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Technical Note 3:
Broadcast Scan

Disruptive Technology Search for Space Applications

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DISRUPTIVE SPACE TECHNOLOGIES

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References

[RD 1] von Hippel, E. (1988). The sources of innovation. New York: Oxford University Press.

[RD 2] Moore, Geoffrey A. (1991). Crossing the Chasm. Harper Business Essentials.

[RD 3] Andersen, L. S. (2007). Book Report of Crossing the Chasm by Geoffrey Moore. Innovation Center Denmark, Silicon Valley.

[RD 4] Rogers, E. M. (2003). Diffusion of innovations (5th ed.). New York: Free Press.

[RD 5] von Hippel, E. (2005). Democratizing Innovation. Cambridge, Massachusetts: MIT Press.

[RD 6] von Hippel, E., Thomke, S., & Sonnack, M. (1999). Creating Breakthroughs at 3M. Harvard Business

[RD 7] Gerrish, J. M., & Blei, D. M. (2010). A Language-based Approach to Measuring Scholarly Impact. Princeton: Princeton University.

[RD 8] Network representation of co-citation patterns among 155 human information behaviour papers. Retrieved January 27, 2012, from http://informationr.net/ir/10-2/paper220.html

[RD 9] Giles, J. (2011, April 18). Innovationsfindung per Algorithmus. Heise online. Retrieved May 18, 2011, from http://www.heise.de/tr/artikel/Innovationsfindung-per-Algorithmus-1229085.html

[RD 10] Tyler, R. (2011, February 06). Technology entrepreneurs are driving UK towards recovery. Retrieved June 07, 2011, from The Telegraph. http://www.telegraph.co.uk/finance/yourbusiness/8304525/Technology-entrepreneurs-are-driving-UK-towards-recovery.html

[RD 11] Interview with Zachary Auger from Quid on 11.08.2011

[RD 12] Hunt, D. & Rodgers M. (2007). Patent searching: tools & techniques. John Wiley & Sons, Inc.

[RD 13] Fellegi, I. P. (2010). Survey Methods and Practices. Statistics Canada.

[RD 14] Global 500 2011. (n.d.). Retrieved July 03, 2011, from CNN Money: http://money.cnn.com/magazines/fortune/global500/2011/index.html

[RD 15] World University Rankings 2011-2012. (n.d.). Retrieved July 03, 2011, from Times Higher Education: http://www.timeshighereducation.co.uk/world-university-rankings/

[RD 16] Ranking Web of World Research Centers. (n.d.). Retrieved July 3, 2011, from Webometrics: http://research.webometrics.info/

[RD 17] Fingerman, K.L. & Perlmutter, M. (1995) Future time perspective and life events across adulthood. Journal of General Psychology, vol 122, 95-111.

[RD 18] Clarke, A.C. (1962) Hazards of Prophecy: The Failure of Imagination, Profiles of the Future: An Enquiry into the Limits of the PossibleGantz, J. F., et al. (2008). The Diverse and Exploding Digital Universe – An updated forecast of worldwide Information growth through 2011. IDC.

[RD 19] Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions of 30 September 2009 – "Preparing for our future: Developing a common strategy for key enabling technologies in the EU"

[RD 20] Giannopapa, C. (2010) Key Enabling Technologies and Open Innovation, European Space Policy Institute (ESPI) report

[RD 21] National Aeronautics and Space Administration (2010) DRAFT Nanotechnology Roadmap Technology Area 10

[RD 22] R.S. Trask, G.J. Williams and I.P. Bond. Bioinspired and Biomimetic Self-Healing of Advanced Composite Materials. Dept. of Aerospace Engineering, University of Bristol, Queens Building, University Walk, Bristol, BA8 1TR, UK.

[RD 23] Biological Diversity (Article 2. Use of Terms) European Union Retrieved July 03, 2011, from http://bch.cbd.int/protocol/nkl/article2/

[RD 24] National Aeronautics and Space Administration. Building a Space Age Stethoscope - Biological Monitoring Challenge Retrieved July 03, 2011, from http://www.nasa.gov/vision/earth/technologies/stethoscope.html

[RD 25] Anne L. Fischer (2009) Solar from space. Article: http://www.photonics.com/Article.aspx?AID=38677

[RD 26] NASA Developing Space Laser Communications. Article: http://www.tititudorancea.com/z/space_laser_communications.htm

[RD 27] Ray Sanders (2011) NASA to Test Laser Communications System. Article: http://www.universetoday.com/89801/nasa-to-test-laser-communications-system

[RD 28] National Aeronautics and Space Administration, Center for Space Microelectronics Technology. NASA Facts

[RD 29] VDI Technology Center, Future Technologies Division (2003) Applications of Nanotechnology in Space Developments and Systems. Düsseldorf

[RD 30] High Level Group on Key Enabling Technologies. Mastering and deploying Key Enabling Technologies (KETs): building the bridge to pass across the KETs "Valley of death" for future European innovation and competitiveness.

[RD 31] European Commission for Enterprise and Industry. ICT for Competitiveness & Innovation Source: http://ec.europa.eu/enterprise/sectors/ict/index_en.htm

[RD 32] OECD Publishing (2004) Space 2030: Exploring the Future of Space Applications

[RD 33] Meyyappan M. (2006) Why Nanotechnology at NASA? NASA Ames Research Center Moffett Field, CA. Source: http://www.ipt.arc.nasa.gov/nanotechnology.html

[RD 34] Commission of the European Communities (2009) Responding to the crisis in the European automotive industry. Brussels

[RD 35] Enabling the future: NASA call for exploration revolution via NIAC concepts. Retrieved July 03, 2011, from http://www.nasaspaceflight.com/2012/01/enabling-future-nasa-call-exploration-revolution-niac-concepts/

[RD 36] Trott, P. (2005) Innovation Management and new Product Development. 3rd edition. FT/Prentice hall

List of Abbreviations

AHP	Analytic Hierarchy Process
DLR	German Aerospace Center (Deutsches Zentrum für Luft- und Raumfahrt)
DST	Disruptive Space Technology
DSTs	Disruptive Space Technologies
DT	Disruptive Technology
ESA	European Space Agency
ICT	Information and Communication Technology
MTR	Mid-Term Review
RD	Reference Document
STEP	Social, Technical, Economic and Political
SMT	Scanning, Monitoring and Tracking
TN	Technical Note
WP	Work Package

Executive Summary

This Technical Note (TN) documents on Work Package 4000, which is the *Broadcast Scan.* The aim of this work package is the creation of a search strategy, identify spin-in markets, scan for potential DSTs and perform a pre-selection for further evaluation. It fits within the overall research as the search strategy development part, highlighted in the overall structure of the research, depicted in Figure 1. In this figure, the second chapter covers the Search Method and Techniques Review part in which various technology search methods are reviewed and evaluated. The third chapter focusses on DST Market Identification, in which several external markets are investigated which are of high interest to the space sector. The fourth chapter involves the creation of a DST Search Strategy in which a strategy is devised to identify potential DSTs and store them into a custom designed database. The fifth chapter documents upon the pre-selection of the identified technologies, these criteria are based on the AHP method and the STEP-Criteria explained in TN02. These chapters are elaborated in more detail below.

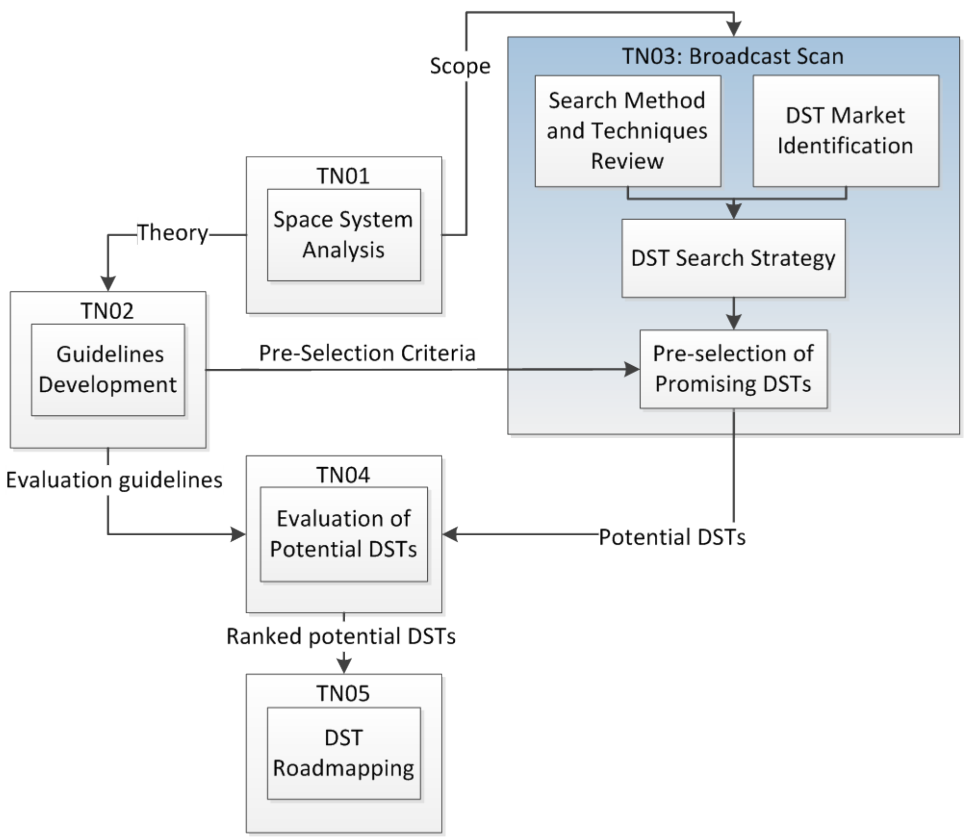


Figure 1: Overall structure of research

Chapter 2: Search Method and Techniques Review

Within this chapter, several common search methods and techniques used for technology identification are analyzed and evaluated. The key features, advantages and disadvantages of every method and technique are described and rated to evaluate which method is most suitable for identifying potential DSTs. The following technology search methods and techniques are described:

- Lead User Method
- Bibliometrics
- Innovation Algorithms
- Patent Search
- Survey-based Data Collection

Table 2-1 shows the key features, advantages and disadvantages of each method. Based on this analysis, a selection of methods for the search strategy of DSTs is made. This selection includes the Bibliometrics and Survey based data collection methods. In addition, the recommendation is given to use innovation algorithms, once they are further developed.

Table 1: Summary of pros, cons and key features.

	Key Features	Advantages	Disadvantages
Lead User Method	Identifies needs of Lead Users to identify future technology trends	Can identify technology needs and therefore opportunities for disruptiveness	Not applicable for small specialized domains like the space sector
Bibliometrics	Searches in a collection of websites articles and papers for relevant information	Can detect most influential documents in a collection. Provides a fast and extensive dataset	Due to a very large dataset, it is highly time consuming to search, without resorting to restrictive keywords
Innovation Algorithms	Uses many different information sources and its own algorithm	Can identify sources for crosscutting technology developments	Non-Public algorithms are used and the results cannot be verified
Patent Search	Searches technology development through larga databases	Is a large source of data and provide information on early stage technology developments	Very time consuming as it is hard to identify DSTs with keywords
Survey-based Data Collection	Enables the gathering of opinions from many experts from all over the world	Allows for the collection of ideas from many different experts and working fields	Requires many experts to participate so a high amount of experts need to be inquired for their cooperation / Bias might effect answers of experts

Chapter 3: DST Market Identification

This chapter elaborates on the process of technology spin-in with respect to the space sector. Spin-in markets for potential DSTs are identified and analyzed on their relevance to the space sector. The following markets have been identified as potential spin-in markets in TN01 (Section 3.3):

- Advanced Materials
- Biotechnology
- Photonics
- Nanotechnology

- Microelectronics
- Information and Communication Technology (ICT)
- Robotics
- Automotive

Figure 3-3 shows relationship circles between the space sector and the potential spin-in technology markets. Especially emerging high technology fields such as nanotechnologies, biotechnologies, and information and communication technologies have a high potential to be a possible source for DSTs. These are fast growing sectors, which are quick in introducing innovative products on the market and frequently employ a more breakthrough or game changing approach to technology development.

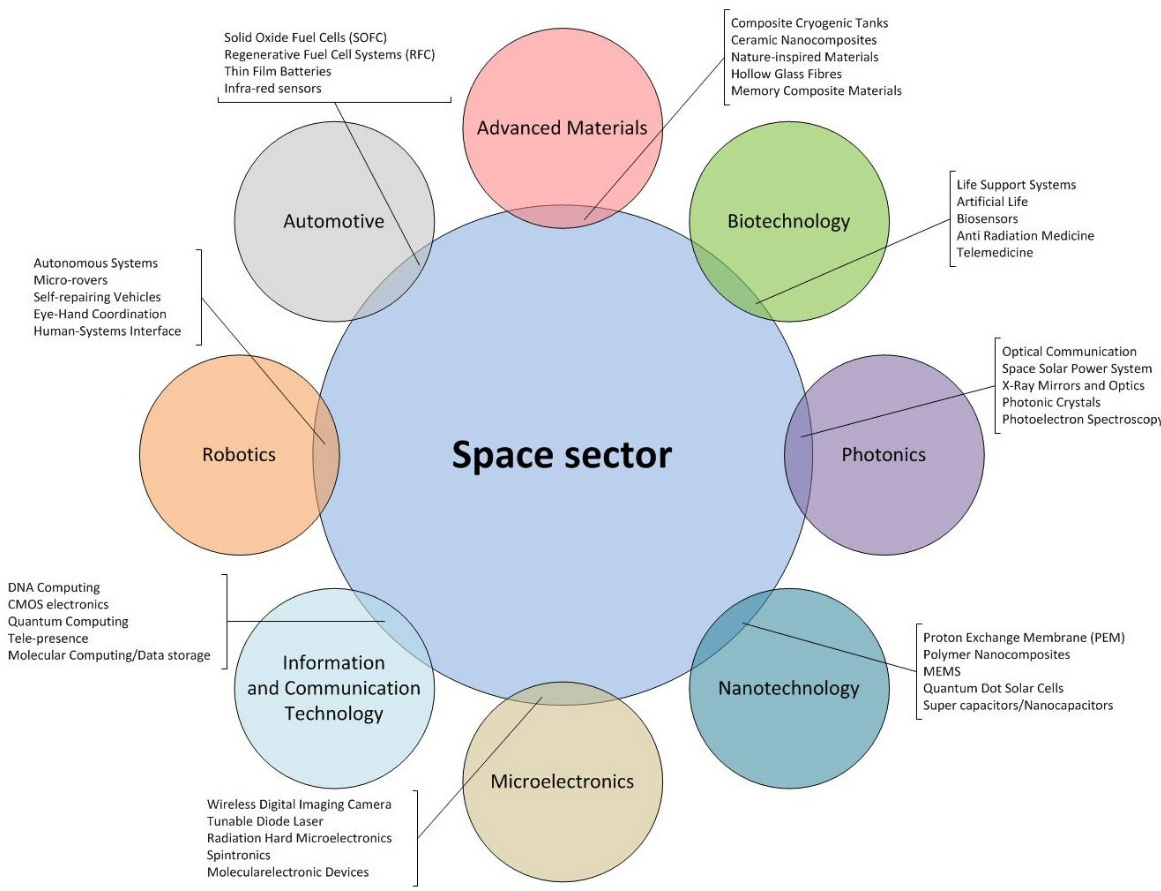


Figure 2: Relationship circles between Spin-in markets and the Space sector

Chapter 4: DST Search Strategy

Within this chapter, the DST search strategy is explained in detail. This strategy is used to identify potential DSTs inside and outside of the space sector. The search of potential DSTs outside of the space sector involves the areas researched in Chapter 3. In general, the search strategy depends on a search in space technology databases, desk research & literature research (bibliometrics), and an expert survey. These elements and their relations are illustrated in Figure 4-1.

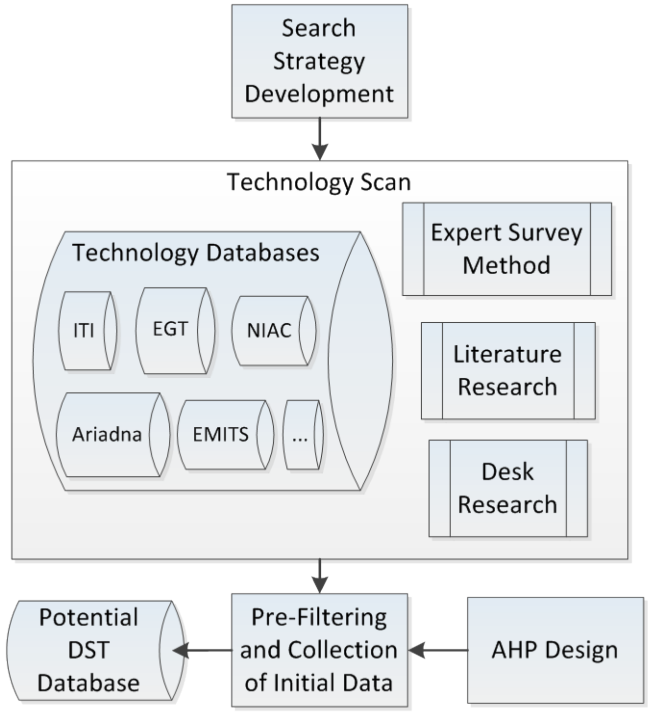


Figure 3: Search strategy overview

The technologies found in these sources are included in the potential DST database if they show a sufficient potential for disruptiveness. A potential for disruptiveness of a technology is determined by its conformity to the theory of DST elaborated in TN01, Chapter 2. This arbitrary selection is done by DST project members and is necessary to deal with the vast amounts of technologies resulting from the search.

Chapter 5: Pre-selection of promising DSTs

Based on Chapter 5.1 of TN02, the AHP is used to establish a pre-selection of promising DSTs, narrowing down the candidates present in the database to a more manageable amount as part of the funneling (TN02, Section 5.2). The evaluation method utilizes a funneling approach because evaluating every technology within the database on basis of the Delphi Method (which is elaborated upon in TN04) would be overly time consuming. The process was performed using the DST project members together with several distinguished experts within various fields of expertise. The resulting technologies are described at the end of the Chapter.

The technologies found in the pre-selection are offered to ESA for selection. This has been done to make sure ESA conforms with the selected technologies and that there is a no double evaluation. The selected technologies are elaborated in TN04 and are futher evaluated there using the Delphi Method and a supporting desk research.

1 Introduction

The main purpose of Work Package 4000 of the *Broadcast Scan* of Project 4000101818/10/NL/GLC is: creating a search strategy, identifying spin-in markets, scanning for potential DSTs and performing a pre-selection. It fits within the overall research as the search strategy development part, highlighted in the overall structure of the research, depicted in Figure 1-1. In this Technical Note (TN), only a first identification and pre-selection of technologies is made. The selected technologies are further evaluated in WP5000, which is documented upon in TN04.

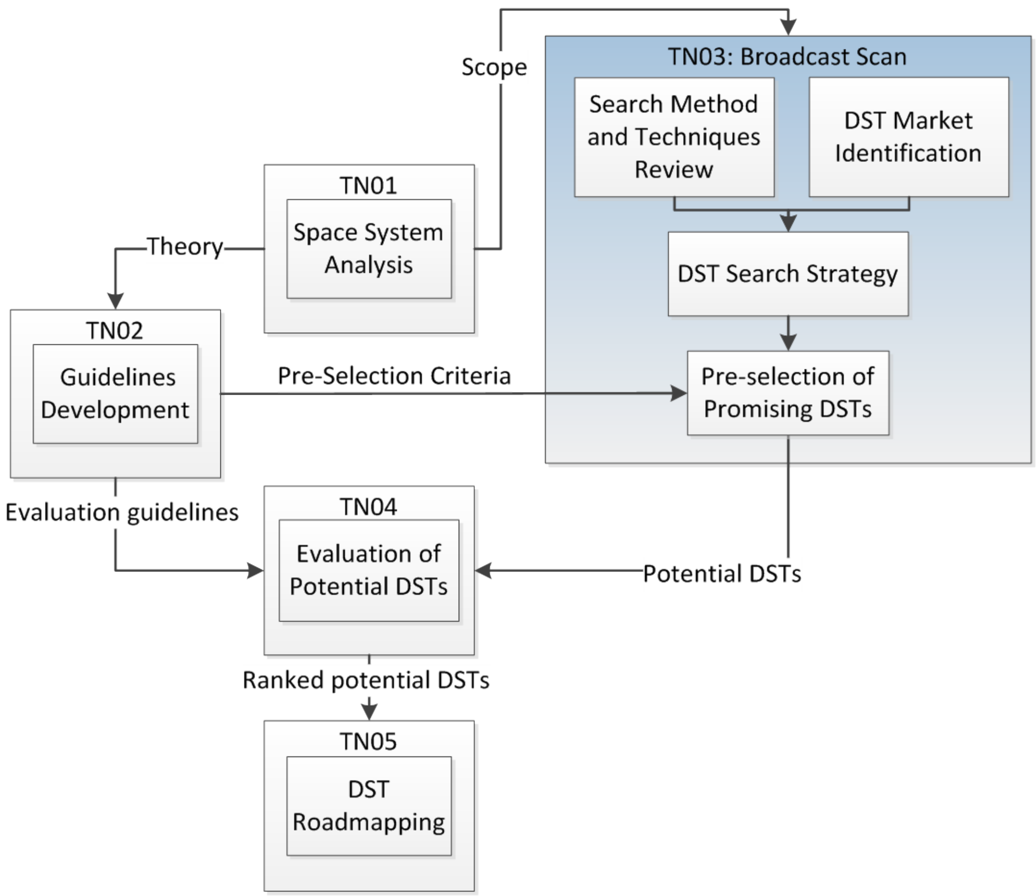


Figure 1-1: Overall structure of research

In preparation of the broadcast scan, Chapter 2 elaborates on the assessment of search methods and techniques. First, a range of search methods are described and their applicability for the search of DSTs is analyzed. Second, their key features are summarized and the most suitable methods and techniques are selected for the search strategy.

Chapter 3 includes a scanning of adjacent high technology markets in order to find potential markets that may be sources of spin-in technologies. These markets are used within the search strategy as a potential source of fringe market disruptions.

Chapter 4 deals with the application of the customized search strategy and how it is used to identify and document potential DTs. It focuses on the scanning of technology databases, desk research, literature research and an expert survey. In addition, the potential DST database structure and layout is explained.

In Chapter 5, a pre-selection and first evaluation of the found technologies is elaborated utilizing the in TN02 developed customized Analytic Hierarchy Process (AHP). Subsequently, the database is updated accordingly to present a ranking of the technologies according to their potential for disruptiveness.

2 Search Method & Techniques Review

This chapter describes several search methods used for technology identification to derive a customized search strategy. The key features, advantages and disadvantages of every method and technique are described and rated to evaluate which method is most suitable for identifying potential DSTs. A number of existing search methods are explained in the following chapters, namely:

- Lead User Method
- Bibliometrics
- Innovation Algorithms
- Patent Search
- Survey-based Data Collection

2.1 Lead User Method

The Lead User Method was developed by Hippel [RD 1] as a tool for finding and developing innovations in a given market. The goal of this method is to achieve major breakthroughs in technology development by having companies and/or research institutes cooperate with customers whose needs are ahead of the mainstream market, i.e. Lead Users. Hippel defines these Lead Users as people who "*face needs that will be general in a marketplace, but they face them months or years before the bulk of that marketplace encounters them, and Lead Users are positioned to benefit significantly by obtaining a solution to those needs*" (RD 1, p107).

Figure 2-1 shows a standard adoption curve of a product or technology including the Lead Users [RD 2]. There are five different user groups in this theory; every group has its own interest in new technologies or products [RD 3]:

- Technologists / Innovators: First users of a technology, "pioneers"; this group of users is generally small
- Visionaries / Early Adopters: See a potential for improvement in using the new technology and prefer breakthroughs rather than incremental improvements of existing products
- Pragmatists / Conservatives: Buy new technologies only on recommendation of other users and focus on support service, quality and compatibility to other products they own; this is the majority of the users
- Skeptics: Do not buy new technologies unless they realize that they need it or that everybody else has it

Moore made an alteration to Rogers' adoption curve by adding a chasm in the technology development. Chasms between the different groups disrupt the adoption of new technologies by the mainstream market [RD 2] [RD 4]. The difference in needs of visionaries and pragmatists create these chasms as shown in Figure 2-1. Pragmatists are not satisfied by recommendations of visionaries but instead rely on reference they get from other pragmatists. This makes it difficult for a new technology to get adopted by the mainstream market [RD 3].

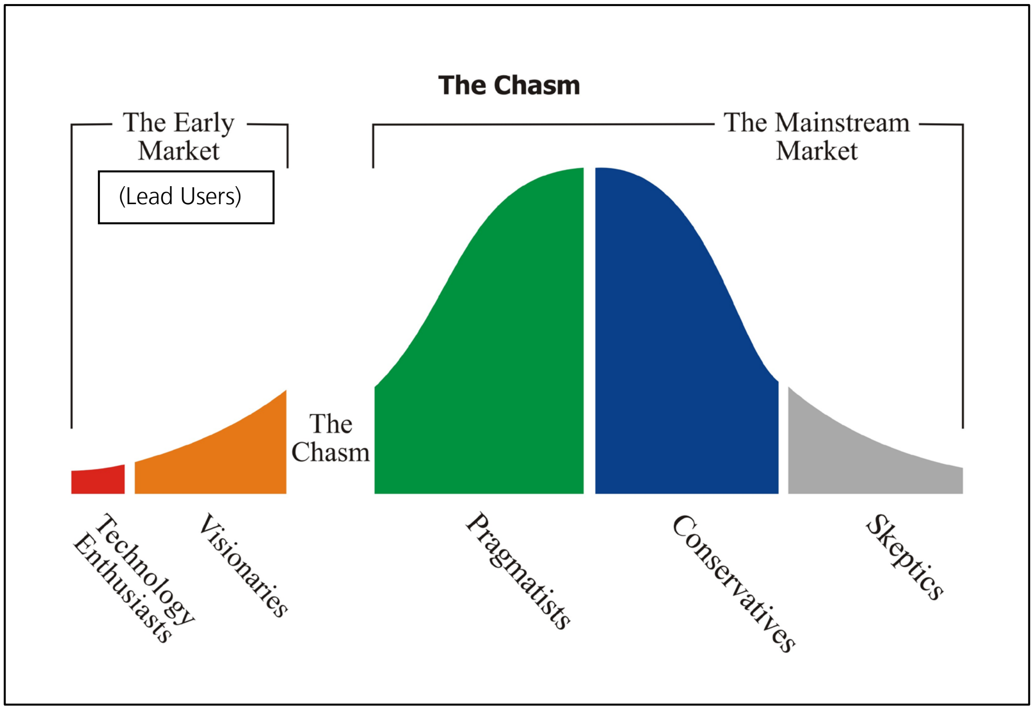


Figure 2-1: Technology Adoption Curve by Moore [RD 2].

Ideas of Lead Users usually result in major improvements of existing products or product with an altered performance on specific attributes [RD 5]. Due to this characteristic, the Lead User method is particulary usefull for identifying disruptive technolgies. Examples for Lead User groups are depicted below:

Domain		Lead Users
• Automotive industry	->	Formula 1
• Smartphones developers	->	iPhone/Android application developers
• Running shoe manufacturers	->	Marathon runners
• Software developers	->	Open source community
• Camping equipment	->	Professional climbers

The Lead User method does not directly search for actual technologies but rather for technology needs. An identification of needs and demands in technological abilities as well as performance can be a useful tool to predict the occurrence of DTs and it could help to direct a search to useful fields of technologies. If several Lead Users identify similar needs it is likely that a technology serving such a need could become disruptive. Therefore, searching for technology developments that actually answer these needs would be a valuable approach when searching for DSTs.

The Lead User Method can be divided into four steps as described by von Hippel, Thomke and Sonnack [RD 6]. This method focuses on identifying lead users and developing breakthroughs in technology developments by performing a workshop with the Lead Users. The four step are decribed in more detail below [RD 6]:

Phase 1: Laying the foundation

- Team building (incl. stakeholder)
- Identify potential target markets or products
- Define the type and level of the technology

Phase 2: Determining trends

- Talk to experts of the field who have a broad view
- Discover the trends in the market

Phase 3: Identifying Lead Users

- Look for Lead Users in the market using literature, internet, publications and networks
- Collect sufficient data on the ideas of the Lead User to determine the most suitable ideas later

Phase 4: Developing the breakthroughs

- Discuss the first concepts in a workshop with the Lead Users and experts of the market
- Analyze the potential of the new product/technology in the market
- Choose some concepts that fit to the needs of the market (and the company & organization)
- Present the results to the stakeholder and make a final evaluation

The Lead User Method has the following advantages and disadvantages:

Advantages

+ Especially usefull for designing DTs

+ The risk of the introduction of new products and technologies is reduced through having a clearer picture of user needs

Disadvantages

- Hard to identify Lead Users for the space sector

- Takes a long time from analysis until result; problematic for fast changing markets [RD 6]

- Its application is complicated in small and isolated markets

- The described stepwise process is more applicable for developing an idea instead of identifying one

The initial search for needs followed by the search for technologies is very time consuming, which would be impractical for a broad search, which is aimed for in this project. Additionally, the European space sector is relatively small with only a few prime contractors and several specialized Small and Medium-sized Enterprises (SMEs) producing on a project based, low volume manner. Because of this, nearly all specialized suppliers can be considered Lead Users in their field, thus making the Lead User method unlikely to provide any new or innovative results for the space sector.

On the basis of this and also taking into account the extensive time requirements for the method, it is considered too costly to apply the Lead User method within the scope of this project. Consequently, no list of Lead Users is provided. Nevertheless, it is still advisable to keep the Lead User method in mind for projects which involve evaluating specific domains within the space sector as it might be that Lead Users can be found in here.

2.2 Bibliometrics

Bibliometrics involves the quantitative analysis of scientific and technological literature. This can be done using either citation analysis as well as content analysis. These two different methods are described below.

2.2.1 Citation analysis

A traditional method to rate the importance of a document is by counting the articles of scientific literature that are citing it. A document that is frequently cited is read and deemed interesting by more people and thus has greater influence on research than a document with fewer citations on it. Google uses a similar method for its web search engine. It is called the PageRank algorithm, which counts the number of links to a website.

The counting of citations is a potent method and has proven its reliability in the last decades; however, it can be impracticable in some cases. Especially the rating of the influence of news stories, blog posts and legal documents is problematic as they often do not use citations. Collections of scanned non-recent scientific literature are critical too. In some cases the text and the citations of these articles cannot be read accurately in their electronic form because the scanning and optical character recognition process can misinterpret characters [RD 7]. A rating method for articles based on citation counting shows only one kind of influence, because all citations count equally. In reality some references might have a larger and some a lower impact. This has no effect on the results of the impact factor of citation counting [RD 7].

2.2.2 Content analysis

Gerrish & Blei developed a method to identify the most influential documents in a specific field. Influential documents affect the speech and writing of future articles. This method looks for comparable writing and speech in a given number of articles and rates the influence of the documents on the others [RD 7]. A visualization of this analysis is illustrated in Figure 2-2, where the papers on human information behavior (HIB) are mapped per discipline [RD 8].

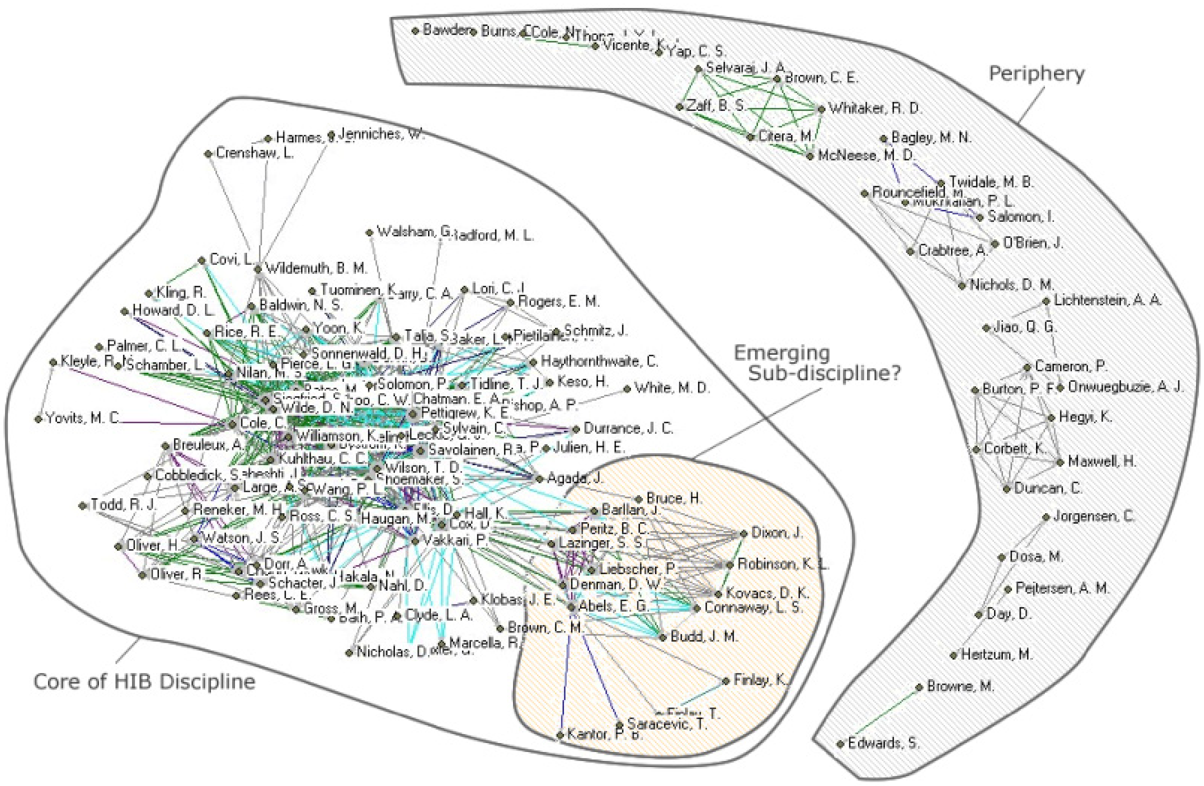


Figure 2-2: A content analysis map of human information behavior papers [RD 8].

Another, perhaps less time consuming content analysis method is the desk research of specific relevant scientific journals, proceeding and technological literature (both magazines and websites), these can be searched for keywords which are indicators for a DSTs. These indicator keywords are:

Innovation	Space	Concept
Disruptive	Disruptive technology	Breakthrough
Game-changing	Cross-cutting	Revolutionary
Radical	Innovative	

This method is easier and faster than the before mentioned citation and content analysis methods.

Bibliometic techniques have the following advantages and disadvantages:

Advantages

+ Accurate detection of the most influential documents in a collection

+ Fast detection of technologies through desk research content analysis

Disadvantages

- Needs a defined collection of documents or articles that needs to be carefully chosen or prepared to prevent possible bias

- Little knowledge about content analysis algorithms of Gerrish & Blei is publicly available

- Specialized on rating the influence of documents and not directly technologies

- Bias through document age: the older a document is, the more often the probability of reference; DTs are not often cited, otherwise they would not be new or disruptive

- Results of a desk research content analysis need to be filtered by the researcher, which may lead to a bias in the search process.

To use this method in the search for possible DSTs a database of articles about technologies is needed. That is problematic, because it is necessary to have a lot of articles about different technologies to evaluate their influence. If a technology is not contained in the database, the algorithm cannot evaluate its influence.

The method of Gerrish & Blei is specialized on rating articles of a collection through their influence on other articles [RD 7]. It cannot directly be used to search for possible DSTs because the content of an influential document is unlikely to contain a potential DST, as it is unlikely to be already well known and well published. When a new technology appears, there are only few publications on the topic and theses publications do not have an influence on already published articles. They can only influence a possible future text, which takes time. Through this method, DSTs would be found too late and only, when other articles get influenced by the DST publication.

The desk research content analysis however could provide a quick, extensive list of relevant results, which may, through an arbitrary selection of the searcher, lead to interesting results.

2.3 Innovation Algorithms

Innovation algorithms are able to search for potential DTs, through the analysis of existing companies, ideas and research. This data can be used to predict which company could develop a disruptive technology [RD 8]. Quid is one company which designed several algorithms which can be used to map innovations in sectors. It does this by capturing data, structuring it, and enabling people to visualize and interact with the information. It collects information about companies, organizations and research groups. The information comes from patent documents, government grants, job offers, advertisements and other publications. All the gathered information is stored in a database.

After building up the database, Quid extracts words and phrases from the collected documents to find out the main market of each of the 35,000 companies. The Quid software tool generates a map with this data and clusters the companies with the same main market at the same spot. However, for some companies their main market is in between established technology sectors. These companies can represent an up-and-coming new or fringe market and they have the potential to develop DTs [RD 8].

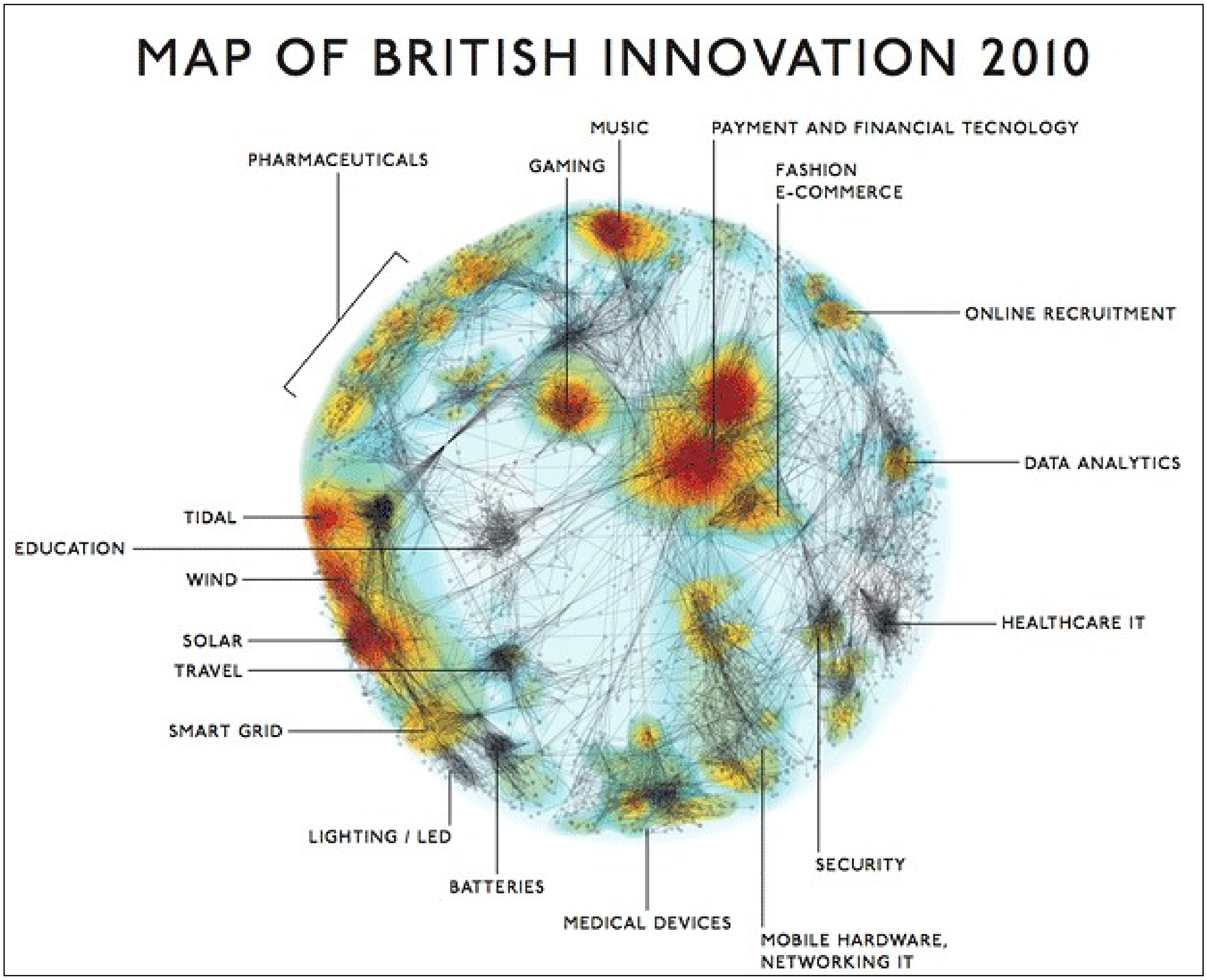


Figure 2-3: Map of technology clusters generated by Quid [RD 9].

Figure 2-3 shows a map generated by Quid concerning the innovations in the United Kingdom in 2010. It can, for example, be seen that payment and financial technology has a larger importance in the field of innovations than education, which only has a very small spot compared to the large red field of the former. In addition, it can be seen there is a major group of companies who are focusing on renewable energies (tidal, wind and solar). The single points between major fields represent companies, which are potentially developing DSTs, as they are crosscutting functional domains. An example of a crosscutting field is illustrated in Figure 2-4.

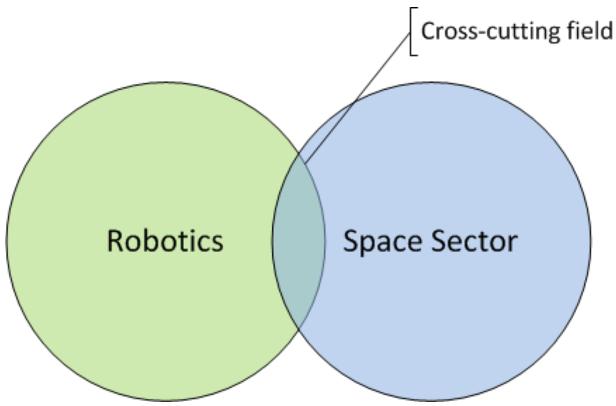


Figure 2-4: Cross-cutting technology area of the Space Sector and Robotics research field.

The aim of Quid is that companies can use this algorithm to find out in which technologies or research strategies they should invest. Quid is currently still in the testing phase of validating the algorithm and adding prediction bars to increase accuracy.

This method has the following advantages and disadvantages:

Advantages

+ It uses several different information sources
+ It detects connections between different technology fields

Disadvantages

- It only searches for innovations between different sectors; some potential DTs within a given sector could be missed
- Quid works with its own protected algorithm written for the program and therefore cannot efficiently be validated
- It is currently in the test phase and needs further development to be efficiently applied
- Costly

Most of the 35,000 companies of the current database of Quid are situated in the USA, rather than worldwide. This increases the chance that important areas of disruption are missed because innovations of other regions and companies outside the USA are not analyzed by the algorithm. To prevent this bias, the database would have to be recreated including European data. Because of this, the application of Quid is impractical for the search of DSTs within this project. It is noted though that this form of technology search might prove to be a very good tool for the future. This was also recognized by NASA, which already contracted Quid to search for game-changing technologies within the American space sector [RD 11]. For this reason, it is advised the innovation algorithms such as Quid and similar services are to be monitored for potential application to the search of DSTs.

2.4 Patent Search

Searching inside patent databases might lead to the identification of a potential DST. According to Hunt & Rodgers [RD 10] there are four types of patent searches, these types will be elaborated within this chapter:

- Patentability search
- Validity search
- Infringement search
- State-of-the-art search.

A *patentability* or *novelty search* is performed when an invention has the potential to cover a patentable subject. Usually, this search type is the first step in the application process of a patent. The patentability search looks for patents with a similar content to the invention. Furthermore, journals, papers and other publications are also taken under investigation. When the patentability search does not find any similarities between available patents or articles and the invention, an application for a patent can be made.

The *validity search* is similar to the patentability search. The difference between the two search types is that the validity search is made on a patent rather than an invention. Typically, a validity search is performed when a product of a company infringes over another company's patent and legal action is being brought against them. In this case, the sued company tries to invalidate the patent and uses the validity search to find errors in the claims of the patent.

The third patent search type is the *infringement* or *clearance search*. It is used to prove that a proposed product or invention does not violate current patents. The infringement search is often used by companies that are not interested in obtaining patent rights; they, however, want to ensure that their product will not infringe the rights of patent owners.

The *state-of-the-art* search is often performed to determine existing inventions and potential competitive companies within a market. This search type is also known as a collection search because it includes patent and non-patent literature research. Usually, the results of a state-of-the-art search give a view on the current developments in a given technology field.

The patent search has the following advantages and disadvantages:

Advantages

\+ The newest inventions from all over the world are listed in the databases of patent offices

\+ Patent databases provide an abundant information source

Disadvantages

- The searching tool of patent databases are optimized for the search of a specific patent rather than for a specific type of technologies e.g. DSTs
- A search through all patents is time intensive
- Highly time consuming

The first three types of patent search focus on the patent application process and the use of patents while the state-of-the-art search is a more general search type. Therefore, the state-of-the-art search is the only applicable type for the search for DSTs. This search type can give an overview of different research fields and though the assumption of the future development of the technology fields can be used to predict potential DSTs. However, a state-of-the-art search is very labor and cost intensive depending on the technology field and the expected quality of the results. This makes patent search less applicable to the search of DSTs.

Furthermore, web based search tools like Espacenet or Departisnet provide only keywords, patent numbers, dates and topics as search criteria. This is helpful for looking for a specific patent or existing technology, but it is impractical for finding a Disruptive Space Technology without exactly knowing what to look for. Furthermore, the databases are too extensive for a simple keyword search, which would offer thousands of results. Because of this, patent analysis is more applicable as a DST evaluation tool and especially potent for scanning monitoring and tracking techniques.

2.5 Survey

A survey is any activity that collects information in an organized and methodical manner about characteristics of interest from some or all members of a population using well-defined concepts, methods and procedures, and compiles such information into a useful summary form [RD 13]. The reason for performing a survey is the lack of information on a specified topic or about a group of people.

Surveys can be divided into two types, census surveys and sample surveys. The first collects data for all units of a population while the second examines only a sub-part of the whole population.

Fellegi describes eleven steps for performing a survey, as listed in in Figure 2-5 [RD 13]. Each of the steps has to be done accurately to guarantee utilizable results from the survey. However, for specific surveys some of the steps are less applicable.

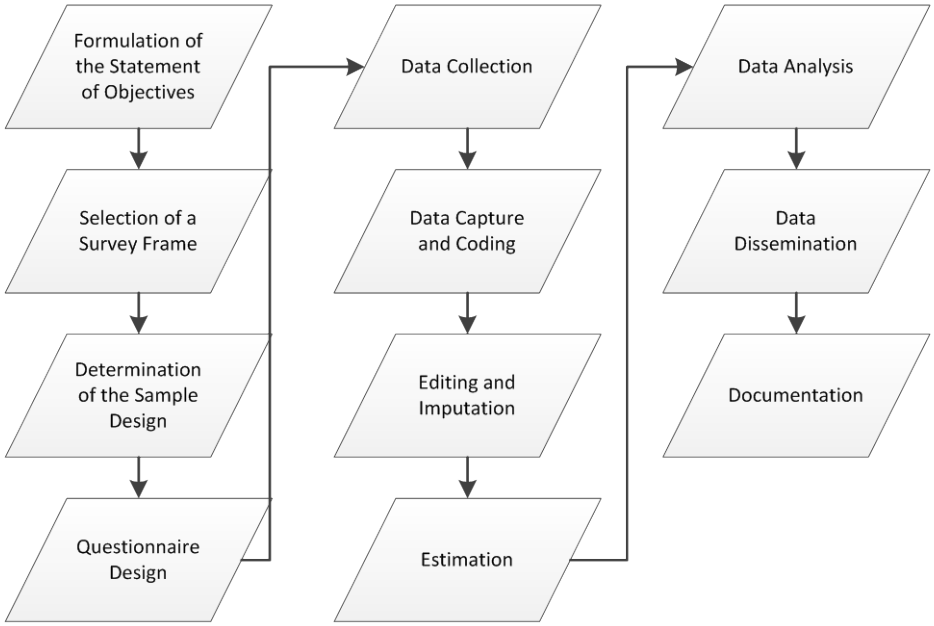


Figure 2-5: Steps of performing a survey according to Fellegi [RD 13].

The formulation of *the Statement of Objectives* is the first step in creating a survey. In this step the administrator of the survey defines its topic, input and output.

The second step is the *Selection of a Survey Frame*, i.e. the decision whether the survey will be a sample or a census survey. This decision affects the choice of participants, the costs, the required resources and the quality of the responses. The *Selection of a Survey Frame* is a milestone in performing a survey: the decisions in this step affect the survey's quality and type of errors.

Fellegi describes the *Determination of the Sample Design* as the third step in creating a survey and it is mandatory only for sample surveys as for census surveys the sample is the whole population [RD 13].

The fourth step is the *Questionnaire Design*, i.e. the selection of questions that the survey participants have to answer. The aim of the questions is to gather all the information required to fulfill the goal of the survey.

The *Data Collection* is step number five in performing a survey. In this step an appropriate way of data collection for the survey has to be considered. The existing methods of data collection can be divided into assisted methods, non-assisted methods and miscellaneous. Assisted data collection methods use an interviewer who queries the participants or supports them in filling out the survey. In non-assisted data collection methods the participants have to fill out the survey by themselves. Direct observation, electronic data reporting and using administrative data are other data collection methods. Each of the mentioned methods can be conducted paper-based or computer-assisted.

Fellegi [RD 11] describes the *Data Capture and Coding* as the sixth step. Usually this step is combined with the data collection. Each response gets an alphanumerical value for later editing and analysis.

The *Editing and Imputation* of the collected data is mentioned as the seventh step in performing a survey. The editing process includes the identification of missing, invalid or inconsistent responses that will result in an error during the analysis of the survey results.

The eighth step: the *Estimation* of the survey responses is the last step before the analysis starts. In this step, a first estimation of the survey responses is made to ensure that the survey fulfills the predefined objective. Out of this process, it can be approximated how many errors the responses have and if more responses are required or not.

The main part in performing a survey, the *Data Analysis*, is step number nine. The Data Analysis is the process that includes the summarizing and interpretation of the collected data. The outcome of the Data Analysis answers the survey goal defined in the statement of objectives in a clear, structured and representative way. Tables, charts and diagrams are the tools used to describe the survey results.

Data Dissemination is the tenth step in the process of creating and performing a survey. Data dissemination means the publication of the results of the survey to the public or to a specified community.

The final step is the *Documentation*. In this, the whole process of creating and performing the survey is described in a clear and detailed way. Usually, the Documentation is part of the whole survey project and gets passed as an electronic or printed document to the initiator of the survey.

The survey-based data collection has the following advantages and disadvantages:

Advantages

+ Collects different ideas from many different experts coming from diverse fields of research
+ Relatively cheap and easy to administer
+ Surveys are efficient in collecting information from a large amount of participants from different parts of the world
+ The results of a survey can be statistically significant when the sample of participants properly represents the population or a specified part of the population
+ There are many tools for creating and conducting surveys

Disadvantages

- The results can be negatively affected by different types of biases
- Incorrect question-answer combinations can lead to vague and impractical results

Surveys have several advantages for the search of DSTs. Especially self-administered surveys, which are relatively inexpensive, are highly applicable. They can be done fast without a personal contact to the participants using an online or email based survey.

Passing out a survey to various experts in different fields of technologies grants the opportunity to receive ideas from all domains, which makes it ideal for searching for spin-in technologies. After receiving the results of the survey, the ideas can be sorted and ranked. However, the result of a survey-based data collection depends on asking persons who are experts in their field and their willingness to participate in the survey. Surveys are a flexible way to collect information; it is possible to ask a large number of participants from all over the world a large amount of questions. The fact that the experts of the space sector are spread over different countries of the world is a pro for choosing a survey for the search of DSTs.

2.6 Conclusion

To evaluate which of the above described search methods are used to identify potential DSTs, the key features as well as the advantages and disadvantages of every method are compared with each other. Table 2-1 shows the key features, advantages and disadvantages of each method. Based on this analysis, a selection of methods for the search strategy of DSTs is made.

The *Lead User Method* is applicable in finding technology needs and not for existing technology concepts or developments. While it can serve as means for identifying opportunities for DSTs, it can only provide a direction of a search. As the application of the Lead User Method would be overly time consuming for this project, it is not selected. It might be good for ESA to consider this method for a more in-depth analysis of a specific field.

From *Bibliometrics,* citation analysis is also not applicable to this project because it is impractical to gather all the documents about the technologies required for the search method. In addition, texts about new technologies can only affect the language of future articles, i.e. it takes time for a technology to manifest itself.

The content analysis however could provide a quick, extensive list of relevant results, which may, through an arbitrary selection of the searcher, lead to interesting results. It is especially applicable, because a large dataset can be researched using several keywords and using the searchers discretion in using results.

Innovation algorithms such as Quid have the potential to be used in the search for DSTs but the algorithm is not published and thus the results cannot be evaluated. Furthermore, the current company database of Quid consists mainly of companies from the USA and is thus not applicable for a worldwide search for DSTs. Nonetheless it is advisable to follow the development of these methods and perhaps apply this technology once its maturity has increased.

Table 2-1: Summary of pros, cons and key features.

	Key Features	Advantages	Disadvantages
Lead User Method	Identifies needs of Lead Users to identify future technology trends	Can identify technology needs and therefore opportunities for disruptiveness	Not applicable for small specialized domains like the space sector
Bibliometrics	Searches in a collection of websites articles and papers for relevant information	Can detect most influential documents in a collection. Provides a fast and extensive dataset	Due to a very large dataset, it is highly time consuming to search, without resorting to restrictive keywords
Innovation Algorithms	Uses many different information sources and its own algorithm	Can identify sources for crosscutting technology developments	Non-Public algorithms are used and the results cannot be verified
Patent Search	Searches technology development through larga databases	Is a large source of data and provide information on early stage technology developments	Very time consuming as it is hard to identify DSTs with keywords
Survey-based Data Collection	Enables the gathering of opinions from many experts from all over the world	Allows for the collection of ideas from many different experts and working fields	Requires many experts to participate so a high amount of experts need to be inquired for their cooperation / Bias might effect answers of experts

A manual *patent search* within a database of 70 million patents is very time intensive. Without a search algorithm or program this method cannot be used to search for DSTs. It is only possible to search for the patents of new inventions.

A *survey* with experts of different fields can generate a lot of ideas about technologies of various research fields. It is also feasible to query the participants of the survey directly on potential DSTs, which is likely to provide valuable data as experienced scientists are likely to know current developments. However, the results still need to be evaluated and it will take time to find experts and their contact information as well as receive and evaluate all answers.

The broad search range of a survey, i.e. inside and outside the space sector, makes it a valuable tool for searching for DTs. A survey leads to different potential DSTs from both inside and outside of the space sector. Also, it is helpful to get new opinions from experts so that the view of the project team can be expanded. The answers of experts outside of the space sector can result in promising spin-in technologies. These technologies are interesting because they are not developed exclusively for the space sector and so some of them can result in DSTs.

In conclusion, content analysis and survey based data collection methods are most suitable for the DST search strategy. These methods are customized for the space sector in Chapter 4.

3 DST Market Identification

In this chapter, the process of spin-in with respect to the space sector is elaborated. Furthermore, spin-in markets for potential Disruptive Space Technologies are identified and analyzed on their relevance to the space sector.

Traditionally, research and technology development within the space sector have resulted in spin-off technologies in terrestrial market sectors (e.g. infrared ear thermometers, advanced silicon-based solar cells, temper foam, and freeze drying). However, within the last two decades, the space sector has become more and more reliant on basic research and technology development outside the space sector. This shift in technology transfer is caused by stagnating budgets and increased complexity and costs of technology development. These factors have forced the space sector to look outside its boundaries for high-tech sectors, from which technology development efforts it can benefit.

The European commission refers to the area of these technology development efforts as Key Enabling Technologies (KETs). These are typically associated with high R&D intensity, rapid innovation cycles, high expenditure and highly-skilled employment [RD 19]. KETs are expected to be driving forces behind potential future space developments. A more common term for technologies that originate from outside the space sector and are used and adapted in designing space systems is spin-in technologies (Compare Figure 3-1).

As spin-in technologies result from fringe-markets, they have a high potential to disrupt dominant space technologies. This is because they come from a cross-functional field, which might not have been explored by the space sector, and may, nonetheless, offer more benefits to customers than dominant space technologies.

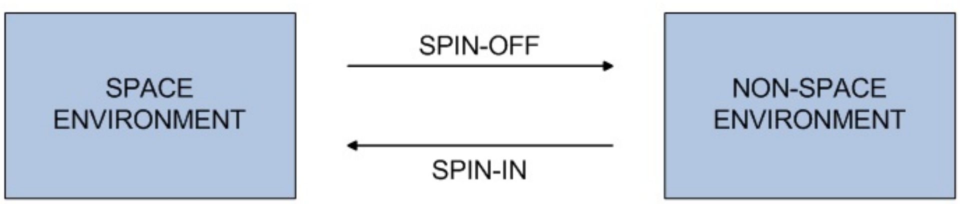


Figure 3-1: Spin-off versus Spin-in.

The following markets have been identified as potential spin-in markets in TN01 (Section 3.3) [RD 19]:

- Advanced Materials
- Biotechnology
- Photonics
- Nanotechnology
- Microelectronics
- Information and Communication Technology (ICT)

- Robotics
- Automotive

These markets are explained and analyzed on their potential to host potential DSTs in the sections below.

3.1 Advanced Materials

Technologies of this field can be categorized as hybrid materials, multi-materials, materials for extreme conditions and multi-functional materials. Advanced materials provide major improvements in a broad variety of fields (e.g. aerospace, construction, healthcare or marine engineering). Advanced materials have the possibility to simplify recycling, reducing the carbon foot-print, lowering energy demand as well as limiting the need for scarce resources. These materials will enable products with enhanced performance, new functionality, higher resource availability and lessened toxicity.

Material science plays a very important role in enabling space technologies. Trends towards light-weight materials and materials with manipulated physical properties to enhance performance are ongoing. Examples of lightweight materials are composite cryogenic tank structures which provide thermal stability, improvements in materials to minimize microcracking, and better insulations. Composite cryogenic tanks enable up to 30% lessened tank mass by using composites instead of metals, which can be used for example in propellant depots [RD 21].

Besides lightweight structures, nano technologies could be used to create multifunctional and self-healing materials. Especially self-healing materials are receiving an increasing amount of interest as a method to address damage in materials and structures for example of space craft components in long-term spaceflights, precisely because space vehicles are expensive and difficult or impossible to repair after launch. Research efforts are under way in using bio-inspired processes to develop self-healing materials based on the inspiration of biological systems, which have the ability to heal after being wounded. An example of bio-inspired self-healing is the using of hollow glass fibres, that can be embedded within a structure, e.g. in polymer composites [RD 22]. These hollow glass fibers can be filled with uncured resin systems that bleed during a damage into site upon fiber fracture, whereby a repair agent passes from within any broken hollow to infiltrate the damage zone and acts to ameliorate the mechanical integrity. The self-healing ability of new smart materials could significantly extend the life of space crafts and its materials.

3.2 Biotechnology

According to United Nations Convention on Biological Diversity, biotechnology is "*any technological application that uses biological systems, living organisms, or derivatives thereof, to make or modify products or processes for specific use*" [RD 23]. It is a fast growing area used in a variety of industry sectors such as healthcare, pharmaceuticals, textiles, chemicals, energy and agriculture. When it comes to innovation, biotechnology is an example of a fast moving sector in putting innovative products on the market, nevertheless, the use of biotechnology and its broad range of applications is still largely untapped [RD 19]. Therefore, biotechnology solutions are increasingly needed to address major social challenges, such as ensuring agriculture supply, environmental protection, ensuring high levels of health care for an ageing population and pursuing rising energy requirements.

The space sector can both benefit from, and contribute to advances in biotechnology. An example provides the topic artificial life. The creation of living devices by integration of cellular structures into robotic systems for instance can be a promising approach for the space sector. In this process, selected features of the robot’s environment are mapped into features of the environment of a living cell. In return, the response of the cell is mapped back onto the robot’s actuators. Cellular structures may be of potential interest for space of their capability to repair and reconfigure themselves.

Besides artificial life, biosensors are other technologies of particular importance to the space sector. Biosensors are analytical devices that combine a living organism and a transducer to provide a signal in the presence of a specific substance in the environment. An example of such a sensor for space can be an instrument that plots biological and physiological measurements. This sensor can be implanted internally, worn externally, or mounted throughout a spacecraft [RD 24]. Biosensors can monitor a wide range of data encompassing for instance the health and well-being of astronauts on a space flight, research subjects, experimental parameters, and the status of the living environment. The data signals generated by the biosensors will be gathered, processed and stored [RD 24].

3.3 Photonics

Photonics is a multidisciplinary domain dealing with light covering its generation, detection and management [RD 26]. Photonics encompasses multiple applications including information, communication, imaging, lighting, displays, manufacturing, energy, life sciences, health care, safety and security. Photonics provides, for example, the technological basis for the economical conversation of sunlight to electricity, which is important for the production of renewable energy as well as a variety of electronic components and equipment such as photodiodes, LEDs and lasers [RD 19].

The potential of photonics technologies is largely untapped and there are plenty of ways in which photonics can serve as a common research ground for the space sector. For example, photonics can play a key role in harnessing solar energy for future energy requirements. Common approaches to space-based solar energy generation are satellites in the geostationary orbit [RD 25]. These satellites consist of mirror arrays or photovoltaic solar panels that collect sunlight using solid-state power amplifiers. The solar power, which was converted by the amplifiers to microwaves, will be beamed to a rectenna towards earth. The rectenna can convert microwave energy into electricity, which at least will be sent to a local power grid. An important benefit of harnessing solar power in space is that solar energy can be harvested around the clock, in addition, the satellites which are in orbit never obscured by clouds and bad weather.

A laser-based optical communication system for space is another example of the photonics technology of particular importance in regard to future space activities and explorations. Optical communications is a form of telecommunication that uses light as the transmission medium [RD 26]. It will enable and improve to undertake future complex space missions that require higher data rates for communications.

Current communication rates are a limiting factor when exploring the space, for example, it takes up to 90 minutes to transmit one high resolution image from the Mars Reconnaissance Orbiter (MRO) back to Earth [RD 27]. The MRO mission equipped with an optical communications system can allow significantly higher data rates, reducing the single image transmission time to on order of 5 minutes, for approximately the same mass, power, and volume than conventional communication systems. In addition laser systems could be used as a basis for propulsion by using the small push effect of light in order to provide a propellantless propulsion system.

3.4 Nanotechnology

Nanotechnology is the science and technology on an atomic and molecular scale. It deals with the creation of useful and functional materials, devices and systems of any size through control and/ or manipulation of matter on the nanometer length scale. Because of its ability to operate in very small dimensions, nanotechnology promises many new properties in a wide variety of fields and is considered as a high potential enabling technology. Healthcare, implants and molecular diagnostics are one of the most important fields of nanotechnology application. In the energy field, nanotechnology applications are mostly related to energy conversion or production followed by energy saving and energy storage.

Nanotechnology can have a broad impact to the space sector and presents a whole new spectrum of opportunities to build entirely new device components and systems for future space missions. Nanotechnology always played a key role in space research and exploration missions. Therefore, materials and structures, energy generation and storage, propulsion and electronics, and sensors and devices are examples of research areas where the space sector can possibly benefit from nanotechnology. In the field of energy generation for example, nanomaterials provide the chance of creating high surface area materials with inherently higher surface activities and reactivity that could significantly enhance the performance of batteries and fuel cells and improve the handling characteristics of propellants. The use of nanostructured metal catalysts in Proton Exchange Membrane (PEM) fuel cells could increase their energy density [RD 21]. PEM fuel cells provide the promise for future specific power up to 140 W/kg upon further work in the area of optimized catalyst chemistries, better materials, and better reliability. Nanotechnology promises to allow electrodes to provide greatly increased surface area and membranes with higher strength and lower ohmic resistance.

Besides energy generation, nanotechnology affords the possibility to improve the mass and performance of propulsion system components by the use of nanostructured materials. New polymer/clay nanocomposites for example have 60% lower permeability and better microcrack resistance than conventional toughened epoxies [RD 21]. The use of nanocomposites and aerogel insulation, combined with new high performance carbon fibers is expected to enable the development of composite cryotanks that are 30% lighter and more damage tolerant than conventional tanks which are used today [RD 21].

3.5 Microelectronics

In addition to nanotechnologies, also micro technologies such as microelectromechanical systems (MEMS) are in particular importance for space applications. MEMS are made up of components in micrometer scale and have been adopted in large number of earth-based applications. It can be used for propulsion, e.g. miniaturize the ion-thruster by micromachining and integrating the electron source, gas handling, nozzle and other components. Switches and antennas are other examples of space relevant applications where MEMS technology can be used [RD 29]. MEMS sensors and actuators combine low mass, low power consumption and tight integration of electronics, and can reduce the size and mass of space components without limiting their functionality.

Microelectronics is a subfield of electronics and deal with small sized materials, processes and devices and their integration into small products and/or systems. This sector is currently in a period of fast evolution and technological advancement [RD 30]. For example, semiconductor components are quickly penetrating in automotive, medical, industrial or consumer markets; the electronic data processing and the telecom sector are the largest markets for microelectronics [RD 29].

The microelectronics sector can increase the performance of space systems for instance in the field of communication, remote sensing, and data processing components.

In the field of imaging for example, microelectronics can provide a possibility of developing a camera on a chip. A small sized wireless digital imaging camera based on active pixel sensors, operating in the ultraviolet, visible and near-infrared realms, can replace the charge-coupled devices (CCDs), which measure light digitally [RD 28]. The active pixel sensor camera uses 100 times less power than the standard CCD camera, has outstanding resolution, and is less sensitive to the radiation damage in space environment. These cameras can be used in landers and/or rovers for space exploration.

A tunable diode laser is another spin-in possibility from the microelectronics market which enables the exploration and measurement of water as well as a variety of other gases in the Martian atmosphere [RD 28]. These lasers can be mounted with their electronics into small sized instruments that provide information regarding the possibility of life. A wide range of sensors can be designed for use on future space vehicles, including passive optical instruments, dust detectors and a variety of spectrometer instruments. A mass spectrometer, for example, is used to identify and measure gases [RD 28]. An X-ray fluorescence spectrometer whereas could measure the absolute abundance of elements at the surface of an airless body, such as an asteroid [RD 28].

Technologies of microelectronics are also essential for components of many other technologies and will very likely continue to progress rapidly and influence trends over the next decades.

3.6 Information and Communication Technology (ICT)

The Information and Communication Technology (ICT) sector has been booming in the last 15 years and it has been the heartbeat of almost every other advancement in science. ICT is one area where progress and innovation are proceeding at a very fast pace and no other sector has been as pervasive and dominant as ICT. The ICT sector is a highly R&D intensive sector and its products and services are important drivers of productivity growth and economic performance across all sectors [RD 31]. A strong technology pull has resulted in many new products and services.

ICT is omnipresent in the space sector, as it is in most technology intense areas. Implication of earth-based technologies will be of particular, rather than incidental, importance to space. Research in processing power in particular is of great significance. Increasing processing power will enhance the capability to usefully process large amounts of data collected by earth observation satellites, which amongst others enables the development of macro-models of environmental processes. Tele-presence, tele-medicine and a host of other network enabled processes, can be carried to remote regions with links provided by satellites. Moreover, increased computer power and data modeling capabilities will influentially increase design and visualization capabilities for space missions [RD 32].

3.7 Robotics

Nowadays, the use of robotics is widely spread. There is hardly any sector that does not use robotic systems in carrying out technical processes. Robotic systems and are getting more and more advanced over time. They can perform high quality work in a shorter amount of time compared to manual processes.

Robotics provides a wide range of possibilities for space activities. The most important contribution of robotics to space activities could be in the development of autonomous, evolving and highly distributed systems. Possible innovation examples in robotics are adaptive, self-repairing mission vehicles or application combined with other technologies, for example the nanotechnology, e.g. enabling the use of micro-rovers that drive, hop, fly and burrow [RD 33], and have an advanced sensing capability, which can be used for a wide range of space activities, including exploration of planets, maintenance and repair [RD 32].

3.8 Automotive

Automotive deals with designing, developing, manufacturing, marketing, and selling of motor vehicles. The automotive sector is one of the largest and most important industry sectors for Europe and a key driver of growth, knowledge and innovation. This sector is characterized by heavy R&D investments that make it Europe’s largest investor in R&D [RD 34]. Because of this, and because of its long tradition and technology know-how, the automotive industry is and will be a potential market in providing and transferring technologies for the space sector.

The automotive sector hosts a wide variety of common research areas and opportunities, from which the space sector can benefit. Possible topics from which the space sector can benefit include e.g. fuel cell technology and electro motors. In the field of power generation for instance, solid oxide fuel cells (SOFC) provide an efficient method because of their high-energy efficiency, long life time, and extremely clean operation. SOFCs, which are also being developed for automobiles, could be used in space, for example, to electrolyze water and generate power for lunar satellites and space stations.

3.9 Conclusion

State-of-the art technologies are essential for successful space missions. To increase its capabilities, innovation is a fundamental enabling factor for the space sector and therefore it should make use of R&D of adjacent sectors in order to save costs and increase performances. Figure 3-2 shows for comparison the R&D expenditure as per cent of sales across industry sectors in 2003.

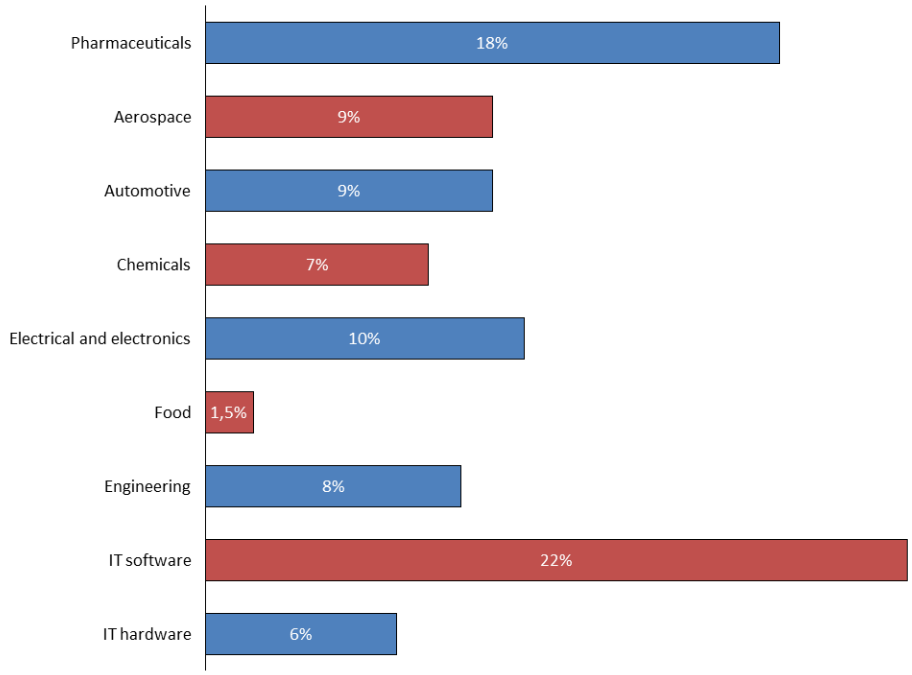


Figure 3-2: R&D expenditure as % of sales across industry sectors (2003) [RD 36].

Considering the common research areas, from which the space sector can benefit through spin-ins, the non-space sector provides a range of possibilities. Figure 3-3 shows relationship circles between the space sector and the potential spin-in technology markets. Especially emerging high technology fields such as nanotechnologies, biotechnologies, and information and communication technologies have a high potential to be a possible source for DSTs. These are fast growing sectors, which are quick in introducing innovative products on the market and frequently employ a more breakthrough or game changing approach to technology development [RD 19]. Compared with fast moving sectors, conservative sectors characteristically prefer a more incremental approach to innovation [RD 19].

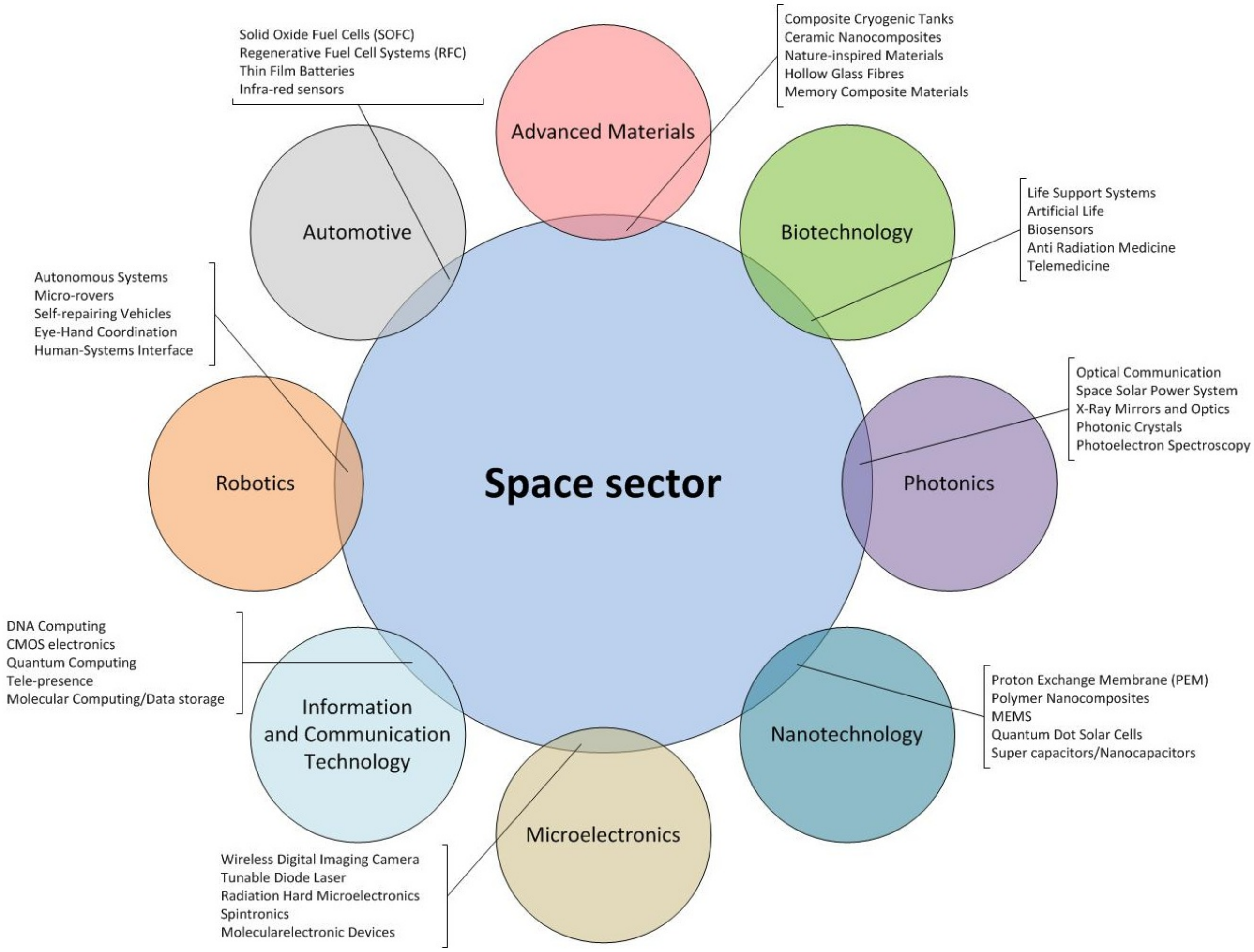


Figure 3-3: Relationship circles between spin-in markets and the space sector.

4 DST Search Strategy

Within this chapter, the DST search strategy is explained in detail. This strategy is used to identify potential DSTs inside and outside of the space sector. The search of potential DSTs outside of the space sector involves the areas researched in Chapter 3. In general, the search strategy depends on a search in space technology databases, desk research & literature research (bibliometrics), and an expert survey. These elements and their relations are illustrated in Figure 4-1.

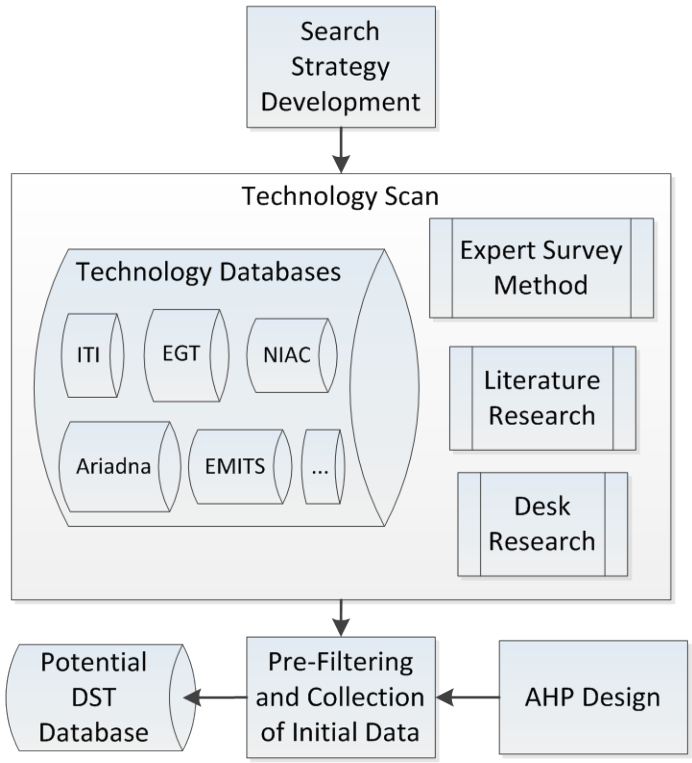


Figure 4-1: Search strategy overview.

The technologies found in these sources are included in the potential DST database if they show a sufficient potential for disruptiveness. A potential for disruptiveness of a technology is determined by its conformity to the theory of DST elaborated in TN01, Chapter 2. This arbitrary selection is done by DST project members and is necessary to deal with the vast amounts of technologies resulting from the search. The selection criteria used by the project members were the following (adopted from the DST characteristics described in section 2.5 in TN01):

- The technology falls under the product innovation category
- The introduction of the technology will be game changing to the field of application
- The technology is in the fluid or concept phase of development which means disruption has not yet occurred and it has not been applied yet or merely has been tested
- The technology provides significant benefits over the current state of the art in the form of performance increases, reduced complexity and/or decreased costs
- The concept is most likely technological feasible

The different sources of the technologies which are subject to this selection are elaborated in the next sections.

4.1 Technology databases

Several technology databases are scanned for potential DTs. These databases include technology listing from ESA innovation seeding projects and NASA spin-in technologies. Mostly these databases list technology development projects, which were funded by basic technology development programs. The following databases are subject to search:

ESA:

- Innovation Triangle Initiative (ITI) database
- Ariadna database
- Electronic Mail Interface to Technical Support (EMITS) database

NASA:

- External Government Technologies (EGT) dataset
- NASA Innovative Advanced Concepts (NIAC)

These databases are explained more elaborately below.

1. Innovation Triangle Initiative (ITI) database

The ITI supports inventors of DSTs by connecting them to developers and potential customers. This speeds up the development process. ITI gives preference to innovations originating out of non-space industrial or research sectors. This means that it is promoting spin-ins for the space sector. The ITI database contains all the technologies that ever went through the ITI process. The technologies which are perceived as potentially disruptive are put into the database.

2. Ariadna database

The Ariadna program provides funding for the development of technologies that can be of interest to ESA in the future. This funding scheme is a brainchild from ESA's Advanced Concepts Team (ACT). Ariadna focuses especially on the academic community and on the long term needs for knowledge and skills of ESA. The Ariadna database contains all technologies ever developed according to this funding scheme. Although most of the technologies seem to be a bit farfetched for the current scope, this database is nonetheless taken into the search.

3. **Electronic Mail Interface to Technical Support (EMITS) database**

EMITS is the system ESA uses to assign projects to industry and research institutes. This database contains all of the external technology development projects of ESA (with exception of the projects running over innovation seeding schemes like ITI and Ariadna).

4. **External Government Technologies (EGT) dataset**

Directorate Integration Office (DIO), under the direction of NASA's Exploration Systems Mission Directorate (ESMD), and supported by NASA Langley Research Center and The Tauri Group, has been developing the EGT data set since 2005. The intention of EGT is to identify and track technology development programs that may share requirements or technical similarities with NASA's technology needs. This data set aims to connect NASA researchers and decision makers to technologies, components, approaches, and research personnel in other areas of the U.S. government. Technical information concerning identified technologies is based on interviews and original source data. The EGT data set is a component of the MATCH (Mapping Applicable Technologies to Exploration Challenges) database.

5. **NASA Innovative Advanced Concepts (NIAC)**

The NIAC funds the development of advanced concepts which have the potential to transform future space missions, enable new capabilities or significantly alter current approaches to launching, building and operating space systems [RD 35]. It solicited visionary, long-term concepts for future technologies for maturation based on their potential value to NASA's future space missions and operational needs. These NIAC projects are technically substantiated and very early in development -- 10 years or more from mission infusion.

Technologies with a potential for disruptiveness found in these databases are put into the DST candidate database.

4.2 Desk Research – Popular Science

Desk research involves the search of various sources to identify DST candidates. These sources range from websites to magazines and newspapers. The following magazines and newspapers were used in the search for DSTs (list is not exhaustive):

Science	Popular Science	Science News	Technology Review
Discover Magazine	Space Daily	Aviation Week & Space Technology	
Techno!	Space news		

The following websites were included (list is not exhaustive):

Spacedaily.com	Space.com	Spacefuture.com	ESA.int
NASA.gov	JAXA.jp	CNSA.gov.cn	Materials views
FierceBiotech	Genomeweb	Nanotechweb	Nanowerk

Robotic Trends Automotive Technology

These sources were searched using a number of keywords combinations (e.g., technology, space, advanced, innovation, concept, disruptive, breakthrough, game changing, cross-cutting, and revolutionary).

4.3 Desk research – Scientific Literature

In addition to popular science magazines and internet pages several academic sources are used for the identification of technologies. In general, these sources are divided into journals and conference proceedings. Examples of sources used for this search are:

Proceedings:

- IAC
- COSPAR
- Toulouse Space Show

Journals:

- Acta Astronautica
- Space Technology Management & Innovation
- Journal of Space Technology and Science
- Journal of Space Technology
- International Journal of Space Technology Management and Innovation

4.4 Expert Survey

The fourth source of DST candidates is a survey involving experts from both the space sector and areas identified in Chapter 3 as potential sources for spin-ins. This section elaborates on the method of expert selection and the survey design.

4.4.1 Expert Selection

The first step in developing the questionnaire for the survey is creating a database of experts containing their contact information, organization and field of work. These experts can come from key players in and outside of the space sector: companies, research institutes, universities and space agencies.

To search for experts within companies, a list of 2011's 500 most profitable companies worldwide, the Global 500, is considered [RD 12]. From this list the target markets have been selected and their high raking supervisors, managers and executives are added to the database of experts. Their contact information is attained through company websites.

For universities, key players are identified through the Times Higher Education World University Ranking 2011 [RD 13]. Since most of the Top 50 Engineering & Technology universities of the world are located in the USA, the universities are selected not only by total score but also by country of origin. This allows the database to have a wider spread of expertise. Professors and fellows can be considered experts on their fields and are thus added to the database.

Finally, the world's leading research institutes and largest space agencies are also considered as key players. A list of the world's top research centers is found in the Ranking Web of World Research Centers [RD 14] and out of various space agencies the focus is on NASA, ESA, Roscosmos, JAXA, CSA, CNES, ASI and DLR. The names of department and division managers and their contact information are collected through the agencies' and institutes' web sites as well as through proceedings of conferences.

In total a database was created of 2300 experts from both in and out of the space sector. These experts were approached for cooperation partially by a general email and partially by a personal email.

4.4.2 Survey Design

The next step for a customized survey is the choice of the type of the survey. Questionnaires can be completed in person, via telephone or online. In person interviews and telephone interviews are not feasible because of the time constraints within the project. As a consequence, the survey is put on a website. The expert of the different fields got an invitation to the survey via email including the link to the website of the questionnaire and information about the DST project. To reduce the costs and the time of the survey design, the survey provider LimeSurvey.org is used. This website offers an easy tool to create surveys and a customizable layout. In addition, the responses can be exported to several file types, which allows the use of different software programs for their analysis. The survey can be reached over the following link: http://dlr-dst.limequery.org/29258/lang-en. The welcome page and general survey design is illustrated in Figure 4-2.

Figure 4-2: Survey Design

The following step is the formulation of questions for the survey. They have to be phrased clearly, in order to get evaluable responses. Furthermore, the amount of questions has to be as small as possible in order to maximize the response rate. After several iterations between project members, the following questions are chosen for the survey. The questionnaire is divided into six question groups with the following questions:

1. Your Field of Work
   - 1.1 Are you working in the space sector?
   - 1.2 Which of the following fields is the most closest to your field of expertise? (s. Tab 1-2)
2. Possible Future Scenarios for the Space Sector
   - 2.1 Please rank the following 5 future scenarios (see below) on their likelihood of occurrence in the next 20 years.
   - a) New Space Race
   - b) Global Cooperation
   - c) Space Tourism
   - d) Lower Budgets
   - e) Commercial Superiority
3. Potential DTs in your Field
   - 3.1 Which technology has the highest potential to revolutionize your field in the next years?

- 3.2 From your point of view when could the technology be fully developed for space application?
- 3.3 Please give us a short description of the technology mentioned.

4. Potential Disruptive Technology outside your field
   - 4.1 Do you know a technology outside your field which might revolutionize space sector within the next years?
   - 4.2 From your point of view when could the technology be fully developed for space application?
   - 4.3 Please give us a short description of the technology mentioned.
5. General Information
   - 5.1 Please specify your age.
   - 5.2 In which kind of institution are you currently working?
   - 5.3 Please select the country where you are working.
6. Contact Data
   - 6.1 Please select what is appropriate to you.
   - 6.2 Please enter your name.
   - 6.3 Please type in your email address, when you want to participate for a future survey of our workgroup.

The first question group consists of two questions. Question 1.1 is a single choice question with the answer options "yes" and "no". If the question is answered with "yes", Question 1.2 with a table of answer options accordingly to the ESA tech tree appears (see Table 4-1). If the answer is "no" the answer options shown in Table 4-2 appear. The questions in the first question group are mandatory.

Table 4-1: Answer options for question 1.2 – space sector.

Aerothermodynamics	Materials and Processes	Space Debris
Automation, Telepresence and Robotics	Mechanisms and Tribology	Space System Control
EEE Components and Quality	Mission Operation and Ground Data Systems	Space System Software
Electromagnetic Technologies and Techniques	On-Board Data Systems	Spacecraft Environment & Effects
Environmental Control and Life Support	Optics	Structures and Pyrotechniques
Flight Dynamics and GNSS	Optoelectronics	System Design and Verification
Ground Station System and Networks	Propulsion	Thermal
In-Situ Resource Utilization	Quality, Dependability and Safety	RF Payload and Systems
Life and Physical Sciences		

Table 4-2: Answer options for question 1.2 – non-space sector

Advanced Materials	Electrical and Electronic Engineering	Photonics
Biotechnology	Information and Communication Systems	Physics
Chemistry	Mechanical Engineering	Robotics
Computer Sciences	Micro- and Nanoelectronics	Other

The question in the second group asks the participants to rate five potential future scenarios of the space sector on their likelihood to occur, from 1 = 'Likely to occur' to 5 = 'Unlikely to occur'. This mandatory question serves three purposes:

- Prepare the mindset of participants for the next questions
- Get results on likely future scenarios that are valuable for later evaluation of concepts
- Check if there is a difference between future views of junior and senior experts.

The third question group consists of three questions where the first is mandatory. In this block, the participants get questions about potential DTs in their field of work. They have to name the most interesting technology. After this, they have to state when the technology could be ready for space application. Three answer options are possible for this question:

In the next 5 years (short-term)

In the next 5 - 15 years (mid-term)

In more than 15 years (long-term)

Afterwards, the participants can describe the technology in a few sentences to give key features and pros and cons of the technology.

Question block number four is identical to number three except that the questions in this group are about potential DTs from outside of the participant's own field of work. Furthermore, this question group has an additional question. The participants can choose in which category of the space sector the technology can be used. The categories are shown in Table 4-3. In addition an 'other'-option with a text field is available where the user can fill in a category.

Table 4-3: Answer options for question 3.3.

Command and Data Handling System	Ground Station Systems	Payload
Communication System	Guidance, Navigation and Control	Propulsion System
Electrical Power System	Mission Analysis	Structures and Mechanisms
Environment Control and Life Support System	Mission Operation	Thermal Control System

The questions in the fifth question group serve the purpose of collecting general information about the participant. The responses of this block are used to estimate the demographic characteristics of the replier and to rate his answers to the other questions. The participants enter their age, select the kind of institution they work for and the country they reside in. All questions in this question group are mandatory.

If the survey participants want to get informed about the study results and/or want to get an invitation to a future study they can choose the appropriate option in question block six. Questions 6.2 and 6.3 will only appear, if the user selects one or both of the first two options. Details about the survey processing and its analysis are described in the next section.

4.5 Survey Results

This section describes the scan for technologies and concepts in- and outside the space sector via the survey adopted by the study team and the analysis of its responses. First, the demographics of the survey population are analyzed. After this, the technologies mentioned by the participants of the questionnaire are examined and divided into technologies of the space sector and spin-in technologies.

All the technologies are evaluated on their disruptive potential by means of subjective weighting of criteria by a panel of decision makers. This method of evaluation is described in TN02 and elaborated upon in Chapter 5. Eventually a list of the most promising DSTs is created and sorted in a table with regard to the Space System Categorization TN01.

Invitations for participation in the survey are sent to over 2300 experts from both in and out of the space sector. After one reminder and five weeks, the online questionnaire was deactivated. In total 171 complete responses were given in addition to 80, which were not sufficiently completed to be taken into account.

Several demographic factors of the answers of the questionnaire are analyzed in this section. In particular the responses to the 1st, 2nd and 5th question group are shown and evaluated.

4.5.1 1st Question Group: Field of Work

The first question group has two purposes: first to divide the participants into experts from the space-sector and from other research fields and second to specify the field of work of the participants.

A value of 28% of the responses are from outside and 72% are from inside the space-sector. One possible reason for this is that people from the space sector have a greater interest in a survey about DSTs than non-space sector experts.

4.5.2 General Information

The questions of the 5th question group cover the participants' age, origin and the type of organization they are employed by.

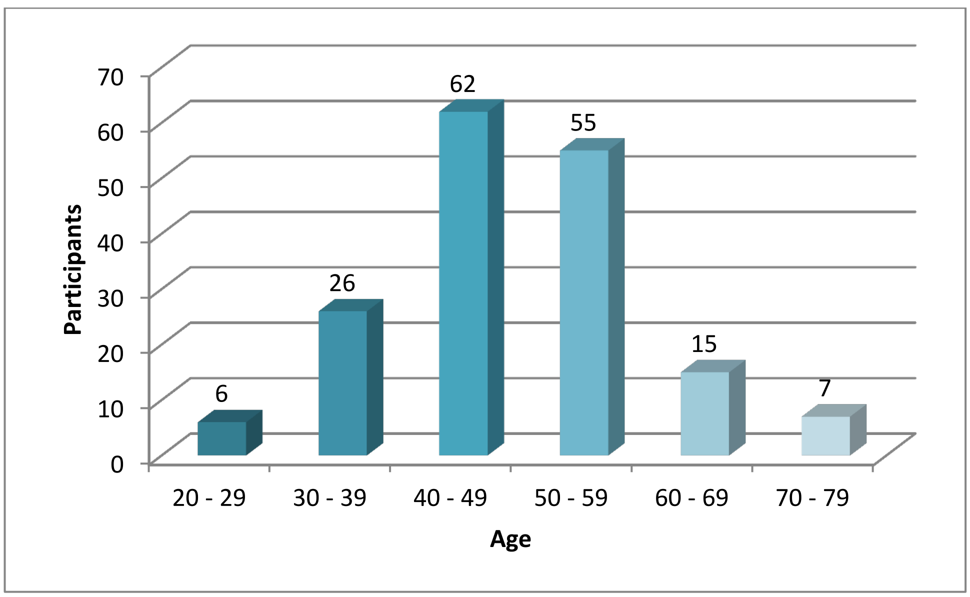


Figure 4-3: Age of the experts.

Figure 4-3 shows the amount of participants from different age spans. As can be seen, most experts are within the age of 40 to 59 years. This can be explained due the fact that young employees do not have enough experience to be considered an expert in their field and usually young people are not in a position of an organization where their contact information can be easily found.

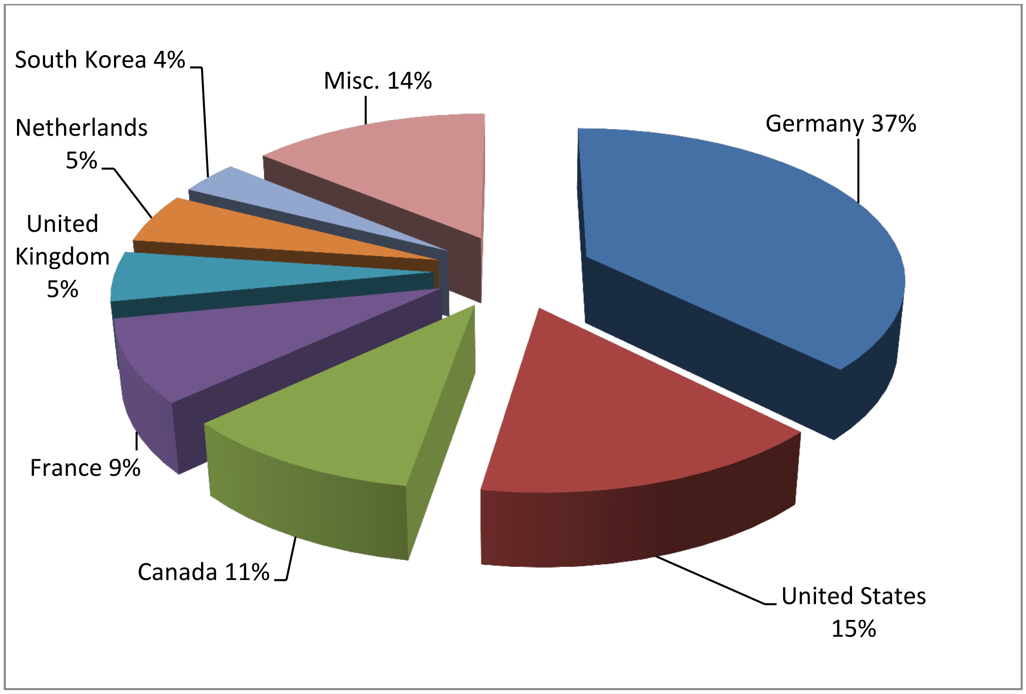


Figure 4-4: Participants per country.

The percentage of the participants' nation of origin is shown in Figure 4-4. The amount of responses of some countries is too low to be shown in an extra slice in the pie chart and they are therefore merged together in the miscellaneous section. Due to the fact that the DLR is a national German organization, the largest amount of responses, 37 %, comes from German experts. While the amount of invitations sent to upcoming space faring nations like China, India and Brazil was quite high, the amount of responses is close to zero. In addition the diagram shows that the amount of responses to the survey is high in the established space faring nations, except Japan and Russia with zero replies.

The number of responses from the different types of organizations is nearly equal to each other i.e. there is no bias due to employment, providing a complete view from the whole range of organizations.

4.5.3 Possible Future Scenarios for the Space Sector

This question asked the participants to rate five potential future scenarios of the space sector on their likelihood to occur, from 1 = 'Likely to occur' to 5 = 'Unlikely to occur', in the next years.

List of possible future scenarios for the space sector:

a) New space race: Another space race will occur between established space faring nations and upcoming economies like China, Brazil and India.

b) Global Cooperation: All different spacefaring nations will have close cooperation in space sciences as well as fair competition in commercial ventures.

c) Space tourism: Space tourism will become a major success and will fly private astronauts to sub-orbit, obit and eventually space hotels.

d) Lower budgets: Governmental budgets are declining because of decreased interest of the general public in space sciences (for example due to economic crisis or political instability)

e) Commercial superiority: Activities from governmental agencies will more and more be taken over by commercial entities which will result in major cost benefits.

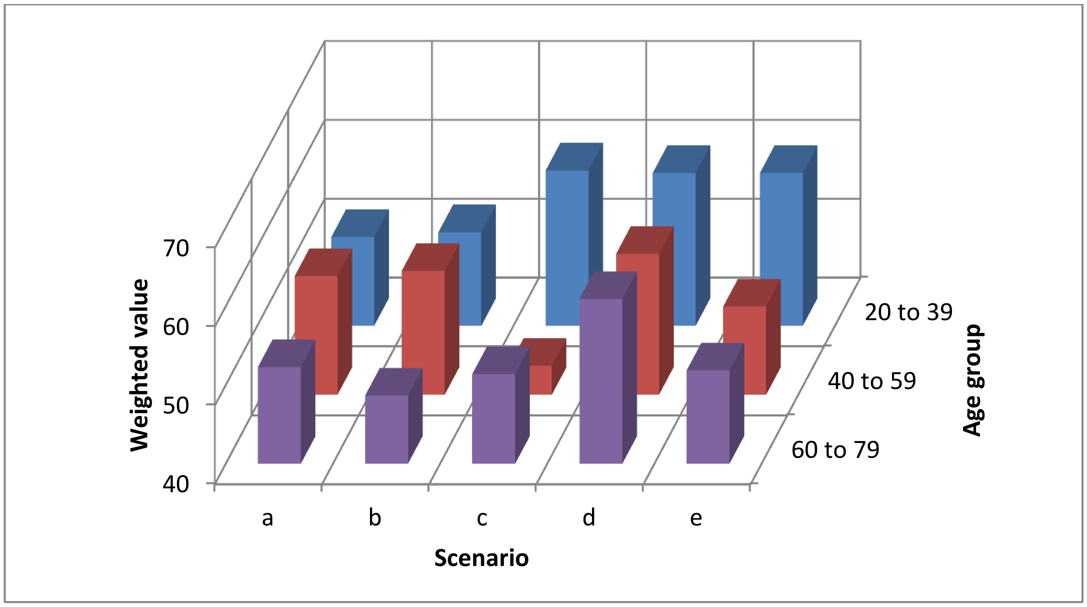


Figure 4-5: Weighted value per answer option and age group weighted by the number of participants per group.

There is a natural tendency to vote for the neutral answer options '2', '3' and '4'. Therefore scaled points are given to each answer option to analyze responses to this question. The distribution of the points is similar to a 3rd order power function.

The score of each scenario is weighted by the number of people per age group. The higher the value of the scenario is, the more the participants think that it might occur. The weighted score of the scenarios a) and b) are close to a value of 50 for each age group. Out of this result it can be assumed that the survey participants have a neutral thinking about these two scenarios. That means the participants are not sure if these scenarios might occur in the next years or not.

The biggest difference between the age groups can be seen in the votes to scenario c). This scenario is about the uprising of space tourism, a new form of spaceflight that is currently followed with a high interest in the general public and in the media.

The highest acceptance of all age groups is achieved by scenario d). Therefore it can be assumed, that the majority of the participants think governmental budgets will decline because of the decreasing interest of the general public in space sciences or due to economic crises or political instability.

Scenario e) shows nearly the same distribution as scenario c). That is another new option for the future of the space sector, which appeared in the last few years. Younger people are more optimistic, that this scenario will occur in the next years, than the other two age groups, which voted more conservatively.

4.5.4 Revolutionary technologies

The participants of the survey mentioned 134 potential DTs from both in and out of the space sector. These technologies were filtered and the relevant technologies were put into the database using the criteria elaborated in the beginning of this chapter. The next section elaborates upon this database.

4.6 Design of Database

The technology database first serves as a deposit for the technologies identified in the search strategy. Second, it serves to provide extra information about the technology to the experts which are involved in the Analytical Hierarchy Process (AHP) process. Third, it is a tool, which supports measuring the opinions of the experts according to the AHP method. This AHP method is explained more elaborately in section 5.1 of TN02 and worked out in Chapter 5 of this TN. The database contains the following information about the technology:

Name	The name of the technology under which it is most commonly known
Description	Contains a short description of the technology, this information can come from multiple sources (e.g. scientific papers, websites, information sheets, discussion blogs)
Advantages	Contains advantages the technologies has over the current state-of-the-art, which would be used in the same field of application
Disadvantages	Contains disadvantages the technologies has over the current state-of-the-art, which would be used in the same field of application
Possible type of DST	Involves which kind market encroachment the technology is. The types of encroachment are illustrated in TN02 and are: Niche-market, Low-end encroachment, High-end encroachment and Fringe encroachment.
Technology Field	Shows whether the technology results from either technology development within the space sector or from outside (spin-in)
Technology Domain	The classification of the technology according to the ESA technology tree.
Technology Subdomain	The classification of the technology according to the ESA technology tree.
Technology Group	The classification of the technology according to the ESA technology tree.

Maturity	Measures the maturity of a technology. The maturity is measured broad for classification purposes so no TRL is measured but rather whether or not the technology's disruption will likely occur up to 5 years, 5-15 years or longer than 15 years from now.
AHP	This part allows for a pre-selection of technologies according to the AHP pre-selection process elaborated in TN02.
Social	Allows of scoring on the social factor of the AHP process
Technical	Allows of scoring on the technical factor of the AHP process
Economic	Allows of scoring on the economic factor of the AHP process
Political	Allows of scoring on the political factor of the AHP process
Total score	List the total score of the technology based on the multiplication of the scores for the individual factors and the weighting determined in Section 5.1 of TN02.

This database can be used as the basis for an extended Scanning, Monitoring and Tracking (SMT) database (Compare recommendations TN02). To adapt it for this purpose, certain fields have to be added (e.g. performance evolution, patent analysis, literature evolution).

5 Pre-selection of promising DSTs

Based on Chapter 5.1 of TN02, the AHP is used to establish a pre-selection of promising DSTs, narrowing down the candidates present in the database to a more manageable amount as part of the funneling (TN02, Section 5.2). The evaluation method utilizes a funneling approach because evaluating every technology within the database on basis of the Delphi Method (which is elaborated upon in TN04) would be overly time consuming. The process was performed using the DST project members together with several distinguished experts within various fields of expertise. This setup has been chosen to ensure a balance between project members and experts with an abundance of experience in space technology development (see short bio's in Annex 2). All participants of the pre-selection process are instructed to the selection process via a manual, elaborated in Annex 3. The entire Database with results from the AHP Pre-selection can be found in Annex 4.

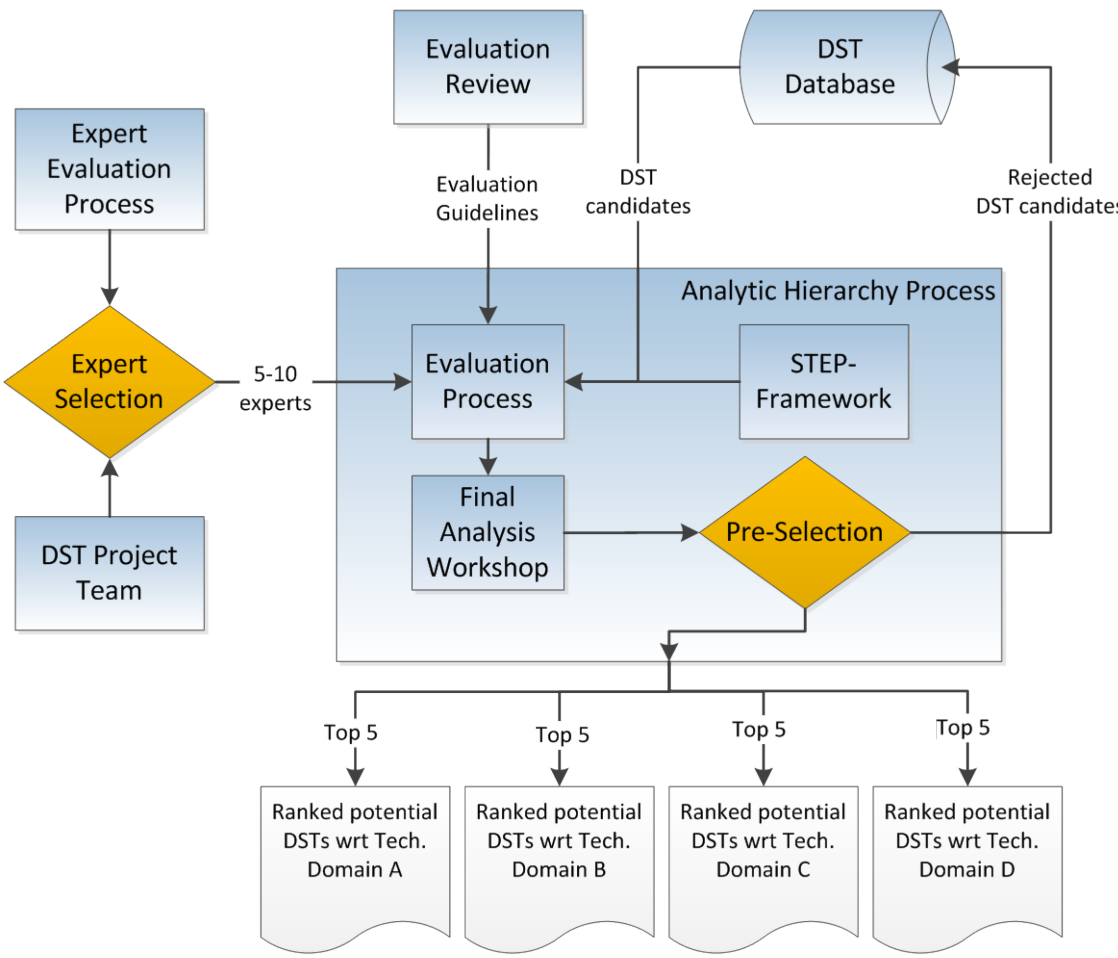


Figure 5-1: AHP overview.

5.1 AHP process

The AHP process was described in Section 5.1 of TN02 as a method for multi-criteria decision analysis. Within this scope, the decision is to allow a technology concept to be further evaluated using the Delphi Method.

Figure 5-1 shows the overview of the AHP process, described in TN02. As can be seen, the input of the AHP evaluation process is a range of experts, the DST database and the evaluation guidelines. Respectively, the experts are listed in Annex 2, the database is described in Chapter 4 and the evaluation guidelines are described in Section 5.1 of TN02. From the total ranking, a top 10 list is set-up from the different fields chosen in the Search Scope (Section 3.3 of TN01). The ranked technologies are presented to ESA, which are able to indicate their preferred technologies for the Delphi round. This additional checkup is done to validate the technologies are not yet under development of ESA as to eliminate the possibility of double work. The by ESA selected technologies are represented in TN04.

5.2 Results of pre-selection

This section lists the technologies which are selected for further evaluation. These technologies are chosen on their time frame of application and their scoring on the pre-selection method. These technologies have been communicated with ESA to ensure their compliance with the selected technologies, which are listed in the following sections

5.2.1 Materials & Processes

The following technologies are ranked highest within the materials & processes domain:

Table 5-1: Top 10 of the pre-selection within the Materials & Processes domain

	AHP Factors				
Technology Name	**Social**	**Technical**	**Economical**	**Political**	**Total**
Ceramic Composite Structures	6,00	7,83	6,50	6,83	**7,35**
Graphene	5,86	7,86	5,86	6,29	**7,15**
Metalic Microlattice	5,40	7,80	6,00	6,20	**7,11**
Graphite Epoxy Composite	5,40	7,80	5,60	5,80	**6,98**
Boron Nitride Nanotubes	4,20	7,40	6,40	5,60	**6,84**
Elastic Memory Composite Material	6,00	7,50	4,83	6,00	**6,67**
Carbon Reinforced Plastics (CFRP)	5,50	7,17	5,17	5,33	**6,44**
Biomimetic Adhesive Polymers Based on Mussel Adhesive Proteins	5,83	7,00	4,50	6,33	**6,32**
Electroactive Polymers	5,33	7,00	5,00	5,50	**6,31**
Basalt Fibers	4,83	6,50	6,50	5,17	**6,28**

Ceramic Composite Structures

Fiber reinforced ceramics are a new class of materials which combine the well-known superior properties of monolithic ceramics like high temperature, chemical resistance, hardness and wear resistance, with very uncommon qualities like extreme thermal shock resistance, damage tolerance and quasi-ductile fracture behavior. Enhanced ceramic matrix composites based on oxidation resistant materials might allow the design and manufacturing of light weight and high performance combustion chambers and nozzles leading to an overall superior performance compared to current designs. Manufacturing reproducibility and reliability need to be improved and successfully demonstrated.

Graphene

A new high-strength, light-weight material, which can be used for many different applications like high performance batteries, super conductors or composite materials. Performance data: Diameter: < 1 nm - 50 nm; Density: 1.5 g/cm^3; Tensile Strength: 60 GP; Thermal Conductivity: 6000 W/ K m The advantages are the high tensile strength, the low density as well as the thermal properties. Can encompass different fullerene forms like Bucky balls, graphene sheets and carbon nanotubes.

Metalic Microlattice

A metallic microlattice is a synthetic porous metallic material, consisting of an ultra-light form of metal foam. Its creators claim it is the "lightest structural material" known, with a density as low as 0.9 mg/ cm^3. Its structure was created of interconnected hollow tubes with a wall thickness of 100 nanometers. The material can completely recover from compression exceeding 50% strain and has extraordinarily high energy absorption properties. The microlattice could be used for battery electrodes, catalyst supports, and acoustic, vibration or shock energy damping.

Graphite Epoxy Composite

Graphite composites are extremely versatile and have exceptional mechanical properties which are unequaled by other materials. Graphite composites have an extremely low coefficient of thermal expansion. The material is strong, stiff, and more lightweight than monolithic materials such as steel and aluminum, which make it attractive for numerous weight critical applications. Graphite composites are ideally suited for applications where high stiffness and lightweight is required, for example in satellite antenna, space- and aircraft structures, scanning and imaging machines, and in precision optical devices. In addition it might have some application in electromagnetic interference shielding covers and grounding planes if the conductivity can be improved.

Boron Nitride (BN) Nanotubes

They can be imagined as a rolled up sheet of boron nitride. Structurally, it is a close analogue of the carbon nanotube, namely a long cylinder with diameter of several to hundred nanometers and length of many micrometers, except carbon atoms are alternately substituted by nitrogen and boron atoms. A BN nanotube is an electrical insulator with a band gap of ~5.5 eV, basically independent of tube chirality and morphology. In addition, a layered BN structure is much more thermally and chemically stable than a graphitic carbon structure. BN nanotubes show promising aerospace applications where integration of boron into structural materials improves their radiation-shielding properties; the improvement is due to strong neutron absorption. Such materials are of particular theoretical value as composite structural materials in future manned interplanetary spacecraft, where absorption-shielding from cosmic ray spallation neutrons is expected to be a particular asset in light construction materials.

Elastic Memory Composite Material

Elastic Memory Composites (EMC) combine the structural properties of fiber reinforced composites with shape memory characteristics of shape memory polymers. The EMC materials use a shape memory polymer matrix and graphite or glass fiber reinforcements. Above its glass transition temperature (T_g), the elastic memory composite has a low modulus and exhibits high strain to failure. In this state, an EMC laminate can be readily folded, and if held in a folded shape and cooled below T_g. Reheating above T_g causes the EMC material to return to its as-cured shape without the use of external force. The EMC material enables a fully cured composite structure regaining its original shape with no degradation or loss in mechanical or physical properties. A component using EMC materials is fabricated in its deployed, on orbit shape using conventional composite manufacturing processes. Then by heating the material and applying force this fully cued composite material can be folded or deformed for packaging. When cooled, it will retain the packaged shape indefinitely. When reheated the structure will regain its original shape with little or no external force. This packaging/deployment cycle is reversible.

Carbon Reinforced Plastics (CFRP)

These new materials could be a way to store liquid hydrogen and oxygen cryogenically. They can manage the extreme stresses of temperature differences between inside 20 K and outside more than 500 K as well as the high pressure inside. They also have a low mass, because they are made of polymers. Although they can be relatively expensive, there are a lot of possible applications in aerospace and automotive fields, where its high strength-to-weight ratio and good rigidity is of importance.

Biomimetic Adhesive Polymers Based on Mussel Adhesive Proteins

Especially for manned long term missions under isolated environmental conditions the used adhesives should not emit monomers to the air and should have a good compatibility to organisms. They need to be non-toxic and could be used for repair processes, also in bio regenerative life support systems. New biomimetic glue concept based on marine mussel is nontoxic, has a higher strength for polycarbonate than unmodified glue and requires only little surface preparation. It is resistant to fungi, durable, and sticks to the most space relevant materials, such as polycarbonate and AlMg³.

Electroactive Polymers

Electroactive Polymers, or EAPs, are polymers that exhibit a change in size or shape when stimulated by an electric field. The most common applications of this type of material are actuators and sensors. A typical characteristic property of an EAP is that they undergo a large amount of deformation while sustaining large forces. The majority of historic actuators are made of ceramic piezoelectric materials. While these materials are able to withstand large forces, they commonly will only deform a fraction of a percent. Performance data: Strain of 10-200 % possible in an electric field of ~100 V/µm

Basalt Fibers

Basalt fiber is a material made from extremely fine fibers of basalt, which is composed of the minerals plagioclase, pyroxene, and olivine. It is similar to carbon fiber and fiberglass, having better physical mechanical properties than fiberglass, but being significantly cheaper than carbon fiber. It is used as a fireproof textile in the aerospace and automotive industries and can also be used as a composite to produce products such as camera tripods.

5.2.2 On-Board Data Systems

The following technologies are ranked highest within the on-board data systems domain:

Table 5-2: Top 10 of the pre-selection within the On-Board Data Systems domain

	AHP Factors				
Technology Name	**Social**	**Technical**	**Economical**	**Political**	**Total**
Quantum computing	7,00	9,00	6,50	7,17	**8,15**
DNA Computer	5,17	8,17	5,50	5,83	**7,18**
Holographic Data Storage	5,80	8,00	5,40	6,40	**7,14**
Quantum Sensor	6,17	7,83	6,00	5,67	**7,11**
Chalcogenide-Based Reconfigurable Memory Electronics	6,17	7,33	6,50	6,17	**6,97**
Quantum communication	7,00	7,50	6,00	5,50	**6,92**
Wireless data handling	5,20	7,20	6,00	6,00	**6,71**
Noise-Robust Speech Recognition for Speech Computer Control	6,60	7,00	5,40	7,00	**6,63**
Three-dimensional integrated circuit	5,67	6,83	5,67	5,83	**6,41**
Gallium Nitride semiconductor technology	5,60	7,60	3,20	5,60	**6,30**

Quantum computing

Quantum computers use the quantum technology to perform complex calculations significantly faster than any silicon-based computer. The use of qubits (quantum bits) instead of bits and the capability of performing calculations in parallel give quantum computers a processing power of 10 teraflops (trillions of floating operations per second). Today's typical desktop computers run speeds are measured in gigaflops (billions of floating-point operations per second).

A classical computer has the bit as the fundamental building block. The bit can only have two states: 0 or 1. Through algorithms calculations are performed, which use the bits with their corresponding state. Quantum computers use the qubit as fundamental building block. The qubit has a complex representation, i.e. it has 2 values at the same time. When an algorithm is applied, the corresponding operation is performed with both values of the qubit in parallel, so the results of 2 calculations are obtained. If the system has 2 qubits, the operation is performed four times; if the system has 3 qubits, the operation is performed eight times. This phenomenon is called "quantum parallelism" and it increases exponentially with the number of qubits. The parallelism makes these computers much faster than any other classical computer.

The biggest advantage offered by the quantum computers is the powerful computer power that enables extremely fast calculations due to the parallel computer tasks. Another advantage is its application to the decryption of many of the cryptographic systems in use today. This advantage, though, can also be seen as a disadvantage: if this capability is not used correctly security issues can be jeopardized.

Although quantum technology seems to be a big improvement for the computing, it is very difficult to implement, and researchers show skepticism because, since the technology is based on quantum mechanics, it is too fragile at the moment to be practical; most development on this field is merely theoretical. Further investigation will be carried out within the next years, and one of the core issues will be the identification of the best way to create qubits from quantum particles.

The main applications for this technology is cryptography, conductance of quantum simulations, which are slow if done with classical computers, and fast search of unsorted databases, enabled by the quantum parallelism. Applications of this method of computing will have major impact on the space sector in the area of communications, simulations, trajectory optimization and many others.

DNA Computer

"DNA computing is a form of computing which uses DNA, biochemistry and molecular biology instead of the traditional silicon-based computer technologies. The aim of the use of DNA as computational element is to take advantage of DNA's extremely dense information storage capability (1bit/nm3), the enormous parallelism it provides (10^18 operations at the same time) and its efficient performance (2x10^19 operations per joule). DNA stores the information about our genes permanently, and this is the basic principle to be used in this technology.

The most significant experiment with DNA computers has been the one conducted by its inventor Leonard Adleman in 1994. It consisted of the application of an algorithm to solve the called Hamilton Path problem. Its goal is to find the shortest route between a number of cities, going through each city only once. The problem becomes more complex if more cities are added. The solution to this problem proved that DNA computers can be used to calculate complex mathematical problems. Adleman's experiment also proved that DNA computers would need human assistance, since he had to narrow down the possible results.

DNA computing provides smaller devices with less power consumption compared to normal computing. Once algorithms are applied, many operations can be performed at the same time, due to the parallelism that characterizes DNA. Moreover, DNA is a cheap resource, since it can be provided as long as there are cellular organisms, and DNA biochips can be maid cleanly, without toxic components.

However, a long research has to be carried out before the expansion of the DNA as means of computing and information storage. Adleman's first DNA computer needed human assistance, and this is an issue to be solved in future development. No efficient implementation has been produced for testing, verification and general experimentation, and radiation effects on DNA computers are unknown. There is no universal method of data representation and the amount of error is at the moment too big. Furthermore, the computation time required to solve problems does not grow exponentially, but the amount of DNA required does.

Holographic Data Storage

Holographic data storage is a potential technology in the area of high-capacity data storage currently dominated by magnetic and conventional optical data storage. Magnetic and optical data storage devices rely on individual bits being stored as distinct magnetic or optical changes on the surface of the recording medium. Holographic data storage overcomes this limitation by recording information throughout the volume of the medium and is capable of recording multiple images in the same area utilizing light at different angles

Quantum Sensor

A quantum sensor therefore is an influencing system that can measure the effect of the quantum state of another physical or particle system on itself. The mere act of measurement influences the quantum state and alters the probability and uncertainty associated with its state during measurement. A quantum sensor is a device that exploits quantum correlations, such as quantum entanglement, to achieve a sensitivity or resolution that is better than can be achieved using only classical systems

Chalcogenide-Based Reconfigurable Memory Electronics

Chalcogenide glasses are materials which contain Sulfur (S), Selenium (Se) and/or Tellurium (Te), or combinations of them. These materials are characterized because of their behavior in front of the passage of an electric current. They change their conductivity dramatically due to a rapid change between polycrystalline and amorphous states. Both states have a completely different electrical resistivity. The polycrystalline state has a low resistance and represents a binary 0. The amorphous state has a high resistance and represents a 1.

This phenomenon has already been exploited in rewriteable DVDs, and optical disk technologies with terabyte densities are on the horizon. With the commercial mass production of phase-change electrical memory being announced, the emphasis is quickly moving to electronic non-volatile memory (NVM), which retains the information when the power is turned off. NVM is typically used for the task of secondary storage, or long-term persistent storage. For the moment RAM (Random Access Memory) is used as primary storage, though it is a volatile form, i.e. without power the information is lost. NVM is used as secondary storage because of limitations of costs and worse performance compared to RAM.

Recent literature results suggest that the long-held dream of an energy-efficient non-volatile memory that switches at DRAM-like speeds is rapidly becoming a reality. Several companies are working on developing non-volatile memory systems comparable in speed and capacity to volatile RAM.

An application to the NVM technology is the development of Phase-Chang Random Access Memory (PCRAM). PCRAM is a resistance based non-volatile memory, where the state of the memory bit is defined by the resistance of the chalcogenide material. The resistance state depends on the microstructure of the material: amorphous or polycrystalline. PCRAM is based on the memristor (memory resistor) created in 2008 by Hewlett Packard: when current flows in one direction, the electrical resistance increases (the chalcogenide glass becomes amorphous). When current flows in the opposite direction, the resistance decreases (polycrystalline state). It has a regime of operation with an approximately linear charge-resistance relationship.

Chalcogenide based PCRAM is one of the most promising non-volatile memories for the next generation of portable electronics, due to its excellent scalability, large sensing margin, fast switching speed, and possible multi-bit per cell operation. Thanks to this technology, memory devices would be smaller, and their speed higher.

While they have been exploited technologically, there are still many fundamental questions to be answered. The different applications of this technology are still in early stage of research.

These materials are also candidates for a variety of reconfigurable applications in RF circuitry, antennae, analog circuits, and even as reconfigurable wiring harnesses.

Quantum communication

Quantum communication is based on the concept of quantum entanglement in which two particles entangled have the similar properties, no mather how far they are located from each other. Although this effect does not allow for faster than light communication, because there is no way to verify a change in spin of a particle, it can nonetheless be possible to use it in unbreakable encryptions which could be used for satelite communication is a new quantum computing era.

Wireless data handling

Reducing or eliminating the wires in satellites or spacecraft and using wireless data handling for reducing the mass. Performance data: Data flow: 1 - 10 Mbps; 10 % vehicle mass reduction in comparison with cables. Besides mass reduction, wireless networking between several manned and unmanned spacecraft could enable the seamless transfer of data and commands. Wireless communication enables the elimination of complex and expensive cable harnesses. Wireless data handling technologies facilitate add-on capabilities to existing spacecraft without significant engineering.

Noise-Robust Speech Recognition for Speech Computer Control

Speech recognition (also known as automatic speech recognition, computer speech recognition, speech to text) converts spoken words to text. The term ""voice recognition"" is sometimes used to refer to recognition systems that must be trained to a particular speaker—as is the case for most desktop recognition software. Recognizing the speaker can simplify the task of translating speech. Speech recognition is a broader solution that refers to technology that can recognize speech without being targeted at single speakers — such as a call system that can recognize arbitrary voices.

Noise-Robust Speech Recognition for Speech Computer Control are techniques to improve the robustness of automatic speech recognition systems to noise and channel mismatches.

Three-dimensional integrated circuit

In electronics, a three-dimensional integrated circuit (3D IC, 3D-IC, or 3-D IC) is a chip in which two or more layers of active electronic components are integrated both vertically and horizontally into a single circuit. This could reduce the amount of circuits in a spacecraft which saves room and mass.

Gallium Nitride semiconductor technology

GaN semiconductors are capable of delivering up to 10-times higher power levels compared with the current technology. GaN semiconductors offer substantially improved power and functionality beyond current semiconductor technologies. They operate at higher voltage levels allowing significantly greater power output for the same chip size. Furthermore, the material characteristics of GaN semiconductors offer efficient multi-band or wideband operation.

5.2.3 Propulsion

The following technologies are ranked highest within the propulsion domain:

Table 5-3: Top 10 of the pre-selection within the Propulsion domain

	AHP Factors				
Technology Name	**Social**	**Technical**	**Economical**	**Political**	**Total**
Laser propelled light craft	5,50	8,00	6,17	5,50	**7,20**
Altitude compensating nozzles	5,20	7,80	5,40	5,80	**6,93**
Fission Fragment Rocket Engine (FFRE)	4,50	7,83	5,67	5,00	**6,89**
Alternative Solid Propellants: CL-20	5,20	7,80	4,80	5,80	**6,79**
Micro Electric Space Propulsion (MEP)/ NanoFET	5,33	7,17	6,17	5,83	**6,72**
Ambient Plasma Wave Propulsion	5,40	7,00	6,20	5,40	**6,57**
Magneto-plasmadynamic thruster (MPDT)	5,40	7,40	4,60	5,80	**6,51**
Magnetic Sails	5,00	7,17	5,50	5,33	**6,49**
Variable specific impulse magnetoplasmarocket (VASIMR)	5,20	7,20	5,20	5,40	**6,46**
Electrodynamic Tether	5,17	6,50	6,67	6,17	**6,44**

Laser propelled light craft

A spacecraft propelled by a stationary laser on Earth to eliminate the mass of the propulsion system at the spacecraft. Performance data: ISP: 200 - 3100 s; For 100 kg payload 150 MW power source is required. Beamed Energy Propulsion (BEP) is a revolutionary technology for future space transportation. Typically, BEP vehicles are driven by power that can be beamed from a remote, reusable, and long-range source. Due to the limited availability of high power long-range sources, propulsion concepts based on on-board radiation sources have become more and more important. The majority of modern BEP techniques are based on lasers. Beamed Energy Propulsion offers unique propulsive characteristics which are superior to traditional thrusters. Vehicles driven by BEP will be smaller, lighter, faster, and more efficient than any currently existing means of space transportation. In addition, BEP offers new and often unique technical solutions which are unattainable by traditional means of propulsion. There is a lack of appropriate highly precise thrusters for attitude and orbit control of scientific satellite missions or formation flight scenarios and an increasing problem of space debris. Both are challenging problems of current interest. BEP technologies, like laser ablative micro propulsion and laser based debris removal, are the promising efforts to tackle these challenges in the future.

Altitude compensating nozzles

An altitude compensating nozzle is a class of rocket engine nozzles that are designed to operate efficiently across a wide range of altitudes. The basic concept of any engine bell is to efficiently direct the flow of exhaust gases from the rocket engine into one direction. The exhaust, a high-temperature mix of gases, has an effectively random momentum distribution, and if it is allowed to escape in that form, only a small part of the flow will be moving in the correct direction to contribute to forward thrust. The problem with the conventional approach is that the outside air pressure also contributes to confining the flow of the exhaust gases. At any one altitude, and thus ambient air pressure, the bell can be designed to be nearly "perfect," but that same bell will not be perfect at other pressures, or altitudes. Thus, as a rocket climbs through the atmosphere its efficiency, and thus thrust, changes fairly dramatically, often as much as 30%.

Fission Fragment Rocket Engine (FFRE)

A FFRE is a nuclear propulsion system which works at a much higher temperature than other nuclear generators. The individual atoms undergo fission at a temperature of millions of degrees and then are used to provide thrust, by extracting them from the rest of the fuel as quickly as possible before their energy is spread out into the surrounding fuel mass. If this technology can be mastered an Isp of 10^6 sec is possible with an efficiency of up to 90%.

Alternative Solid Propellants: CL-20

CL-20 is the highest energy single component compound known to date and, in addition, has the highest density of any known organic substance. It has a better oxidizer-to-fuel ratio than conventional HMX or RDX. CL-20 produces 20% more energy than traditional HMX-based propellants, and is widely superior to conventional high-energy propellants and explosives. CL-20 has better detonation properties than octogen, higher energy density, but lower impact and friction sensitivity.

Micro Electric Space Propulsion (MEP)/ NanoFET

Type of thruster that uses nanoparticles as propellant. Much of the engine is etched directly onto a wafer-thin piece of silicon via micro-electromechanical systems technologies, known as MEMS, that are more commonly used in the semiconductor industry. Measuring no thicker than a half-inch (1 centimeter, including the fuel) and with tens of thousands of accelerators able to fit on an area smaller than a postage stamp, these “stick-on” thrusters could power tiny spacecraft over vast distances. Performance data: ISP: 100 - 10.000 s; Efficiency of over 80%. Today used chemical propulsion have a maximum ISP of around 500 s.

Ambient Plasma Wave Propulsion

The propulsion system is based on helicon waves. They have the benefit to produce higher density plasmas than other types of plasma engines. The system can work as a rocket engine in zero-g as well as an air-breathing engine. The big advantage would be that the propulsion system can use the ambient atmosphere as propellant for station keeping of satellites.

Magneto-plasmadynamic thruster (MPDT)

A very powerful electric propulsion system which could make interplanetary manned flights possible but it needs also a huge amount of electric energy. Performance data: Exhaust velocity: 80.000 m/s; Isp: 2500-8000 s; Thrust: several hundred Newton are possible. The Magnetoplasmadynamic (MPD) thruster (MPDT) is a form of electric propulsion (a subdivision of spacecraft propulsion) which uses the Lorentz force (a force resulting from the interaction between a magnetic field and an electric current) to generate thrust. It is sometimes referred to as Lorentz Force Accelerator (LFA) or (mostly in Japan) MPD arc jet.

Magnetic Sails

A magnetic sail or E-Sail is a proposed method of spacecraft propulsion which would use a static magnetic field to deflect charged particles radiated by the Sun as a plasma wind, and thus impart momentum to accelerate the spacecraft. A magnetic sail could also thrust directly against planetary and solar magnetospheres. Performance data: delta-v: 10-20 km/s possible, but low acceleration.

Variable specific impulse magnetoplasmarocket (VASIMR)

The Variable Specific Impulse Magnetoplasma Rocket (VASIMR) is an electro-magnetic thruster for spacecraft propulsion. It uses radio waves to ionize and heat a propellant and magnetic fields to accelerate the resulting plasma to generate thrust. It is one of several types of spacecraft electric propulsion systems. The method of heating plasma used in VASIMR was originally developed as a result of research into nuclear fusion. VASIMR is intended to bridge the gap between high-thrust, low-specific impulse propulsion systems and low-thrust, high-specific impulse systems. VASIMR is capable of functioning in either mode. A spaceflight is planned for 2013. Performance data: Pel: 200KW; 72% efficiency; ISP: 3000s - 5000s; Thrust: 5.7N

Electrodynamic Tether

Electrodynamic tethers (EDTs) are long conducting wires, such as one deployed from a tether satellite, which can operate on electromagnetic principles as generators, by converting their kinetic energy to electrical energy, or as motors, converting electrical energy to kinetic energy.[1] Electric potential is generated across a conductive tether by its motion through the Earth's magnetic field. The choice of the metal conductor to be used in an electrodynamic tether is determined by a variety of factors. Primary factors usually include high electrical conductivity, and low density. Secondary factors, depending on the application, include cost, strength, and melting point.

5.2.4 Spacecraft Electrical Power

The following technologies are ranked highest within the spacecraft electrical power domain:

Table 5-4: Top 10 of the pre-selection within the Spacecraft Electrical Power domain

	AHP Factors				
Technology Name	**Social**	**Technical**	**Economical**	**Political**	**Total**
High temperature superconductors	6,29	8,00	5,57	6,43	**7,21**
UltraFlex solar panels	8,00	6,00	9,00	9,00	**7,10**
Advanced Stirling Radioisotope Generator (ASRG)	4,29	8,00	5,71	5,57	**7,05**
Quantum-Dot Solar cell	6,67	6,83	7,17	6,67	**6,89**
Unitized regenerative fuel cell (URFC)	6,00	7,40	5,60	6,40	**6,83**
Holographic Planar Concentrator Photovoltaic (PV) Module	6,80	7,60	4,40	7,00	**6,78**
Aluminum-Celmet for Li-Ion Batteries	5,67	7,33	5,83	5,67	**6,74**
Silicon Nanowire Lithium-Ion Battery	5,20	7,40	5,40	5,60	**6,66**
Nano Composite Solar Cell	6,20	6,80	6,40	6,20	**6,62**
Super/Ultra capacitors	5,33	7,00	6,33	5,17	**6,58**

High temperature superconductors

High-temperature superconductors (abbreviated high-Tc or HTS) are materials that have a superconducting transition temperature (Tc) above 30 K (–243.2 °C). From 1960 to 1980, 30 K was thought to be the highest theoretically possible Tc. Developments have continued and let to the discovery of Fe-based super conductors in 2008. Performance data: 300 times lighter wires are possible; Power density: 20.000 A/cm² (currently used transmission lines have around 100 A/cm²)

UltraFlex solar panels

Flexible highly efficient Ultraflex solar arrays are lighter and increasingly foldable then the current state of the art. The lightweight allows reduced launch costs. Ultra flex solar cells, have 25 % less mass, 5% higher efficiency and have increased foldability compared to traditional triple junction GaAs cells. Ultra flex solar cells have a compact and extremely low stowage volume (25% less volume of standard arrays) which enables spacecraft and launch vehicle flexibility.

Advanced Stirling Radioisotope Generator (ASRG)

The ASRG is a radioisotope power system using Stirling power conversion technology and is being designed for multi-mission use in environments with and without atmospheres for both deep space and for example the Mars atmosphere. Because of the Stirling cycle the efficiency is 4-5 times higher than current radioisotope generators. It is designed to have a lifetime of 14 years and has a specific power of 8,5 We/kg (in comparison a Multi-Mission RTG [MMRTG] has only 2,8 We/kg)

Quantum-Dot Solar cell

By using two or more p-n solar cell junctions, tandem cells made of different semiconductors, a multi-heterojunction design yields a better match to the solar spectrum than a single-junction cell. Efficiency of up to 66% (In comparison: Efficiency record of flexible solar cells: 18,7%; Overall efficiency record: Thin-film gallium-arsenide cell with 27,6%), Quantum dot solar cells are an emerging field in solar cell research that uses quantum dots as the photovoltaic material, as opposed to better-known bulk materials such as silicon, copper indium gallium selenide (CIGS) or CdTe. Quantum dots have bandgaps that are tunable across a wide range of energy levels by changing the quantum dot size. This is in contrast to bulk materials, where the bandgap is fixed by the choice of material composition. This property makes quantum dots attractive for multi-junction solar cells, where a variety of different energy levels are used to extract more power from the solar spectrum. The potential performance of the quantum dot approach has led to widespread research in the field. Early examples used costly molecular beam epitaxy processes, but alternative inexpensive fabrication methods have been developed. These attempts rely on quantum dot synthesis using wet chemistry (colloidal quantum dots – CQDs) and subsequent solution processability of quantum dots. CQD solar cells currently hold the performance record for quantum dot solar cells.

Unitized regenerative fuel cell (URFC)

An URFC could replace batteries for telecommunication satellites because the energy demand is rising up to 30kW which is hard to deliver with a light weight battery for a long time. The fuel cells can also run the process backwards for recharging which means it can make hydrogen and oxygen out of water and solar energy. The fuel cell is much lighter than a generator and an electrolyser and has the highest storage capacity of all non-nuclear storage systems.

Holographic Planar Concentrator Photovoltaic (PV) Module

The Holographic Planar Concentrator (HPC) is a highly effective solution for increasing the power production of solar power modules. Holographic film diffracts usable frequencies of direct and diffuse sunlight and guides that energy toward strip of photovoltaic (PV) or thin film solar cells. The HPC prototypes have shown consistent 1.5 times increased power production with as much as 2 times in low light conditions

Aluminum-Celmet for Li-Ion Batteries

A new battery technology with 1.5 to 3 times higher energy density than ordinary Li-Ion Batteries. The Aluminum-Celmet can replace the aluminum or copper foil, which is used for the conductor, because it has a much higher conductivity and corrosion resistance. In addition, Aluminum-Celmet also has a lower mass.

Silicon Nanowire Lithium-Ion Battery

The electrical storage capacity of lithium-ion batteries is limited by how much lithium can be held in the battery's anode, which is typically made of carbon. Although silicon has a higher capacity than carbon, it swells upon charging and then shrinks during use. This expand/shrink cycle typically degrades the performance of the battery, unless it uses a nanostructure, which has silicon regions and voids or contraction regions. While one layer expands, the other contracts, producing a net effect of zero expansion. The lithium is stored in a forest of tiny silicon nanowires, each with a diameter one-thousandth the thickness of a sheet of paper. The nanowires inflate four times their normal size as they soak up the lithium. The nanostructures provide greater total surface area, improving lithium uptake.

Nano Composite Solar Cell

Solar cells based on poly (3-hexylthiophene) (P3HT):TiO2 nanocomposite films were studied. The influence of nanoparticle concentration, solvent used for spin coating, and the film morphology on the device properties was investigated. For low nanoparticle concentration (20–30%) the device performance was worse compared to pure P3HT, while for higher concentrations (50% and 60%) significant improvements were obtained. It was found that the change of solvent (from chloroform to xylene) yields one to two orders of magnitude improvement in the nanocomposite photovoltaic cell efficiency. For optimal fabrication conditions, external quantum efficiency up to 15% and AM1 power conversion efficiency of 0.42% were obtained.

Super/Ultra capacitors

A super- or ultra-capacitor is an energy storing device which has a much higher storing capability than normal capacitors due to the extremely high surface area of their interior materials (for example carbon nanotubes). They have the advantages that they do not store the energy chemically, just by separating the positive and negative charges and they have no moving parts (long life span). Main advantages: -Virtually unlimited life cycle - cycles millions of time -10 to 12 year life; -Low impedance; -Charges in seconds; -No danger of overcharge; -Very high rates of charge and discharge; -High cycle efficiency (95% or more); -Super capacitors and ultra-capacitors are relatively expensive in terms of cost per watt.

5.3 Conclusion

The technologies found in this pre-selection are offered to ESA for selection. This has been done to make sure ESA conforms with the selected technologies and that there is a no double evaluation. The selected technologies are elaborated in TN04 and are futher evaluated there using the Delphi Method and a supporting desk research.

Annex 1: Areas of responses

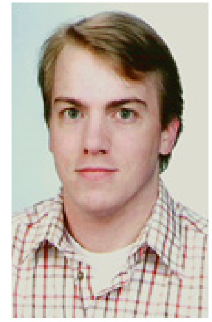
Category according to ESA tech tree	Responses	Category according to ESA tech tree	Responses
Life and Physical Sciences	13	Spacecraft Environment & Effects	3
Propulsion	12	Ground Station System and Networks	2
Environmental Control and Life Support	10	Optics	2
System Design and Verification	10	Space Debris	2
Thermal	10	Space System Control	2
Electric, Electronic and Electromagnetic Components and Quality	6	Structures and Pyrotechniques	2
Flight Dynamics and GNSS	6	Electromagnetic Technologies and Techniques	1
On-Board Data Systems	6	In-Situ Resource Utilization	1
Optoelectronics	6	Quality, Dependability and Safety	1
RF Payload and Systems	6	Spacecraft Electrical Power	1
Aerothermodynamics	5	Space System Software	0
Materials and Processes	5	Mechanisms and Tribology	0
Mission Operation and Ground Data Systems	4	Automation, Telepresence, Robotics	0

Annex 2: Short Biographies of Evaluation Board

Dipl. Ing. **Daniel Schubert** works for DLR in Bremen since December 2007 within the department of System Analysis Space Segment (SARA). Until May 2010, Mr. Schubert has been project leader for ESA contract (Knowledge Capitalization in a CE-Environment). He did several cost estimations for unmanned and manned space missions. As another task Mr. Schubert creates analytical evaluations of space missions, projects and systems. Furthermore, he developed (incl. patent registration) a micro solar dynamic generator using Power-MEMS technology as energy supply for satellites. He has held the project responsibility of the DST project since the start in 2010. Within his Industrial Engineering Diploma at the Technical University of Berlin he specialized on Technology & Innovation Management and has a profound knowledge about different technology evaluation methods. Here he also coordinated a research team, where several System Dynamics (SD) simulation models about complex economical relationships were programmed.

During his long time of work within the space industry Dr. **Oliver Romberg** has gained extensive experience as project manager and systems engineer in several areas and Phases A, B, C and D of space projects. Since July 2007 he has taken over the role of Head of Department within the "System Analysis Space Segment" at German Aerospace Center (DLR). Key subjects of his work are analyses and evaluations of existing and future space systems concerning technical, economic and social political aspects. One major task of Dr. Romberg presently is the build-up, development and operation of DLR`s Concurrent Engineering Facility (CEF).

Mr. **Egbert Jan van der Veen** works since October 2009 within the department of System Analysis Space Segment. He is performing a PhD on DSTs and manages the day to day responsibilities of the DST project. He has a Masters of Science in Technology Management from the University of Groningen and a Bachelor of Engineering in Industrial Engineering and Management from the Hanze University of Applied Sciences in Groningen. Before he started working at the DLR he worked for various multinationals like T-Mobile and Google.



Mr**. Volker Matthäus Maiwald** has been a member of the Department of System Analysis Space Segment since February 2010, where he works as systems engineer and mission analyst. Currently he is mostly involved in Concurrent Engineering Studies, teaching at the University of Bremen on the subject of space flight mechanics and since early 2011, as a project member in the DST project. He has obtained the degree of Dipl.-Ing. at the Technical University of Aachen and is elaborating a PhD study on the subject of low-thrust trajectory optimization. Previously he worked for the Fraunhofer Society Institute for Laser technology and EADS.

Ms. **Rosa Paris Lopez** works since June 2011 in the department of System Analysis Space Segment at the DLR. Since then her work has been focused on Concurrent Engineering and the simulation and analysis of subsystems in early phases of design. Within the DST project she took part in the technology evaluation and rating. She graduated in Aerospace Engineering from the Polytechnic University of Catalonia after presenting her final thesis at the Institute of Astronautics at the Technical University of Munich.

Dr. **Tim van Zoest** is the Head of the Department of Exploration Systems within the Institute of Space Systems of DLR in Bremen, Germany. After finishing his Master Thesis in Giessen in 2004, he worked as a PhD Student at the University of Hanover where he received his PhD in 2008. Since 2009 he is working in the Institute of Space Systems in Bremen.

As the Head of the Department of Exploration Systems he is responsible for the Management of several exploration projects. Next to the Mobile Asteroid Surface Scout (MASCOT) project, he is involved in the HP3 study team (a penetrometer system for Moon and Mars), in Landing System dynamics with the landing and mobility test facility (LAMA) and in several smaller projects running in the department (development of rover wheels, deployment mechanisms of space tethers and Space System Studies for Exploration Missions).

Dr. rer. nat. **Farid Gamgami** received his diploma in Mechanical Engineering from the RWTH in Aachen, after which he completed his doctoral study with magna cum laude at the institute for theoretical Astrophysics of the University of Heidelberg. From 2007 he worked at the DLR Institute for Space Systems as a scientific assistant of the research group SART (Space Launcher Systems Analysis). From 2010 he started to work for OHB system group in Bremen.

Annex 3: Evaluation Manual for AHP Pre-selection

When opening the Excel file, a list of technologies, with a description, advantage/disadvantages, disruption type, technology domain and maturity can be seen. In addition, there are four columns which represent the performance of a technology of several domains. These domains are:

- Social Domain
- Technological Domain
- Economic Domain
- Political Domain

These domains need to be answered according to the scoring scale illustrated below:

Rating	Relative performance
0	Much worse than the state-of-the-art
3	Worse than the state-of-the-art
5	Same as the state-of-the-art
8	Better than the state-of-the-art
10	Much better than the state-of-the-art

This scale allows for a measurement which compares the situation with the technologies which are being used today, or state-of-the-art, to the Disruptive Space Technology candidate. The aim here is to check if it over performs or under performs over the state-of-the-art. The description of the factors is listed below:

Social

The European space sector has to abide to certain social rules. Social factors influence technology diffusion within the space sector by influencing the demand of the technology in either a positive or negative way. A number of possible social factors are:

- Environment
- Depletion of energy sources
- Human wellbeing
- Healthcare
- Malnutrition
- Overpopulation
- Waste management
- Disaster mitigation

On the one hand, if a technology can help solve problems in this social context, it has a higher potential for disruptiveness. On the other hand if a technology contributes to one of these social problems, it will have a lower potential for disruptiveness. In this case, the technology should be compared to the current state-of-the-art (e.g. technologies in use today) within the evaluation. A lower than 5 score on this factor would mean that the technology will worsen social problems than the state of the art, while a higher than 5 score means it would (contribute to) solve social problems.

Technical

The technical factor is the most important factor, because an over performing technology (in several different performance indicators) is essential to disruption. Because of this, the technical performance of a technology concept versus the state-of-the-art will have to be determined. It is important that the technology does not need to be obviously better than the state-of-the-art rather that a group of customers of the technology would find the performance more suited to their needs than the state of the art. A lower than 5 score on this factor would mean that the technology underperforms upon the state of the art, while a higher than 5 score means it over performs.

Economic

DSTs are defined as technologies that make operations simpler, cheaper, more flexible and/or more responsive compared to the incumbent technology. Because of this, economic aspects are of high importance in identifying space technologies. A rating on the economic factor should encompass whether or not the technology concept provides significant economic benefits to its users. A lower than 5 score on this factor would mean that the technology will cost the user more than the state of the art, while a higher than 5 score means it costs less.

Political

The development of technologies is highly influenced by governments and thus political decisions. This political influence is documented in the European space policy. The European space policy is influenced by the representatives of participating nations that are a part of the ESA. The ESA European space policy can be seen as the overall strategy of the European space sector. The European Space policy is defined as follows:

- *To develop and exploit space applications serving Europe's public policy objectives and the needs of European enterprises and citizens, including in the field of environment, development and global climate change*
- *To meet Europe's security and defense needs as it regards space*
- *To ensure a strong and competitive space industry, which fosters innovation, growth and the development and delivery of sustainable, high quality, cost-effective services*

- *To contribute to the knowledge-based society by investing strongly in space-based science and playing a significant role in the international exploration endeavor*
- *To secure unrestricted access to new and critical technologies, systems and capabilities in order to ensure independent European space applications*

For new technologies this means that they have to fit within these policies in order to have a chance of being developed. For a concept to have a high potential for disruptiveness, it should fit within the policy stated by the governing bodies. A lower than 5 score on this factor would mean that the technology will fit less with the policy than the state of the art, while a higher than 5 score means it fits better.

Annex 4: Technology Database

Potential Disruptive Space Technologies

Index	Technology Name	Description	Advantages	Possible type of DST	Technology Fiel	Technology Domai	Years to Disruptio	AHP
DST-009	**Self-powered wireless Nano device**	That future is a Nano scale device that manages to transmit data wirelessly up to 30 feet and operate without a battery, instead harvesting energy from the environment via such sources as the pulse of a blood vessel or the gust of a breeze. "It is entirely possible to drive these devices by scavenging energy from sources in the environment such as gentle airflow, vibration, sonic wave, solar, chemical, and/or thermal energy," researchers write in the journal Nano Letters.	self-powered, small	Low-End Encroachement	Spin-In	EEE_Components_and_quality	5	**6,35**
DST-011	**Light slowing Metamaterials**	To maximize the data rate (especially on the internet but also on many other applications) the usage of light in fiber optic cables is the best way. The problem is that the light needs to be converted in electrical energy for switching at the routers which slows the system with a factor of around 1000. If it would be possible to slow or even stop the light the conversion would not be necessary anymore. With new metamaterials and ultra-cold gases first successes were made.	Possiblitiy to transfer information faster	Fringe Market Disruption	Spin-In	Electromagnetic_Technologies_and_Techniques	5 to 15	**6,35**
DST-013	**X-Ray Communication**	Communication via X-rays offers significant advantages to both civilian and military space programs. Although currently at a very low technology- readiness level, it has the potential to provide high-data rates at low power over vast distances in space. In addition, such a communication system could penetrate RF shielding on the ground and communicate with hypersonic vehicles during that short period of time when the build-up of heat during reentry blocks traditional communications signals. Data rate 50 kbps - 1 Mbps.	contact during reentry, high data rate with low power	Fringe Market Disruption	Space Sector	Electromagnetic_Technologies_and_Techniques	5 to 15	**6,08**
DST-016	**Electrochromics Coating**	thin films that change their optical absorptance or reflectance as a function of injected ions (typically H+ or Li+ species),	to control the transmittance to the most desirable and comfortable level independent of incident UV light	Fringe Market Disruption	Spin-In	Electromagnetic_Technologies_and_Techniques	> 15	**5,73**
DST-017	**Magnetic Refrigeration**	Magnetic refrigeration is a cooling technology based on the magnetocaloric effect. In this method for cooling material down to 1mK by using adiabatic demagnetization. Because this is not a continuous method a dilution refrigerator with Helium3 and Helium4 is used today. But it could be possible to use magnetic refrigeration near the Curie Point to build cooling devices which have no mechanical parts and use no substance which is harmful for the environment.	This technique can be used to attain extremely low temperatures (well below 1 K), as well as the ranges used in common refrigerators, depending on the design of the system.	High-End Encroachement	Spin-In	Electromagnetic_Technologies_and_Techniques	5	**5,37**
DST-018	**Artificial Photosynthesis**	An energy system which is up to now only tested for application on Earth. It can produce 30 kWh from 1 l Water and solar power by converting carbon dioxide and water into oxygen, hydrogen and carbonhydrates. The process creates hydrogen which can either be recombined with the oxygen in a fuel cell to generate electricity or converted into a liquid fuel.	Process creates hydrogen and oxygen from water, solar energy can immediately be converted and stored, by-products are environmentally friendly.	Fringe Market Disruption	Spin-In	Environmental_Control_Life_Support__ECLS__and_In_Situ_Resource_Utilisation__ISRU	5	**5,97**
DST-023	**In Vitro Meat (Cultured Meat)**	Meat which is made in a test glass by using muscle cells and giving them some proteins which let them grow could be promising for manned long term space missions. It could be quite difficult to put enough cows in a space craft for a 3 year mission, so a viable alternative can be to grow in vitro meat in small test glasses.	Space saving, less amount of resources	Fringe Market Disruption	Spin-In	Life__Physical_Sciences	> 15	**6,59**
DST-028	**Tissue Engineering**	Tissue engineering was once categorized as a sub-field of bio materials, but having grown in scope and importance it can be considered as a field in its own right. It is the use of a combination of cells, engineering and materials methods, and suitable biochemical and physio-chemical factors to improve or replace biological functions. Often, the tissues involved require certain mechanical and structural properties for proper functioning. The term has also been applied to efforts to perform specific biochemical functions using cells within an artificially-created support system (e.g. an artificial pancreas, or a bio artificial liver).	engineering tissue as needed	Fringe Market Disruption	Spin-In	Life__Physical_Sciences	5 to 15	**5,62**

Index	Technology Name	Description	Advantages	Possible type of DST	Technology Field	Technology Domain	Years to Disruption	AHP
DST-029	**Resveratrol against bone mass loss and muscle degradation in zero-g environment**	The new study shows that resveratol can reduce the core inflammatory gene signal, NF-kappaB. Resvertol in regular diet is likely to prevent inappropriate activation of NF-kappaB in bones in the first place. Furthermore as resveratol activites the survival and anti-aging gene known sirtuin 1, it directly boosts the production of bone-building osteoblasts. Thus, resveratrol helps to bring the balance of osteoblasts and osteoclasts into harmony so human body can more easily manage bone health.	Also good for heart	Fringe Market Disruption	Spin-In	Life__Physical_Sciences	5 to 15	**5,39**
DST-030	**Ceramic Composite Structures**	Fiber reinforced ceramics are a new class of materials which combine the well-known superior properties of monolithic ceramics like high temperature, chemical resistance, hardness and wear resistance, with very uncommon qualities like extreme thermal shock resistance, damage tolerance and quasi-ductile fracture behavior. Enhanced ceramic matrix composites based on oxidation resistant materials might allow the design and manufacturing of light weight and high performance combustion chambers and nozzles leading to an overall superior performance compared to current designs. Manufacturing reproducibility and reliability need to be improved and successfully demonstrated.	Outstanding properties for applications under harsh thermal, corrosive, and mechanical loading conditions	High-End Encroachement	Spin-In	Materials__Processes	5 to 15	**7,35**
DST-031	**Graphene**	A new high-strength, light-weight material, which can be used for many different applications like high performance batteries, super conductors or composite materials. Performance data: Diameter: < 1 nm - 50 nm; Density: 1.5 g/cm³; Tensile Strength: 60 GP; Thermal Conductivity: 6000 W/ K m The advantages are the high tensile strength, the low density as well as the thermal properties. Can encompass different fullerene forms like Bucky balls, graphene sheets and carbon nanotubes.	High tensile strength, Lower mass, Thermal properties	Fringe Market Disruption	Spin-In	Materials__Processes	5 to 15	**7,15**
DST-032	**Metalic Microlattice**	A metallic microlattice is a synthetic porous metallic material, consisting of an ultra-light form of metal foam. Its creators claim it is the "lightest structural material" known, with a density as low as 0.9 mg/cm3. Its structure was created of interconnected hollow tubes with a wall thickness of 100 nanometers. The material can completely recover from compression exceeding 50% strain and has extraordinarily high energy absorption properties. The microlattice could be used for battery electrodes, catalyst supports, and acoustic, vibration or shock energy damping.	Ultra light structural material, Recovery of previous state after pressure	Fringe Market Disruption	Spin-In	Materials__Processes	5	**7,11**
DST-033	**Graphite Epoxy Composite**	Graphite composites are extremely versatile and have exceptional mechanical properties which are unequaled by other materials. Graphite composites have an extremely low coefficient of thermal expansion. The material is strong, stiff, and more lightweight than monolithic materials such as steel and aluminum, which make it attractive for numerous weight critical applications. Graphite composites are ideally suited for applications where high stiffness and lightweight is required, for example in satellite antenna, space- and aircraft structures, scanning and imaging machines, and in precision optical devices. In addition it might have some application in electromagnetic interference shielding covers and grounding planes if the conductivity can be improved.	Light weight, High performance	High-End Encroachement	Spin-In	Materials__Processes	5 to 15	**6,98**
DST-034	**Boron Nitride Nanotubes**	They can be imagined as a rolled up sheet of boron nitride. Structurally, it is a close analogue of the carbon nanotube, namely a long cylinder with diameter of several to hundred nanometers and length of many micrometers, except carbon atoms are alternately substituted by nitrogen and boron atoms. A BN nanotube is an electrical insulator with a band gap of ~5.5 eV, basically independent of tube chirality and morphology. In addition, a layered BN structure is much more thermally and chemically stable than a graphitic carbon structure. BN nanotubes show promising aerospace applications where integration of boron into structural materials improves their radiation-shielding properties; the improvement is due to strong neutron absorption. Such materials are of particular theoretical value as composite structural materials in future manned interplanetary spacecraft, where absorption-shielding from cosmic ray spallation neutrons is expected to be a particular asset in light construction materials.	Absorption-shielding resistant, Light construction material, More thermally and chemically stable then a graphitic carbon structure	Fringe Market Disruption	Spin-In	Materials__Processes	5 to 15	**6,84**
DST-035	**Elastic Memory Composite Material**	Elastic Memory Composites (EMC) combine the structural properties of fiber reinforced composites with shape memory characteristics of shape memory polymers. The EMC materials use a shape memory polymer matrix and graphite or glass fiber reinforcements. Above its glass transition temperature (Tg), the elastic memory composite has a low modulus and exhibits high strain to failure. In this state, an EMC laminate can be readily folded, and if held in a folded shape and cooled below Tg. Reheating above Tg causes the EMC material to return to its as-cured shape without the use of external force. The EMC material enables a fully cured composite structure regaining its original shape with no degradation or loss in mechanical or physical properties. A component using EMC materials is fabricated in its deployed, on orbit shape using conventional composite manufacturing processes. Then by heating the material and applying force this fully cued composite material can be folded or deformed for packaging. When cooled, it will retain the packaged shape indefinitely. When reheated the structure will regain its original shape with little or no external force. This packaging/deployment cycle is reversible.	Light material keeping the strength of materials. Shape memory	Fringe Market Disruption	Spin-In	Materials__Processes	5	**6,67**

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DST-036	**Carbon Reinforced Plastics (CFRP)**	These new materials could be a way to store liquid hydrogen and oxygen cryogenically. They can manage the extreme stresses of temperature differences between inside 20 K and outside more than 500 K as well as the high pressure inside. They have also a low mass, because they are made of polymers. Although they can be relatively expensive, there are a lot of possible applications in aerospace and automotive fields, where its high strength-to-weight ratio and good rigidity is of importance.	Lower tank mass, High strength to weight ratio	High-End Encroachement	Space Sector	Materials__Processes	5	**6,44**
DST-037	**Biomimetic Adhesive Polymers Based on Mussel Adhesive Proteins**	Especially for manned long term missions under isolated environmental conditions the used adhesives should not emit monomers to the air and should have a good compatibility to organisms. They need to be non-toxic and could be used for repair processes, also in bio regenerative life support systems. New biomimetic glue concept based on marine mussel is nontoxic, has a higher strength for polycarbonate than unmodified glue and requires only little surface preparation. It is resistant to fungi, durable, and sticks to the most space relevant materials, such as as polycarbonate and AlMg3.	Durable, Non-toxic, High strength with little surface preparation, Resistant to fungi	Fringe Market Disruption	Spin-In	Materials__Processes	5 to 15	**6,32**
DST-038	**Electroactive Polymers**	Electroactive Polymers, or EAPs, are polymers that exhibit a change in size or shape when stimulated by an electric field. The most common applications of this type of material are in actuators and sensors. A typical characteristic property of an EAP is that they will undergo a large amount of deformation while sustaining large forces. The majority of historic actuators are made of ceramic piezoelectric materials. While these materials are able to withstand large forces, they commonly will only deform a fraction of a percent. Performance data: Strain of 10-200 % possible in an electric field of ~100 V/µm	High mechanical energy density, Can operate for a long time in room conditions	Fringe Market Disruption	Spin-In	Materials__Processes	5	**6,31**
DST-042	**Nanocrystalline diamond Aerogel**	A material which can be used to create tough but well insulated windows for spacecraft because it is completely transparent. It is also biocompatible so it can be used in medical applications. And it releases electrons to its surrounding so it can be used in ultra-light, ultra-tough quantum computers and other electronics. Performance data: 40 times more dense than air; Samples of the gel are about 200 microns wide .Aerogels are a fascinating class of high surface-area continious solids with a board range of both commercial and fundamental scientfic applicationsmjm (1-8). Both crystalline and amophous structures have been synthesiyed. These materials have myriad scientfic and technological applications.	large intrinsic surface areas and ultralow densities	Fringe Market Disruption	Spin-In	Materials__Processes	5 to 15	**6,16**
DST-043	**Diamond Nanotube Composite Materials**	combination of the world's hardest known material – diamond – with the world's strongest structural form – carbon nanotubes. A new process for "growing" diamond and carbon nanotubes together opens the way for its use in a number of energy-related applications. Potential for use in low-friction, wear-resistant coatings, catalyst supports for fuel cells, high-voltage electronics, low-power, high-bandwidth radio frequency microelectromechanical/nanoelectromechanical systems (MEMS/NEMS), thermionic energy generation, low-energy consumption flat panel displays and hydrogen storage.	Significant material strength and hardness	High-End Encroachement	Spin-In	Materials__Processes	> 15	**6,15**
DST-044	**Nematic elastomer Nanocomposites (Shape Memory Material)**	This new two-ways shape-memory composite material, which is based on carbon nanotubes, can be used for integration in textile structures to enable smart actuation and solidification of deployable and inflatable structures. It has a strain of 400%, which is far more than any other shape-memory material has a recovery stress of 1Mpa and a mechanical strength (Young modulus) of ~ 1TPa.	High capacity	Fringe Market Disruption	Spin-In	Materials__Processes	5 to 15	**6,07**
DST-045	**Self Healing Materials, Polymers**	In order for this process to happen at room temperature, and for the reactants to remain in a monomeric state within the capsule, a catalyst is also imbedded into the thermoset. The catalyst lowers the energy barrier of the reaction and allows the monomer to polymerize without the addition of heat. The capsules (often made of wax) around the monomer and the catalyst are important maintain separation until the crack facilitates the reaction.	healing on its own	Low-End Encroachement	Spin-In	Materials__Processes	5	**6,07**

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DST-046	**Cathodic Arc Application of Amorphous Boron Coatings**	Boron (B) has excellent surface properties, e.g. corrosion resistance, high hardness, refractory properties, and a strong tendency to bond with most substrates. The potential technological benefits of the material have not been realized, because it is difficult to deposit it as coating. B is difficult to evaporate, does not sputter well, and cannot be thermally sprayed. A robust system, based on the vacuum (cathodic) arc technology, can however be used to create such layers	Great material properties	High-End Encroachement	Space Sector	Materials__Processes	> 15	**6,03**
DST-048	**EMP Shielding With Ceramic/Metal Nanophase Multilayer Composite**	An electromagnetic pulse (sometimes abbreviated EMP) is a burst of electromagnetic radiation. The abrupt pulse of electromagnetic radiation usually results from certain types of high energy explosions, especially a nuclear explosion, or from a suddenly fluctuating magnetic field. The resulting rapidly changing electric fields and magnetic fields may couple with electrical/electronic systems to produce damaging current and voltage surges. One possible shielding is nanophase multilayer composite.	lighter and more effective	High-End Encroachement	Space Sector	Materials__Processes	5 to 15	**5,94**
DST-049	**Supramolecular polymers**	Most polymers consist of long molecular chains made up of many units connected by covalent bonds — but supramolecular polymers are different. The strikingly dynamic properties of these materials arise from the reversible bonds that hold their chains together, and open up the prospect of many new applications.	high temperature dependency (low melting point), self-healing	Low-End Encroachement	Spin-In	Materials__Processes	5 to 15	**5,90**
DST-050	**Self Healing Materials, Automend**	The material, which the researchers call Automend, is said to be a tough, clear plastic that is solid at room temperature and has mechanical properties similar to epoxy resin. Automend can be fractured and healed repeatedly by heating it to 240-250 degrees Fahrenheit.	self-healing effect by heating	Low-End Encroachement	Spin-In	Materials__Processes	5	**5,80**
DST-051	**Soft Surface Antibacterial Polymer**	A new study by MIT researchers demonstrates that bacteria adhere poorly to soft surfaces and stick to firm ones. This could hold the key to creating better antibacterial coatings. The researchers have also created soft polymer films that might serve as antibacterial coatings for medical devices and other objects on which harmful bacteria congregate.	anti-bacterial	Fringe Market Disruption	Spin-In	Materials__Processes	5	**5,75**
DST-052	**3-D Printers in orbit**	Application of 3D printing for manufacture in orbit can reduce launch mass by ca. 30% as the compressed material needs a smaller launch volume (and thus smaller launcher). Also the parts can be produced thinner and less stiff as they do not have to withstand launch stress	Less volume, materials do not need to withstand launch stress (less material requirement = lower mass requirements), higher flexibility,	Fringe Market Disruption	Spin-In	Materials__Processes	5 to 15	**5,59**
DST-053	**Boron Epoxy Composite**	Epoxy is used as a structural matrix material which is then reinforced by fiber. The finite element method is used to analyze the behavior of a crack repaired by a boron/epoxy patch by computing the stress intensity factor at the crack tip in mode I and mixed mode. The effects of the mechanical and geometrical properties of the patch as well as the harmful disband effect on the fracture parameters are highlighted. The results show that the stress intensity factor is affected by the negative disband effect. A disband around the crack provokes its growth causing a shorter life of a cracked plate, but a full-width disband has the worst effect. The stress intensity factor in the presence of disband is appreciably reduced when the patch thickness approaches that of the plate (eR/eP → 1). Beyond this ratio, a linear relation links them. It is noted that the disband develops in the high shear stress regions around the crack in the plate. However, the disbanding in the patching should lead to a redistribution of the residual stress. The change in the residual stress depends on the type, applied stress, crack location and relative stiffness between the patch and the plate.	Low electrical conductivity, lower chance of galvanic corrosion compared to graphite epoxy	Low-End Encroachement	Spin-In	Materials__Processes	5	**5,58**
DST-054	**Friction Stir Welding (FSW)**	This is a welding method for connecting materials in a solid state by using a cylindrical-shouldered tool, with a profiled threaded/unthreaded probe rotating and welding the materials together. This results in several advantages like the possibility to connect different materials, to work at low temperature in the solid phase so the deformation is low. The problem is that huge forces from 1kN-20kN are necessary for the process.	Welding process without the use of heat	Fringe Market Disruption	Spin-In	Materials__Processes	> 15	**5,49**

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DST-055	**Zeolith Crystals**	Zeolites are hydrated aluminosilicate minerals, with a micro-porous crystalline framework that includes a network of interconnected tunnels, creating a structure similar to a honeycomb. A sort of mineral sponge, their microporous structure enables zeolites to very specifically absorb and release chemical species, including various cations and gas molecules such as H2O, CO2, N2, Freon, and more.	specifically absorb and release chemicals	Fringe Market Disruption	Spin-In	Materials__Processes	> 15	**5,37**
DST-056	**Microelectromechanical systems (MEMS)**	Microelectromechanical systems (MEMS) is the technology of very small mechanical devices driven by electricity. MEMS are separate and distinct from the hypothetical vision of molecular nanotechnology or molecular electronics. MEMS are made up of components between 1 to 100 micrometres in size and MEMS devices generally range in size from 20 micrometres to a millimetre. They usually consist of a central unit that processes data, the microprocessor and several components that interact with the outside such as microsensors. At these size scales, the standard constructs of classical physics are not always useful. Because of the large surface area to volume ratio of MEMS, surface effects such as electrostatics and wetting dominate volume effects such as inertia or thermal mass.	Diverse fields of applications , devices are cheap if they are mass produced, they are very small , effective solutions to many problems	Fringe Market Disruption	Spin-In	Mechanisms__Tribology	> 15	**6,73**
DST-065	**DNA Computer**	DNA computing is a form of computing which uses DNA, biochemistry and molecular biology instead of the traditional silicon-based computer technologies. The aim of the use of DNA as computational element is to take advantage of DNA's extremely dense information storage capability (1bit/nm3), the enormous parallelism it provides (10^18 operations at the same time) and its efficient performance (2x10^19 operations per joule). DNA stores the information about our genes permanently, and this is the basic principle to be used in this technology. The most significant experiment with DNA computers was the one performed by its inventor Leonard Adleman in 1994. It consisted of the application of an algorithm to solve the called Hamilton Path problem, whose goal is to find the shortest route between a number of cities, going through each city only once. The problem becomes more complex if more cities are added. The solution to this problem proved that DNA computers can be used to calculate complex mathematical problems. Adleman's experiment also proved that DNA computers would need human assistance, since he had to narrow down the possible results. DNA computing provides smaller devices with less power consumption compared to normal computing. Once algorithms are applied, many operations can be performed at the same time, due to the parallelism that characterizes DNA. Moreover, DNA is a cheap resource, since it can be provided as long as there are cellular organisms, and DNA biochips can be maid cleanly, without toxic components. However, a long research has to be carried out before the expansion of the DNA as means of computing and information storage. Adleman's first DNA computer needed human assistance, and this is an issue to be solved in future development. No efficient implementation has been produced for testing, verification and general experimentation, and radiation effects on DNA computers are unknown. There is no universal method of data representation and the amount of error is at the moment too big. Furthermore, the computation time required to solve problems does not grow exponentially, but the amount of DNA required does.	Faster, smaller and less power consumption compared to normal computing. High storage capability	Fringe Market Disruption	Spin-In	On_Board_Data_Systems	> 15	**7,18**
DST-066	**Holographic Data Storage**	Holographic data storage is a potential technology in the area of high-capacity data storage currently dominated by magnetic and conventional optical data storage. Magnetic and optical data storage devices rely on individual bits being stored as distinct magnetic or optical changes on the surface of the recording medium. Holographic data storage overcomes this limitation by recording information throughout the volume of the medium and is capable of recording multiple images in the same area utilizing light at different angles	Higher capacity, Faster storage	High-End Encroachement	Spin-In	On_Board_Data_Systems	> 15	**7,14**

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DST-068	**Chalcogenide-Based Reconfigurable Memory Electronics**	Chalcogenide glasses are materials which contain Sulfur (S), Selenium (Se) and/or Tellurium (Te), or combinations of them. These materials are characterized because of their behavior in front of the passage of an electric current. They change their conductivity dramatically due to a rapid change between polycrystalline and amorphous states. Both states have a completely different electrical resistivity. The polycrystalline state has a low resistance and represents a binary 0. The amorphous state has a high resistance and represents a 1. This phenomenon has already been exploited in rewriteable DVDs, and optical disk technologies with terabyte densities are on the horizon. With the commercial mass production of phase-change electrical memory being announced, the emphasis is quickly moving to electronic non-volatile memory (NVM), which retains the information when the power is turned off. NVM is typically used for the task of secondary storage, or long-term persistent storage. For the moment RAM (Random Access Memory) is used as primary storage, though it is a volatile form, i.e. without power the information is lost. NVM is used as secondary storage because of limitations of costs and worse performance compared to RAM. Recent literature results suggest that the long-held dream of an energy-efficient non-volatile memory that switches at DRAM-like speeds is rapidly becoming a reality. Several companies are working on developing non-volatile memory systems comparable in speed and capacity to volatile RAM. An application to the NVM technology is the development of Phase-Chang Random Access Memory (PCRAM). PCRAM is a resistance based non-volatile memory, where the state of the memory bit is defined by the resistance of the chalcogenide material. The resistance state depends on the microstructure of the material: amorphous or polycrystalline. PCRAM is based on the memristor (memory resistor) created in 2008 by Hewlett Packard: when current flows in one direction, the electrical resistance increases (the chalcogenide glass becomes amorphous). When current flows in the opposite direction, the resistance decreases (polycrystalline state). It has a regime of operation with an approximately linear charge-resistance relationship. Chalcogenide based PCRAM is one of the most promising non-volatile memories for the next generation of portable electronics, due to its excellent scalability, large sensing margin, fast switching speed, and possible multi-bit per cell operation. Thanks to this technology, memory devices would be smaller, and their speed higher. While they have been exploited technologically, there are still many fundamental questions to be answered. The different applications of this technology are still in early stage of research. These materials are also candidates for a variety of reconfigurable applications in RF circuitry, antennae, analog circuits, and even as reconfigurable wiring harnesses.	Large memory electronics in small devices, High speed, Already applied on commercial market	Low-End Encroachement	Spin-In	On_Board_Data_Systems	> 15	**6,97**
DST-069	**Quantum communication**	Quantum communication is based on the concept of quantum entanglement in which two particles entangled have the similar properties, no mather how far they are located from each other. Although this effect does not allow for faster than light communication, because there is no way to verify a change in spin of a particle, it can nonetheless be possible to use it in unbreakable encryptions which could be used for satelite communication is a new quantum computing era.	Possibility to make unbreakable encryptions, increases the amount of information per photon send	Fringe Market Disruption	Spin-In	On_Board_Data_Systems	> 15	**6,92**
DST-070	**Wireless data handling**	Reducing or eliminating the wires in satellites or spacecraft and using wireless data handling for reducing the mass. Performance data: Data flow: 1 - 10 Mbps; 10 % vehicle mass reduction in comparison with cables. Besides mass reduction, wireless networking between several manned and unmanned spacecraft could enable the seamless transfer of data and commands. Wireless communication enables the elimination of complex and expensive cable harnesses. Wireless data handling technologies facilitate add-on capabilities to existing spacecraft without significant engineering.	Less mass, Reduced complexity	Fringe Market Disruption	Spin-In	On_Board_Data_Systems	> 15	**6,71**
DST-072	**Three-dimensional integrated circuit**	In electronics, a three-dimensional integrated circuit (3D IC, 3D-IC, or 3-D IC) is a chip in which two or more layers of active electronic components are integrated both vertically and horizontally into a single circuit. This could reduce the amount of circuits in a spacecraft which saves room and mass.	Higher performance, Smaller, Less power consumption	High-End Encroachement	Spin-In	On_Board_Data_Systems	> 15	**6,41**
DST-073	**Gallium Nitride semiconductor technology**	GaN semiconductors are capable of delivering up to 10-times higher power levels compared with the current technology. GaN semiconductors offer substantially improved power and functionality beyond current semiconductor technologies. They operate at higher voltage levels allowing significantly greater power output for the same chip size. Furthermore, the material characteristics of GaN semiconductors offer efficient multi-band or wideband operation.	Mechanically stable material with high capacity and thermal conductivity	High-End Encroachement	Space Sector	On_Board_Data_Systems	> 15	**6,30**

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DST-075	**Plasma Antenna**	A plasma antenna is a type of radio antenna currently in development in which plasma is used instead of the metal elements of a traditional antenna. A plasma antenna can be used for both transmission and reception. Plasma antennas have only become practical in recent years. In an ionized gas plasma antenna, a gas is ionized to create a plasma. Unlike gasses, plasmas have very high electrical conductivity so it is possible for radio frequency signals to travel through them so that they act as a driven element (such as a dipole antenna) to radiate radio waves, or to receive them. Alternatively the plasma can be used as a reflector or a lens to guide and focus radio waves from another source.	Invisible to radar, Replaces need of multiple antennas, Much less thermal noise	Fringe Market Disruption	Spin-In	On_Board_Data_Systems	> 15	**6,24**
DST-077	**Plug & Play design**	For rapid and low cost integration of components in spacecraft, a bit like COTS products. Could be disruptive especially in combination with guidance, navigation, and control (GN&C) systems. It could enable a completely new satellite mission by exchanging some plug n play cards quickly.	Flexibility, Extensibility	Fringe Market Disruption	Spin-In	On_Board_Data_Systems	> 15	**6,13**
DST-078	**Field Programmable Gate Array (FPGA)**	A field-programmable gate array (FPGA) is an integrated circuit designed to be configured by the customer or designer after manufacturing—hence "field-programmable". The FPGA configuration is generally specified using a hardware description language (HDL), similar to that used for an application-specific integrated circuit (ASIC) (circuit diagrams were previously used to specify the configuration, as they were for ASICs, but this is increasingly rare). FPGAs can be used to implement any logical function that an ASIC could perform. The ability to update the functionality after shipping, partial re-configuration of the portion of the design[1] and the low non-recurring engineering costs relative to an ASIC design (notwithstanding the generally higher unit cost), offer advantages for many applications. With satellite lifetimes increased far beyond 10 years, much longer than the validity of telecom standards, reprogrammability in flight becomes a stringent requirement. If software solutions are not possible, RFPGA may soon be the only solution. In contrary to ASIC or one-time (antifuse) programmable FPGA, the configuration of RFPGA is stored in an SRAM, which is sensitive to SEU's.	Very small chip with millions of connections	High-End Encroachement	Spin-In	On_Board_Data_Systems	> 15	**5,95**
DST-081	**Written Electronic Circuitry**	Fast and easy creating of electronic circuits by writing it with a special pen. Perfect for creating small and easy circuits very fast or to repair damaged circuits. University of Illinois engineers have developed a silver-inked rollerball pen capable of writing electrical circuits and interconnects on paper.	Fast individual circuits	Fringe Market Disruption	Spin-In	On_Board_Data_Systems	> 15	**5,77**
DST-082	**Optical Intersatellite Links**	Major system components and performance criteria for laser intersatellite links are identified, and the transmission characteristics are modeled analytically. Five types of laser transmitters are considered: HeNe, GaAs, CO2, Nd:YAG, and frequency doubled Nd:YAG. Under the assumptions of a Poisson distribution for the photon arrival rate and quantum statistics of black body radiation for the background solar noise input, a parametric study of the link is conducted using a computer program developed for this investigation. Antenna size requirements and achievable bit rates are determined as functions of the mutual separation between the satellites, and the bit error rate for a binary pulse gate transmission system is calculated under various operating conditions. Finally, inherent system tradeoffs and the comparative viability of laser communications for high-capacity intersatellite links in a global digital satellite communication network are assessed.	Phase modulation, direct communication between satellites	Fringe Market Disruption	Space Sector	Optics	> 15	**6,59**
DST-083	**Ghost Imaging of Space Objects**	With this technology it is possible to make images of invisible objects. The physic behind that phenomenon is not clear till now. However by using two light detectors, one pointed at the object to be imaged and the other at the light source illuminating the object, these pictures could be made. This approach could lead to the detection of unlighted and non-light producing space objects.	Higher amount of detectable objects	High-End Encroachement	Spin-In	Optics	> 15	**6,52**
DST-085	**Coded Aperture Imaging Arrays**	They facilitate a lens-less, or reduced lens count imaging system, thus reducing mass. Recorded image data is 'encoded' by an optical mask. The image is obtained by decoding this data digitally. Adopting a hybrid digital / optical approach micro shutter arrays have been incorporated into coded-aperture cameras operating at visible and infra-red wavelengths. Possible space applications: Multi-object spectroscopy; Compact, lightweight imager for collision avoidance, tracking, maneuvering and docking.	Are simple to build and incorporate into practical, robust and compact optical system designs, all measurements of single frame of scene can be collected in single "snapshot", no inherent noise limit	Fringe Market Disruption	Spin-In	Optics	> 15	**6,31**

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DST-088	**Hollow-Waveguide Applications**	Hollow waveguides offer miniaturized optical systems which are inherently much smaller and lighter than conventional optical benches. Complete instruments can be made using HWG with volumes 1-2 orders of magnitude smaller than conventional systems. As the waveguides are "hollow", they suffer lower losses and transmit higher powers, resulting in a higher performance than more conventional systems.	decrease in instrument size by a factor of 10 to 100	Fringe Market Disruption	Spin-In	Optics	> 15	**6,11**
DST-091	**Laser Communication**	Communication from ground stations with satellites or between satellites via laser. Laser links can reach the nanometer for satellite-to-satellite tracking measurements, whereas microwave links seem to be restricted to the micrometer. It will have a great impact on the geodetic determination of the fluid transfers at the surface of the Earth (hydrosphere, cryosphere, post-glacial rebound), connected with the global change issue. Performance data: 50 % lower mass and 65 % less power consumption compared to radio frequency systems; Data flow: up to 10 Gbps	Faster connections and the option to communicate with far objects	High-End Encroachement	Space Sector	Optoelectronics	> 15	**6,93**
DST-092	**Ultra-Light "Photonic Muscle" Space Structures**	Fabrication of large space optics that are accurately shaped to better than a 1000th of the width of a human hair is an enormous challenge. Traditional space telescope fabrication methods require rigid and therefore heavy mirrors, expensive spacecraft and massive rocket launch vehicles. This breakthrough technology allows every molecule of a polymer substrate to also serve as a laser powered Nano-actuator. These molecules are used to control the shape of a super thin inexpensive large curved mirror, reducing cost and mass by a factor of 100.	lower mass, higher accuracy	High-End Encroachement	Space Sector	Optoelectronics	> 15	**6,90**
DST-093	**Laser-based trapping / Optical tweezers**	Optical tweezers (originally called "single-beam gradient force trap") are scientific instruments that use a highly focused laser beam to provide an attractive or repulsive force (typically on the order of piconewtons), depending on the refractive index mismatch to physically hold and move microscopic dielectric objects. Optical tweezers have been particularly successful in studying a variety of biological systems in recent years	High definition technique on laser technology, very precise	High-End Encroachement	Spin-In	Optoelectronics		**6,02**
DST-094	**Asynchronous temporal contrast silicon retina for robotic High Speed Vision**	Asynchronous temporal contrast silicon retina are dynamic vision sensors, also known as DVS. This sensor system has two asynchronous silicon retinas to make high speed vision for robotics possible. So they can react much faster to the environment.	Tracking objects, no frame memory, no frame correspondence problem, applicable in many areas, from microorganisms to tracking satellites, low power consumption	Fringe Market Disruption	Spin-In	Optoelectronics	5 to 15	**5,90**
DST-098	**Altitude compensating nozzles**	An altitude compensating nozzle is a class of rocket engine nozzles that are designed to operate efficiently across a wide range of altitudes. The basic concept of any engine bell is to efficiently direct the flow of exhaust gases from the rocket engine into one direction. The exhaust, a high-temperature mix of gases, has an effectively random momentum distribution, and if it is allowed to escape in that form, only a small part of the flow will be moving in the correct direction to contribute to forward thrust. The problem with the conventional approach is that the outside air pressure also contributes to confining the flow of the exhaust gases. At any one altitude, and thus ambient air pressure, the bell can be designed to be nearly "perfect," but that same bell will not be perfect at other pressures, or altitudes. Thus, as a rocket climbs through the atmosphere its efficiency, and thus thrust, changes fairly dramatically, often as much as 30%.	Less fuel consumption, Optimal thrust at every altitude (highest efficiency)	High-End Encroachement	Space Sector	Propulsion	5 to 15	**6,93**
DST-099	**Fission Fragment Rocket Engine (FFRE)**	A FFRE is a nuclear propulsion system which works at a much higher temperature than other nuclear generators. The individual atoms undergo fission at a temperature of millions of degrees and then are used to provide thrust, by extracting them from the rest of the fuel as quickly as possible before their energy is spread out into the surrounding fuel mass. If this technology can be mastered an Isp of 10^6 sec is possible with an efficiency of up to 90%.	Increased particle energy usage	High-End Encroachement	Space Sector	Propulsion		**6,89**
DST-100	**Alternative Solid Propellants: CL-20**	CL-20 is the highest energy single component compound known to date and, in addition, has the highest density of any known organic substance. It has a better oxidizer-to-fuel ratio than conventional HMX or RDX. CL-20 produces 20% more energy than traditional HMX-based propellants, and is widely superior to conventional high-energy propellants and explosives. CL-20 has better detonation properties than octogen, higher energy density, but lower impact and friction sensitivity.	High performance, High energy content, Very high energy density	High-End Encroachement	Space Sector	Propulsion	5	**6,79**

Index	Technology Name	Description	Advantages	Possible type of DST	Technology Field	Technology Domain	Years to Disruption	AHP
DST-101	**Micro Electric Space Propulsion (MEP)/ NanoFET**	Type of thruster that uses nanoparticles as propellant. Much of the engine is etched directly onto a wafer-thin piece of silicon via micro-electromechanical systems technologies, known as MEMS, that are more commonly used in the semiconductor industry. Measuring no thicker than a half-inch (1 centimeter, including the fuel) and with tens of thousands of accelerators able to fit on an area smaller than a postage stamp, these "stick-on" thrusters could power tiny spacecraft over vast distances. Performance data: ISP: 100 - 10.000 s; Efficiency of over 80%. Today used chemical propulsion have a maximum ISP of around 500 s.	Flexible, Lightweight, High-efficiency, Scalable micropropulsion	Fringe Market Disruption	Space Sector	Propulsion		**6,72**
DST-103	**Magneto-plasmadynamic thruster (MPDT)**	A very powerful electric propulsion system which could make interplanetary manned flights possible but it needs also a huge amount of electric energy. Performance data: Exhaust velocity: 80.000 m/s; Isp: 2500-8000 s; Thrust: several hundred Newton are possible. The Magnetoplasmadynamic (MPD) thruster (MPDT) is a form of electric propulsion (a subdivision of spacecraft propulsion) which uses the Lorentz force (a force resulting from the interaction between a magnetic field and an electric current) to generate thrust. It is sometimes referred to as Lorentz Force Accelerator (LFA) or (mostly in Japan) MPD arc jet.	MPD thrusters could produce extremely high specific impulses (Isp) with an exhaust velocity of up to and beyond 80,000 m/s	Fringe Market Disruption	Space Sector	Propulsion		**6,51**
DST-104	**Magnetic Sails**	A magnetic sail or E-Sail is a proposed method of spacecraft propulsion which would use a static magnetic field to deflect charged particles radiated by the Sun as a plasma wind, and thus impart momentum to accelerate the spacecraft. A magnetic sail could also thrust directly against planetary and solar magnetospheres. Performance data: delta-v: 10-20 km/s possible, but low acceleration.	Can also use the planetary magnetic field around a planet	Fringe Market Disruption	Space Sector	Propulsion		**6,49**
DST-106	**Electrodynamic Tether**	Electrodynamic tethers (EDTs) are long conducting wires, such as one deployed from a tether satellite, which can operate on electromagnetic principles as generators, by converting their kinetic energy to electrical energy, or as motors, converting electrical energy to kinetic energy.[1] Electric potential is generated across a conductive tether by its motion through the Earth's magnetic field. The choice of the metal conductor to be used in an electrodynamic tether is determined by a variety of factors. Primary factors usually include high electrical conductivity, and low density. Secondary factors, depending on the application, include cost, strength, and melting point.	Cheap system to change orbits, No need of propellant	Low-End Encroachement	Space Sector	Propulsion		**6,44**
DST-109	**Helicon Double Layer Thruster (HDLT)**	A Helicon Double Layer Thruster (HDLT) is a type of plasma thruster, which ejects high velocity ionized gas to provide thrust to a spacecraft. In this thruster design, gas is injected into a tubular chamber (the source tube) with one open end. Radio frequency AC power (at 13.56 MHz in the prototype design) is coupled into a specially shaped antenna wrapped around the chamber. The electromagnetic wave emitted by the antenna causes the gas to break down and form a plasma. The antenna then excites a helicon wave in the plasma, which further heats the plasma. The device has a roughly constant magnetic field in the source tube (supplied by Solenoids in the prototype), but the magnetic field diverges and rapidly decreases in magnitude away from the source region, and might be thought of as a kind of magnetic nozzle. Performance data: Specific impulse between 1000 and 1500 s; 5 hour burn with 1 gram propellant.	Low fuel consumption, specific impulse > chemical engines	High-End Encroachement	Space Sector	Propulsion		**6,34**
DST-111	**Green propellant**	Environmentally friendly propulsion, which is much easier to store and to handle and has no or very less toxic exhaust gases. Performance data: ISP: 300 s; 40 - 50 % higher density of ADN in comparison to NTO/MMH --> Reduction in mass	less toxic for environment and for handling, i.e. less costs	Fringe Market Disruption	Space Sector	Propulsion		**6,27**
DST-112	**Alternative Solid Propellants: Nitrogen Salts**	Solid nitrogen fuel could lighten rocket load. Findings suggest that it is feasible that the production of a solid form of nitrogen packs twice the energy of current space propellants.	Less volume than current space propellants	High-End Encroachement	Space Sector	Propulsion	5 to 15	**6,23**
DST-116	**Micro Pulsed Plasma Thrusters**	Pulsed Plasma Thrusters are electromagnetic propulsion devices which store electrical energy in a capacitor to periodically form a high current arc discharge across the propellant (typically Teflon). The most common PPT technology is the solid propellant technology, where the propellant is a block of teflon.	Extreme simplicity	Fringe Market Disruption	Space Sector	Propulsion		**6,00**
DST-117	**Alternative Solid Propellants: ADN**	Novel type of high performance propellants for use in solid rocket motors. Ammonium salt of dinitramidic acid NH4N(NO2)2 (ADN) has attracted wide interest as a potentially useful energetic oxidizer for rocket propellants because of its clean and environment-friendly exhaust products during burning.	Green propellant, energetic material, clean propellant, Environment-friendly exhaust products during burning	High-End Encroachement	Space Sector	Propulsion	5 to 15	**5,71**

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DST-122	**Transpirationally Cooled Thrust Chamber**	In transpiration cooling, a gaseous coolant is fed through a slit in the protected surface to the outer, "hot" side, thus blocking the effect of the high-temperature external medium. As the stream of coolant mixes with the hot gas, however, its obstructing effect is reduced. Therefore, a system of sequentially arranged slits is used to protect large surfaces. This method is used in aviation for thermal protection of the combustion chambers and nozzles of air-breathing jet engines, in which the outside air is used as the coolant	Works with gas	Fringe Market Disruption	Space Sector	Propulsion	5 to 15	**5,31**
DST-124	**Microwave energy transfer**	It is the use of microwaves to transmit power through outer space or the atmosphere without the need for wires. It is a sub-type of the more general wireless energy transfer methods. It is the most commonly proposed method for transferring energy to the surface of the Earth from solar power satellites or other in-orbit power sources. It is occasionally proposed for the power supply in [beam-powered propulsion] for orbital lift space ships.	Wireless	Fringe Market Disruption	Space Sector	RF_Payload_and_Systems	5 to 15	**6,65**
DST-128	**Multicarrier signals**	The basic concept behind multicarrier (MC) transmission is in dividing the available spectrum into subchannels, assigning a carrier to each of them, and distributing the information stream between subcarriers. Each carrier is modulated separately, and the superposition of the modulated signals is transmitted. Such a scheme has several benefits: if the subcarrier spacing is small enough, each subchannel exhibits a flat frequency response, thus making frequency-domain equalization easier. Each substream has a low bit rate, which means that the symbol has a considerable duration; this makes it less sensitive to impulse noise. When the number of subcarriers increases for properly chosen modulating functions, the spectrum approaches a rectangular shape. The multicarrier scheme shows a good modularity. It is possible to choose the constellation size (bit loading) and energy for each subcarrier, thus approaching the theoretical capacity of the channel.	Signal-to-noise ratio (SNR) can be discarded	Fringe Market Disruption	Spin-In	RF_Payload_and_Systems	5 to 15	**5,84**
DST-133	**TECPRO Barrier for Space Debris shielding**	TECPRO Barriers walls made of a new impact absorption material which should replace the tires which reduce the impact forces during a crash in Formula 1 or cart races. This material could maybe be used to damp vibration or absorb impact energy during the flight. The main advantages of using TECPRO Barrier are: Maximum amount of energy absorption, does not collapse upon impact, reduction of impact 'G' force	reusable, cheap	Fringe Market Disruption	Spin-In	Space_Debris		**5,63**
DST-138	**UltraFlex solar panels**	Flexible highly efficient Ultraflex solar arrays are lighter and increasingly foldable then the current state of the art. The lightweight allows reduced launch costs. Ultra flex solar cells, have 25 % less mass, 5% higher efficiency and have increased foldability compared to traditional triple junction GaAs cells. Ultra flex solar cells have a compact and extremely low stowage volume (25% less volume of standard arrays) which enables spacecraft and launch vehicle flexibility.	Very lightweight, low volume due to foldability	Fringe Market Disruption	Spin-In	Spacecraft_Electrical_Power	5	**7,10**
DST-139	**Advanced Stirling Radioisotope Generator (ASRG)**	The ASRG is a radioisotope power system using Stirling power conversion technology and is being designed for multi-mission use in environments with and without atmospheres for both deep space and for example the Mars atmosphere. Because of the Stirling cycle the efficiency is 4-5 times higher than current radioisotope generators. It is designed to have a lifetime of 14 years and has a specific power of 8,5 We/kg (in comparison a Multi-Mission RTG [MMRTG] has only 2,8 We/kg)	Increase specific power of RTGs	High-End Encroachement	Space Sector	Spacecraft_Electrical_Power	5 to 15	**7,05**
DST-140	**Quantum-Dot Solar cell**	By using two or more p-n solar cell junctions, tandem cells made of different semiconductors, a multi-heterojunction design yields a better match to the solar spectrum than a single-junction cell. Efficiency of up to 66% (In comparison: Efficiency record of flexible solar cells: 18,7%; Overall efficiency record: Thin-film gallium-arsenide cell with 27,6%), Quantum dot solar cells are an emerging field in solar cell research that uses quantum dots as the photovoltaic material, as opposed to better-known bulk materials such as silicon, copper indium gallium selenide (CIGS) or CdTe. Quantum dots have bandgaps that are tunable across a wide range of energy levels by changing the quantum dot size. This is in contrast to bulk materials, where the bandgap is fixed by the choice of material composition. This property makes quantum dots attractive for multi-junction solar cells, where a variety of different energy levels are used to extract more power from the solar spectrum. The potential performance of the quantum dot approach has led to widespread research in the field. Early examples used costly molecular beam epitaxy processes, but alternative inexpensive fabrication methods have been developed. These attempts rely on quantum dot synthesis using wet chemistry (colloidal quantum dots – CQDs) and subsequent solution processability of quantum dots. CQD solar cells currently hold the performance record for quantum dot solar cells.	High potential efficiency, Mechanical flexibility and low cost, Clean power generation	Fringe Market Disruption	Spin-In	Spacecraft_Electrical_Power	5 to 15	**6,89**

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DST-143	**Aluminum-Celmet for Li-Ion Batteries**	A new battery technology with 1.5 to 3 times higher energy density than ordinary Li-Ion Batteries. The Aluminum-Celmet can replace the aluminum or copper foil, which is used for the conductor, because it has a much higher conductivity and corrosion resistance. In addition, Aluminum-Celmet also has a lower mass.	Lower mass, Higher energy density, High corrosion resistance	High-End Encroachement	Spin-In	Spacecraft_Electrical_Power	5	**6,74**
DST-144	**Silicon Nanowire Lithium-Ion Battery**	The electrical storage capacity of lithium-ion batteries is limited by how much lithium can be held in the battery's anode, which is typically made of carbon. Although silicon has a higher capacity than carbon, it swells upon charging and then shrinks during use. This expand/shrink cycle typically degrades the performance of the battery, unless it uses a nanostructure, which has silicon regions and voids or contraction regions. While one layer expands, the other contracts, producing a net effect of zero expansion. The lithium is stored in a forest of tiny silicon nanowires, each with a diameter one-thousandth the thickness of a sheet of paper. The nanowires inflate four times their normal size as they soak up the lithium. The nanostructures provide greater total surface area, improving lithium uptake.	Higher energy density	Low-End Encroachement	Spin-In	Spacecraft_Electrical_Power	5	**6,66**
DST-146	**Super/Ultra capacitors**	A super- or ultra-capacitor is an energy storing device which has a much higher storing capability than normal capacitors due to the extremely high surface area of their interior materials (for example carbon nanotubes). They have the advantages that they do not store the energy chemically, just by separating the positive and negative charges and they have no moving parts (long life span). Main advantages: -Virtually unlimited life cycle - cycles millions of time -10 to 12 year life; -Low impedance; -Charges in seconds; -No danger of overcharge; -Very high rates of charge and discharge; -High cycle efficiency (95% or more); -Super capacitors and ultra-capacitors are relatively expensive in terms of cost per watt	Long lifetime, high rates of charge and discharge, high efficiency (low life time cost)	Fringe Market Disruption	Spin-In	Spacecraft_Electrical_Power		**6,58**
DST-147	**Solar Power Satellite via Arbitrarily Large Phased Array (SPS-ALPHA)**	SPS-ALPHA is a novel, bio-mimetic approach to the challenge of space solar power. If successful, this project will enable the construction of huge platforms from tens of thousands of small elements that can deliver remotely and affordably 10s to 1000s of megawatts using wireless power transmission to markets on Earth and missions in space.	Cheap base load power plant	High-End Encroachement	Space Sector	Spacecraft_Electrical_Power	5 to 15	**6,52**
DST-148	**Bacterial Nanowires**	A new kind of bacteria that produces long stringy filaments outside its body that conduct electrons better than metals. The strings of nanowires allow the bacteria to get rid of electrons that are a by-product of its digestive process. This could lead to very small and cheap high performance batteries as well as conductors or sensors.	Small and cheap electrical devices, High performance, Inexpensive metallic-like conduction	Fringe Market Disruption	Spin-In	Spacecraft_Electrical_Power	5 to 15	**6,40**
DST-149	**Organic Solar cells**	An organic photovoltaic cell (OPVC) is a photovoltaic cell that uses organic electronics--a branch of electronics that deals with conductive organic polymers or small organic molecules for light absorption and charge transport. The plastic itself has low production costs in high volumes. Combined with the flexibility of organic molecules, this makes it potentially lucrative for photovoltaic applications. Molecular engineering (e.g. changing the length and functional group of polymers) can change the energy gap, which allows chemical change in these materials. The optical absorption coefficient of organic molecules is high, so a large amount of light can be absorbed with a small amount of materials.	High optical absorption coefficient	Fringe Market Disruption	Spin-In	Spacecraft_Electrical_Power	5 to 15	**6,38**
DST-151	**Traveling wave reactor**	A traveling-wave reactor, or TWR, is a type of conceptual nuclear reactor that theorists speculate can convert fertile material into fissile fuel as it runs using the process of nuclear transmutation. TWRs differ from other kinds of fast-neutron and breeder reactors in their ability to, once started, reach a state where after they can achieve very high fuel utilization while using no enriched uranium and no reprocessing, instead burning fuel made from depleted uranium, natural uranium, thorium, spent fuel removed from light water reactors, or some combination of these materials	Manly use of waste material for other nuclear power plants, Long burning duration	High-End Encroachement	Spin-In	Spacecraft_Electrical_Power		**6,30**
DST-154	**Printed Solar Cells**	The technology, known as 3PV (Printed Paper Photovoltaics) uses methods similar to those already applied in printing magazines. The scientists said this discovery would be "a paradigm shift in solar technology," as it would allow producing much cheaper electricity than conventional solar cells. Naturally oxidized zinc is applied in a special printing process as the base electrode. Then, the transparent counter electrode is printed with a conductive polymer called PEDOT.	Cheaper production than conventional solar cells	Fringe Market Disruption	Spin-In	Spacecraft_Electrical_Power	5 to 15	**6,19**

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DST-155	**Thermalphotovoltaics (TPV)**	With thermal photovoltaics, light is concentrated on a material to heat up which will emit a specific wavelength of the light that the solar cell can convert more efficiently. It is expected that the efficiency of such a system would be around 85%. MIT researchers have developed a Nano-structured thermal photovoltaic energy conversion system that relies on heat not sunlight. The material's surface converts heat into precisely tuned light wavelengths that are transmitted on to matched photovoltaic cells.	higher efficiency, other possible materials	High-End Encroachement	Spin-In	Spacecraft_Electrical_Power	5	**6,18**
DST-158	**Embedded Zinc Oxide Nanogenerator**	Called nanogenerators, these devices are made of so-called piezoelectric materials that generate a current of electricity when stretched or strained	Small, thin	High-End Encroachement	Spin-In	Spacecraft_Electrical_Power	5 to 15	**5,92**
DST-161	**Proton Exchange Membrane Hydrogen Fuel Cell**	Proton exchange membrane fuel cells, also known as polymer electrolyte membrane (PEM) fuel cells (PEMFC), are a type of fuel cell being developed for transport applications as well as for stationary fuel cell applications and portable fuel cell applications. Their distinguishing features include lower temperature/pressure ranges (50 to 100 °C) and a special polymer electrolyte membrane. They are a leading candidate to replace the aging alkaline fuel cell technology, which was used in the Space Shuttle.	Better performance than the aging alkaline fuel cells used at space shuttle.	Fringe Market Disruption	Space Sector	Spacecraft_Electrical_Power	5 to 15	**5,69**
DST-163	**Amorphous Silicon on Polymer Substrate for PV Applications**	Amorphous silicon has no long-range periodic order. The application of amorphous silicon to photovoltaic as a standalone material is somewhat limited by its inferior electronic properties. The polymer substrate (around one mm thick) is used as endless basic layer to put the amorphous silicon on in a very thin layer.	good for mass production, thin layer	Low-End Encroachement	Spin-In	Spacecraft_Electrical_Power	5	**5,44**
DST-170	**Multi-Functional Structures -- Satellite Structure**	Multifunctional Structure (MFS) technology developed by Lockheed Martin Astronautics, BMDO, and the Air Force Research Laboratory (formerly Phillips Laboratory) provides an alternative to conventional satellite structures. Multichip modules instead of circuit cards and flexible circuitry instead of electric cables are embedded in a structure that provides structural support as well as thermal control. The embedded electronics architecture could also be used for panel structures in aircraft and on factory floors for better safety and reliability. The architecture reduces the volume of electronic components because the number of electronic wires, chassis, and cables are reduced. BMDO funded this work, along with DARPA and the AFRL, for their lightweight satellite attack warning system. It is an enabling technology for distributed small satellite systems: the Air Force is looking at it for TechSat 21 microsats. NASA's Deep Space 1 (DS1) spacecraft will provide the first flight test of MFS architectures. The technology experiment demonstrates key elements: an embedded electronics interconnect system using flex circuitry, multichip modules and sockets, flex jumpers, and anisotropic electrical bonding. Demonstration experiments include testing electrical interconnection and measuring thermal performance.	Will provide weight reduction for commercial satellites	High-End Encroachement	Space Sector	Structures__Pyrotechnics	5 to 15	**6,24**
DST-181	**Nanofluid coolants**	The resulting heat-transfer fluids conduct heat more efficiently than conventional coolants because the suspended Nano scale particles have a higher percentage of their atoms near their surfaces, improving the fluid's ability to absorb and transfer heat. The particles' small mass does not damage heat exchange surfaces.	higher heat transfer rate	Low-End Encroachement	Spin-In	Thermal	5	**5,84**