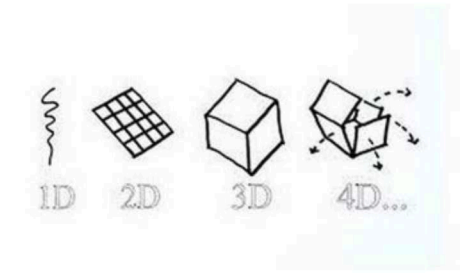
Ferroelectrics as a means of computer storage

Sources:
https://www.haptic.ro/using-ferroelec...
Enhancing the Energy Density of Tricr...
9 - Lead-based and lead-free ferroele...

Impact Assessment

Time to impact	Area Domamain	Impact Strenght
0-5 years	Energy	■ Low
5-10 years	Earth and Environment	Medium
■ 10+ years	Life and Health	High
	Transport	
	■ Quantum Materials for IT	
	Cross-cuting trend	

CROSS-CUTTING TRENDS



Trend

FIBRES.

3D & 4D printing

Experts' comments:

- Potentially impacted scientific areas: Materials Science/Materials Informatics (in combination with Artificial Intelligence); Economic Sectors: Manufacturing, Engineering, Aerospace, Automotive.
- Sectors: manufacturing, automotive, aerospace. Being in contact with a 3D printing startup, I know that they're still struggling very much. As of now, the technology is not seen as sufficiently proven by the incumbents and prices are not yet competitive. Thus, it will depend on the progress regarding price and quality if the technology enters mainstream industry

Sources:
Poper R., Oksanen J., Virkkunen M., R...
100 Radical Innovation Breakthroughs ...
3D and 4D printing for optics and met...
On the digital twin application and t...

Impact Assessment

Time to impact	Area Domamain	Impact Strenght
0-5 years	Energy	Low
■ 5-10 years	Earth and Environment	■ Medium
10+ years	Life and Health	High
	Transport	
	Quantum Materials for IT	
	■ Cross-cuting trend	

Trend

FIBRES.

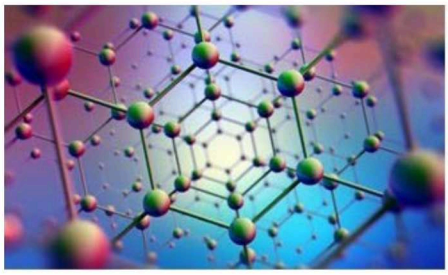
Artificial Intelligence

Experts' comments:
AI will help in new materials development and support the understanding of materials properties. In a few years, materials & product development in industry will not work without AI.
It will be hard to find any economic & scientific sectors that will not be potentially impacted by AI in 10-15 years. The one that will be impacted most/first are sectors that are data-rich and have a huge combinatorial search space ...
Most industries will be affected. While some companies will use it for product development/quality improvement (e.g., when selling wood), ...

Sources:
https://www.nature.com/articles/s4159...
Kendrew Lecture 2021 pt1 - Using AI t...
McKinsey Global Survey - The state of...
Physics-informed machine learning

Impact Assessment

Time to impact	Area Domamain	Impact Strenght
☐ 0-5 years	☐ Energy	☐ Low
■ 5-10 years	☐ Earth and Environment	☐ Medium
☐ 10+ years	☐ Life and Health	■ High
	☐ Transport	
	☐ Quantum Materials for IT	
	■ Cross-cuting trend	



Trend

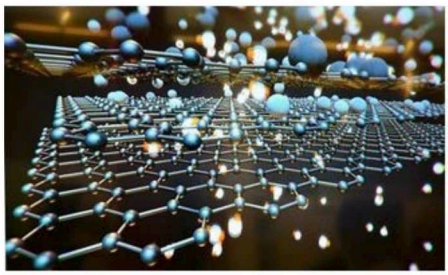
FIBRES.

Nanotechnologies

Experts' comments:
Most impact is expected in nanomedicine & personalized with huge economic impact in 10-15 years.
Nanotechnology does already and will play a role in many economic sectors. Most importantly electronics/opto-electronics and medicine, but also in applications where "surfaces" play a role.

Impact Assessment

Time to impact	Area Domamain	Impact Strenght
☐ 0-5 years	☐ Energy	☐ Low
■ 5-10 years	☐ Earth and Environment	■ Medium
☐ 10+ years	☐ Life and Health	☐ High
	☐ Transport	
	☐ Quantum Materials for IT	
	■ Cross-cuting trend	



Trend

FIBRES.

Graphene-based technologies

Sources:
https://graphene-flagship.eu/
Graphene Market Outlook - 2020–2027
100 radical innovation breakthroughs ...
Graphene

Impact Assessment

Time to impact	Area Domamain	Impact Strenght
☐ 0-5 years	☐ Energy	☐ Low
☐ 5-10 years	☐ Earth and Environment	■ Medium
■ 10+ years	☐ Life and Health	☐ High
	☐ Transport	
	☐ Quantum Materials for IT	
	■ Cross-cuting trend	

ASSESSMENT OF TRENDS BY CATEGORY

Trends	Time to Impact	Impact Strength	Certainty Level	Trend Label	Scientific Background	Political and Legal	TRL Level	Market Uptake	Economic Impact	Addressing SDG
Batteries	0-5 years	High	Certain	Emerging	High	Conducive	High	Very High	Very High	Very High
Green and Bio-Energy	5-10 years	Medium	Certain	Convergent	Sufficient	Supporting	Sufficient	High	Moderate	Moderate
Solar energy	0-5 years	Medium	Certain	Emerging	High	Supporting	Very High	High	High	High
Thermal Energy	+10 years	Low	Uncertain	-	-	-	-	-	-	-
Additive Manufacturing	5-10 years	High	Certain	Emerging	Sufficient	Supporting	High	High	High	High
Energy harvesting	0-5 years	High	Uncertain	Disruptive	High	Neutral	Low	High	High	High
Biodiversity extinction	0-5 years	High	Certain	Disruptive	Very High	Neutral	Very High	Very High	Very High	Very High
Wastewater	0-5 years	High	Certain	Disruptive	Sufficient	Supporting	Sufficient	High	High	Very High
Water scarcity	0-5 years	High	Certain	Emerging	Sufficient	Supporting	Very High	Low	High	High
Underwater living	+10 years	Low	+Uncertain	Emerging	Low	Neutral	Low	Low	Low	Moderate
Splitting Carbon dioxide	+10 years	Medium	Uncertain	Disruptive	High	Supporting	High	High	High	High
Electric-Drive Vehicles	0-5 years	High	Certain	Emerging	High	Supporting	High	High	Very High	High
Intelligent transport Systems	5-10 years	High	Uncertain	Emerging	High	Neutral	Sufficient	High	High	High
Drones	5-10 years	Medium	Certain	Emerging	High	Supporting	High	High	High	High
Hydrogen-fuel cell tech	5-10 years	Medium	Uncertain	Emerging	Sufficient	Supporting	Sufficient	High	High	High
Cell & Gene-therapy	5-10 years	Medium	Uncertain	Emerging	High	Neutral	High	High	High	Moderate
Soil/land degradation	0-5 years	High	Certain	-	-	-	-	-	-	-
Water quality	0-5 years	High	Certain	-	High	Neutral	High	High	High	High
Biodegradable sensors	5-10 years	Medium	Uncertain	Emerging	High	Neutral	Sufficient	Sufficient	High	High
Lab-on-a-chip	5-10 years	Medium	Uncertain	Emerging	Sufficient	Neutral	Sufficient	High	Moderate	Moderate
Multilayers	0-5 years	High	Certain	Convergent	High	Supporting	Very High	High	High	High
Carbon nano-tubes	5-10 years	High	Uncertain	Convergent	High	Supporting	Very High	High	Moderate	Moderate
Ferroelectrics	+10 years	Low	Uncertain	Emerging	Sufficient	Neutral	Low	Low	Moderate	Low
Graphene-based tech.	+10 years	Medium	Uncertain	Emerging	High	Neutral	Sufficient	Sufficient	Moderate	Moderate
Artificial Intelligence	5-10 years	High	Wildcard	Disruptive	High	Supporting	Sufficient	Very High	Very High	High
Nanotechnologies	5-10 years	Medium	Certain	Disruptive	Very High	Neutral	High	Sufficient	High	High
3D & 4D printing	5-10 years	Medium	Uncertain	Emerging	Sufficient	Neutral	Sufficient	Sufficient	Moderate	Moderate

CONTACT

Deutsches Elektronen-Synchrotron DESY
Innovation & Technologietransfer

Miriam Hufnagl, Advisor Policy & Impact
T: 0 40 – 8998 4818
E: miriam.hufnagl@desy.de
Web: innovation.desy.de
Notkestr. 85 I 22607 Hamburg