DLR Deutsches Zentrum für Luft- und Raumfahrt

Technical Note 4:

Technology Evaluation

Disruptive Technology Search for Space Applications

4000101818/10/NL/GLC

Issue: 2.0 - Date 07.11.2012

DISRUPTIVE SPACE TECHNOLOGIES

esa

Document Change Record

Issue/ Revision	Date	Affected Pages	Description
1.0	23.07.2012	All	Draft
2.0	15.11.2012	All	Final Version

Table of Content

Table of Content 3
List of Figures 9
List of Tables 10
References 10
List of Abbreviations 10
Executive Summary 12
1 Introduction 17
2 DST Evaluation Methodology 18
2.1 DST Evaluation Method 19
2.1.1 Desk Research 19
2.1.2 First Delphi Round 20
2.1.3 Second Delphi Round 20
2.1.4 Third Delphi Round 21
2.1.5 Concept Scoring 21
2.2 Delphi Questions 21
2.2.1 Social Questions 21
2.2.2 Technical Questions 22
2.2.3 Economic Questions 22
2.2.4 Political Questions 23
2.3 Weighting & Scoring 24
2.4 Selection of Experts 24
3 Results 25
3.1 Presentation of the Results 25
3.2 Analysis of the Results 26
3.3 Assessment of the Evaluation Process and Recommendations 27
Annex 1: Technology Fact Sheets 28
1 Materials 28
1.1 Cathodic Arc Application of Amorphous Boron Coatings 28

1.2 Ceramic Composite Structures 31
1.3 Highly Conducting Graphite Epoxy Composite 34
1.4 Metallic Microlattice 36
1.5 Nanocrystalline diamond Aerogel 39
2 Data Handling 41
2.1 Chalcogenide-Based Reconfigurable Memory Electronics 41
2.2 Holographic Data Storage 44
2.3 Multicarrier signals 47
2.4 Light slowing Metamaterials 49
3 Propulsion 52
3.1 Ceramic Combustion chamber concept based on transpiration cooling 52
3.2 Aerospike engine 54
3.3 Nanoparticle Field Extraction Thruster (NanoFET) 56
3.4 Magnetoplasmadynamic thruster (MPDT) 59
3.5 Alternative Solid Propellants: CL-20 62
4 Power 65
4.1 Aluminum-Celmet for Lithium-Ion Batteries 65
4.2 Super-/ Ultracapacitors 67
4.3 Bacterial Nanowires 70
4.4 UltraFlex Solar Panels 72
4.5 Silicon Nanowire Lithium-Ion Battery 74
4.6 Quantum-Dot Solar Cell 76
Annex 2: Delphi Results 79
1 General Notes / Table legends 79
2 Materials 80
2.1 Cathodic arc application of amorphous boron coatings (CAAABC) 80
2.1.1 Technology description 80
2.1.2 Social, Economic and Political (SEP) questions 81
2.1.3 Technical questions (performance attributes) 82
2.1.3.1 Selection of attributes (1st round) 82

2.1.3.2 Rating (2nd & 3rd round) ... 82
2.1.3.3 Weighting (2nd & 3rd round) ... 83
2.2 Ceramic composite structures ... 83
2.2.1 Technology description ... 83
2.2.2 Social, Economic and Political (SEP) questions ... 84
2.2.3 Technical questions (performance attributes) ... 86
2.2.3.1 Selection of attributes (1st round) ... 86
2.2.3.2 Rating (2nd & 3rd round) ... 86
2.2.3.3 Weighting (2nd & 3rd round) ... 87
2.3 Graphite epoxy composites ... 87
2.3.1 Technology description ... 87
2.3.2 Social, Economic and Political (SEP) questions ... 88
2.3.3 Technical questions (performance attributes) ... 89
2.3.3.1 Selection of attributes (1st round) ... 89
2.3.3.2 Rating (2nd & 3rd round) ... 90
2.3.3.3 Weighting (2nd & 3rd round) ... 90
2.4 Nanocrystaline diamond aerogel ... 91
2.4.1 Technology description ... 91
2.4.2 Social, Economic and Political (SEP) questions ... 91
2.4.3 Technical questions (performance attributes) ... 93
2.4.3.1 Selection of attributes (1st round) ... 93
2.4.3.2 Rating (2nd & 3rd round) ... 93
2.4.3.3 Weighting (2nd & 3rd round) ... 94
2.5 Metallic microlattice ... 94
2.5.1 Technology description ... 94
2.5.2 Social, Economic and Political (SEP) questions ... 95
2.5.3 Technical questions (performance attributes) ... 96
2.5.3.1 Selection of attributes (1st round) ... 96
2.5.3.2 Rating (2nd & 3rd round) ... 97
2.5.3.3 Weighting (2nd & 3rd round) ... 97

3 On-board data ... 98
3.1 Chalcogenide-based reconfigurable memory electronics (CBRME) ... 98
3.1.1 Technology description ... 98
3.1.2 Social, Economic and Political (SEP) questions ... 99
3.1.3 Technical questions (performance attributes) ... 100
3.1.3.1 Selection of attributes (1st round) ... 100
3.1.3.2 Rating (2nd & 3rd round) ... 100
3.1.3.3 Weighting (2nd & 3rd round) ... 101
3.2 Holographic data storage ... 101
3.2.1 Technology description ... 101
3.2.2 Social, Economic and Political (SEP) questions ... 102
3.2.3 Technical questions (performance attributes) ... 103
3.2.3.1 Selection of attributes (1st round) ... 103
3.2.3.2 Rating (2nd & 3rd round) ... 104
3.2.3.3 Weighting (2nd & 3rd round) ... 104
3.3 Multicarrier signals ... 104
3.3.1 Technology description ... 104
3.3.2 Social, Economic and Political (SEP) questions ... 105
3.3.3 Technical questions (performance attributes) ... 106
3.3.3.1 Selection of attributes (1st round) ... 106
3.3.3.2 Rating (2nd & 3rd round) ... 107
3.3.3.3 Weighting (2nd & 3rd round) ... 107
4 Power ... 108
4.1 Aluminium-celmet for li-ion batteries ... 108
4.1.1 Technology description ... 108
4.1.2 Social, Economic and Political (SEP) questions ... 108
4.1.3 Technical questions (performance attributes) ... 109
4.1.3.1 Selection of attributes (1st round) ... 109
4.1.3.2 Rating (2nd & 3rd round) ... 110
4.1.3.3 Weighting (2nd & 3rd round) ... 110

4.2 Bacterial nanowire 111
4.2.1 Technology description 111
4.2.2 Social, Economic and Political (SEP) questions 111
4.2.3 Technical questions (performance attributes) 113
4.2.3.1 Selection of attributes (1st round) 113
4.2.3.2 Rating (2nd & 3rd round) 113
4.2.3.3 Weighting (2nd & 3rd round) 114
4.3 Silicon nanowire lithium ion-battery 114
4.3.1 Technology description 114
4.3.2 Social, Economic and Political (SEP) questions 115
4.3.3 Technical questions (performance attributes) 116
4.3.3.1 Selection of attributes (1st round) 116
4.3.3.2 Rating (2nd & 3rd round) 116
4.3.3.3 Weighting (2nd & 3rd round) 117
4.4 Super/ultra capacitors 117
4.4.1 Technology description 117
4.4.2 Social, Economic and Political (SEP) questions 118
4.4.3 Technical questions (performance attributes) 120
4.4.3.1 Selection of attributes (1st round) 120
4.4.3.2 Rating (2nd & 3rd round) 120
4.4.3.3 Weighting (2nd & 3rd round) 121
4.5 Quantum-dot solar cells 121
4.5.1 Technology description 121
4.5.2 Social, Economic and Political (SEP) questions 122
4.5.3 Technical questions (performance attributes) 123
4.5.3.1 Selection of attributes (1st round) 123
4.5.3.2 Rating (2nd & 3rd round) 124
4.5.3.3 Weighting (2nd & 3rd round) 124
4.6 UltraFlex solar panels 125
4.6.1 Technology description 125

4.6.2 Social, Economic and Political (SEP) questions 126
4.6.3 Technical questions (performance attributes) 127
4.6.3.1 Selection of attributes (1st round) 127
4.6.3.2 Rating (2nd & 3rd round) 127
4.6.3.3 Weighting (2nd & 3rd round) 128
5 Propulsion 128
5.1 Magnetoplasmadynamic thruster 128
5.1.1 Technology description 128
5.1.2 Social, Economic and Political (SEP) questions 129
5.1.3 Technical questions (performance attributes) 133
5.1.3.1 Selection of attributes (1st round) 133
5.1.3.2 Rating (2nd & 3rd round) 133
5.1.3.3 Weighting (2nd & 3rd round) 134
5.2 Alternative solid propellant CL-20 135
5.2.1 Technology description 135
5.2.2 Social, Economic and Political (SEP) questions 136
5.2.3 Technical questions (performance attributes) 138
5.2.3.1 Selection of attributes (1st round) 138
5.2.3.2 Rating (2nd & 3rd round) 138
5.2.3.3 Weighting (2nd & 3rd round) 139
5.3 Micro-electric space propulsion MEP/NanoFET 139
5.3.1 Technology description 139
5.3.2 Social, Economic and Political (SEP) questions 140
5.3.3 Technical questions (performance attributes) 143
5.3.3.1 Selection of attributes (1st round) 143
5.3.3.2 Rating (2nd & 3rd round) 143
5.3.3.3 Weighting (2nd & 3rd round) 144
5.4 Aerospike engine 144
5.4.1 Technology description 144
5.4.2 Social, Economic and Political (SEP) questions 146

5.4.3 Technical questions (performance attributes) ... 148
5.4.3.1 Selection of attributes (1st round) ... 148
5.4.3.2 Rating (2nd & 3rd round) ... 148
5.4.3.3 Weighting (2nd & 3rd round) ... 149
5.5 Transpiration cooling ... 149
5.5.1 Technology description ... 149
5.5.2 Social, Economic and Political (SEP) questions ... 150
5.5.3 Technical questions (performance attributes) ... 152
5.5.3.1 Selection of attributes (1st round) ... 152
5.5.3.2 Rating (2nd & 3rd round) ... 153
5.5.3.3 Weighting (2nd & 3rd round) ... 153
Annex 3: AHP results ... 155
1 Overall factors ... 155
2 Social ... 156
3 Economic ... 157
4 Political ... 158
Annex 4: Concept Scoring ... 159
1 Materials ... 159
2 Data Handling ... 159
3 Power ... 161
4 Propulsion ... 162

List of Figures

Figure 1: Overall structure of the DST research ... 12
Figure 2: Delphi overview ... 13
Figure 3: Sample of the Delphi expert database. Sample shows the diverse composition of the survey participants regarding age, organization and geographical position. Personal information is not shown. ... 14
Figure 4: Overview of weights per factor and per question ... 14
Figure 1-1: Overall structure of research. ... 17

Figure 2-1: Overview of the evaluation method (described in more detail in TN02)........................18
Figure 2-2: Delphi overview...19
Figure 2-3: Overview of weights per factor and per question..24

List of Tables

Table 1: Concept scoring matrix for the Power domain 15
Table 2: Results of the Delphi Method, ranked by category 16
Table 3-1: Results of the Delphi Evaluation Method 26

References

[RD 1] Saaty, T. L. (1980). The Analytic Hierarchy Process: Planning, Priority Setting and Resource Allocation. New York: McGraw-Hill International Book Co.

[RD 2] Dalkey, N. C. (1969). *The Delphi Method: An Experimental Study of Group Opinion.* Santa Monica, CA: The Rand Corporation.

[RD 3] Ulrich, K. T., & Eppinger, S. D. (2000). Product Design and Development. Boston: McGraw Hill.

[RD 4] Häder, M., & Häder, S. (1998). Neuere Entwicklungen bei der Delphi Methode: Literaturbericht II. Mannheim: ZUMA-Arbeitsbericht 98/05.

[RD 5] Dunlap, R. E. (1991). Trends in public opinion toward environmental issues: 1965–1990. Society & Natural Resources: An International Journal, 4(3), 285-312.

[RD 6] Cegłowski, M. (2005, August 03). A Rocket To Nowhere. Retrieved April 03, 2012, from Idle Words: http://www.idlewords.com/2005/08/a_rocket_to_nowhere.htm

[RD 7] Govindarajan, V., & Kopalle, P. K. (2005). The Usefulness of Measuring Disruptiveness of Innovations Ex Post in Making Ex Ante Predictions. Journal of Product Innovation Management, 23(1), 12-18.

[RD 8] Kamien, M. I., & Schwartz, N. L. (1982). Market Structure and Innovation. Cambridge: Cambridge University Press.

[RD 9] Beer, H. (2000). Hochschul-Spin-offs im High-Tech-Wettbewerb Entrepreneurship-Theorie, -Education und -Support. Hamburg: Verlag Dr. Kovac.

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
ESA	European Space Agency
NASA	National Aeronautics and Space Administration
RD	Reference Document
SPE	Social, Political and Economic
TN	Technical Note
WP	Work Package

Executive Summary

This Technical Note (TN) documents on Work Package (WP) 5000 of Project 4000101818/10/NL/GLC. Its main purpose is to evaluate the technologies that resulted from the Disruptive Space Technology (DST) search and pre-selection. It fits within the overall research as the DST Roadmapping part, highlighted in the overall structure of the research, depicted in Figure 1. In this figure, the second chapter covers explanation of the DST Evaluation Methodology. After implementation of the DST Evaluation, the third chapter presents the results. These chapters are elaborated in more detail below. The selected technologies are subjected to a roadmapping process in WP5300, which is documented upon in the final report. These chapters are elaborated in more detail below.

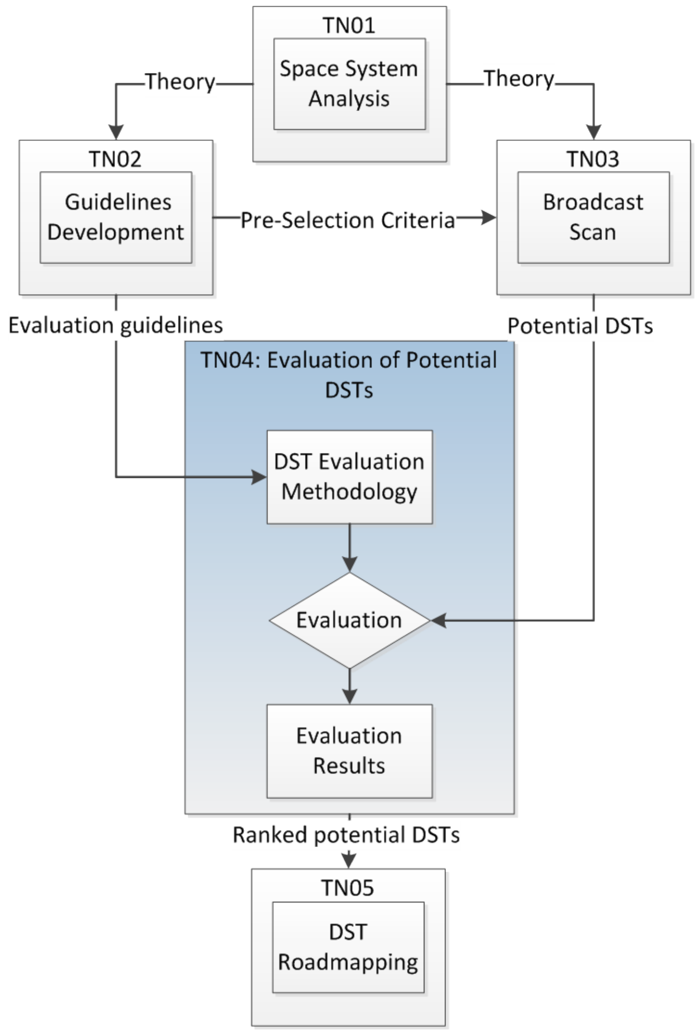


Figure 1: Overall structure of the DST research

Chapter 2: DST Evaluation Methodology

Within this chapter, the method used for the evaluation of technologies, resulting from the pre-selection stage is explained. The method uses the principles of the Analytical Hierarchy Process (AHP), Delphi Method and Concept Scoring and a modelisation of this is depicted in Figure 2.

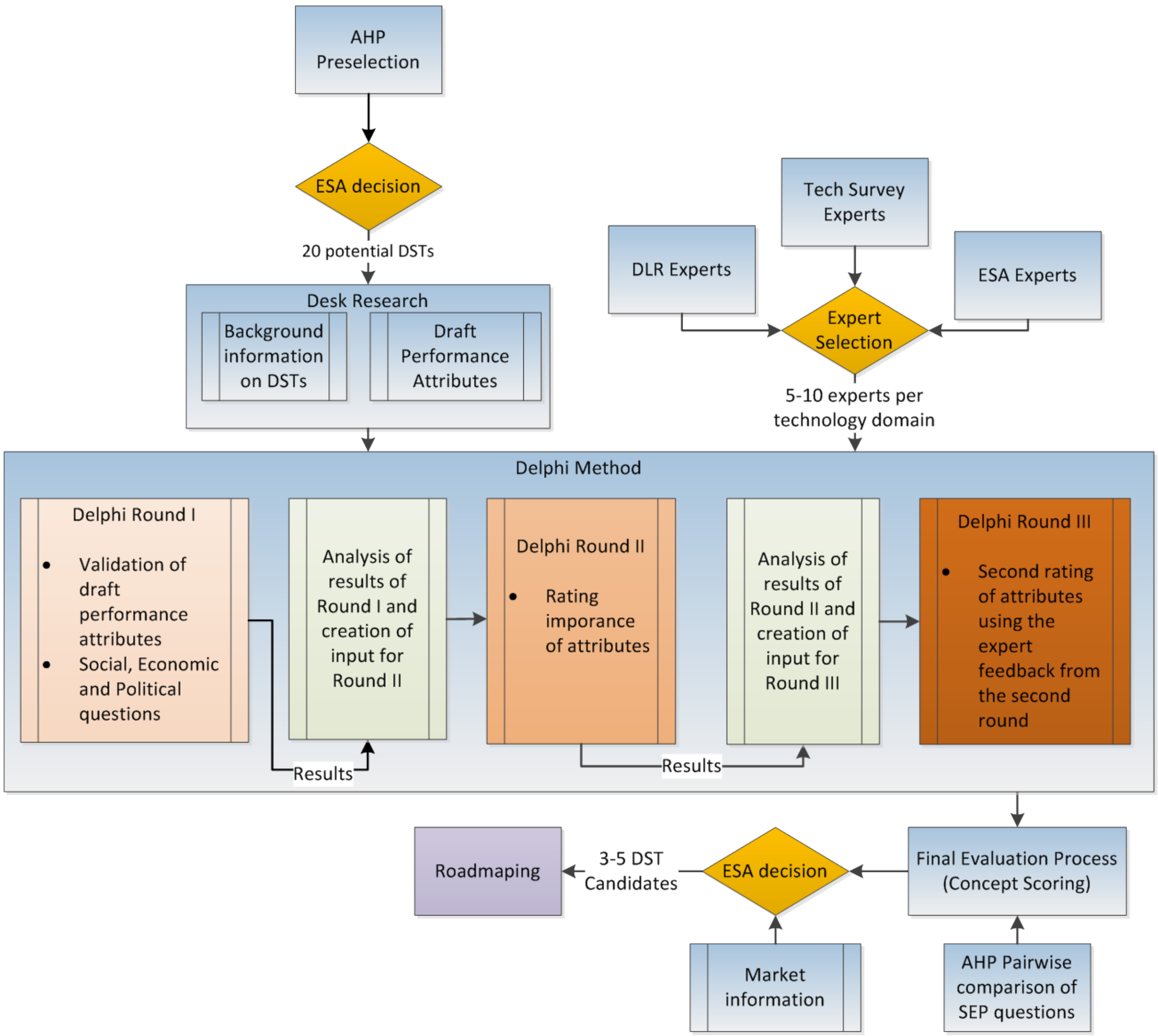


Figure 2: Delphi overview

The Delphi survey consists out of three different round and is performed using 48 experts (18 in propulsion, 10 in data handling, 9 in power and 11 in materials). These experts are working both in and outside the space sector over spread out across the world. Example of the database used to store and contact experts is illustrated in Figure 3. The participation of experts was attained by contacting participants of the technology survey that expressed interest in the participation in further studies, by asking cooperation from leading experts after a search and by internal experts suggested by the technical officer.

Space Secto	Field	Position	age	organization	country
Yes	propulsion		37	University	Austria
Yes	propulsion		42	Research Institute	Netherlands
Yes	propulsion		32	Company	Germany
Yes	propulsion		70	Governmental Agency	United States
Yes	propulsion		47	Governmental Agency	Japan
Yes	propulsion		32	University	Germany
Yes	propulsion		64	Company	United Kingdom
Yes	aerothermodynamics		49	University	United States
Yes	aerothermodynamics		47	University	South Korea
Yes	flight dynamics and GNSS		32	Research Institute	Spain
Yes	propulsion	Senior Technologist and the C		National Aeronautics and Space A	United States
Yes	propulsion	Senior Scientist/Technologist		National Aeronautics and Space A	United States
Yes	propulsion	Head of Propulsion and Aerot		European Space Agency	Netherlands
Yes	propulsion	Head of the Institute of Propu		German Aerospace Center	Germany
Yes	propulsion	Director of the Institute of Sp		German Aerospace Center	Germany
Yes	propulsion	Institute of Space Technology		Japan Aerospace Exploration Age	Japan
Yes	propulsion	Head Rocket Propulsion Depa		German Aerospace Center	Germany
Yes	propulsion			National Aeronautics and Space A	United States
Yes	on-board data systems		32	Governmental Agency	Netherlands
No	information and communication systems		78	University	United States
Yes	automation, telepresence and robotics		43	Research Institute	Germany
Yes	automation, telepresence and robotics		51	Governmental Agency	Canada
Yes	mission operation and ground data systems		32	Governmental Agency	France
Yes	space system control		43	University	Italy
Yes	on-board data systems	Institute of Communications a		German Aerospace Center	Germany
Yes	on-board data systems	Prof. at Institute of Space and		Japan Aerospace Exploration Age	Japan
No	on-board data systems	Aerospace Information Techn		University	Germany
Yes	on-board data systems	Head of Avionic Systems Dep		German Aerospace Center	Germany
Yes	system design and verification		41	Governmental Agency	France
No	renewable energy		45	Research Institute	Germany
Yes	electromagnetic technologies and techniques		48	Research Institute	Germany
Yes	electric, electronic and electromagnetic components		51	Company	Germany
Yes	thermal systems		52	Company	United Kingdom
Yes	thermal systems		55	Company	United States
Yes	spacecraft electrical power	Space Power Systems Group		Japan Aerospace Exploration Age	Japan
No	solar cells			Company	Germany
No	solar cells			Research Institute	Germany
Yes	materials and processes		43	University	United Kingdom

Figure 3: Sample of the Delphi expert database. Sample shows the diverse composition of the survey participants regarding age, organization and geographical position. Personal information is not shown.

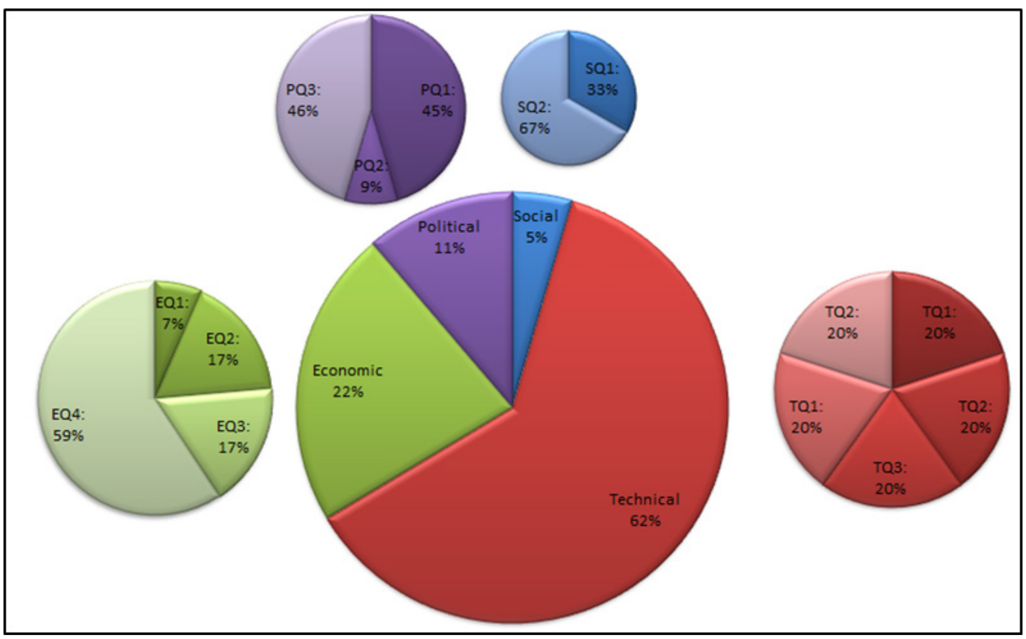


Figure 4: Overview of weights per factor and per question

The experts were asked by email to fill in several questions within several factors of the STEP analysis. The weights of the different criteria were partially established using the AHP method and partially by the experts themselves (the technology specific attributes) An overview of the weights is illustrated in Figure 4.After each round a summary of the results was made and send back to the experts who could comment on it. After three rounds the results were entered in a concept scoring matrix of which a example is shown in Table 1.

Table 1: Concept scoring matrix for the Power domain

	Aluminium-celmet for li-ion batteries			Bacterial nanowire			Silicon nanowire lithium ion-battery			Super/ultra capacitors			Quantum-dot solar cells			UltraFlex solar panels		
Criteria	Average weight	Average Score	Weighted Score	Average weight	Average Score	Weighted Score	Average weight	Average Score	Weighted Score	Average weight	Average Score	Weighted Score	Average weight	Average Score	Weighted Score	Average weight	Average Score	Weighted Score
SOCIAL	**4,5%**			**4,5%**			**4,5%**			**4,5%**			**4,5%**			**4,5%**		
SQ1	33,3%	2,1	0,03	33,3%	0,7	0,01	33,3%	1,8	0,03	33,3%	2,1	0,03	33,3%	0,7	0,01	33,3%	1,1	0,02
SQ2	66,7%	0,0	0,00	66,7%	-0,4	-0,01	66,7%	-0,4	-0,01	66,7%	0,0	0,00	66,7%	-0,7	-0,02	66,7%	0,0	0,00
TECHNICAL	**61,9%**			**61,9%**			**61,9%**			**61,9%**			**61,9%**			**61,9%**		
A1	20,6%	3,0	0,38	21,3%	1,9	0,25	19,0%	2,4	0,29	15,6%	2,0	0,19	18,8%	0,6	0,07	18,4%	2,7	0,31
A2	20,4%	1,4	0,18	18,2%	-0,1	-0,02	17,0%	2,0	0,21	14,7%	1,4	0,13	17,6%	-0,6	-0,06	17,1%	2,6	0,27
A3	16,2%	1,4	0,14	16,5%	1,3	0,13	18,3%	2,3	0,26	18,0%	2,9	0,32	14,4%	-0,4	-0,04	15,7%	1,7	0,17
A4	15,4%	0,7	0,07	15,7%	-0,3	-0,03	15,3%	0,7	0,07	17,0%	2,0	0,21	18,6%	0,4	0,05	16,1%	0,3	0,03
A5	13,5%	-0,1	-0,01	13,7%	-1,3	-0,11	14,8%	2,0	0,18	18,2%	3,6	0,40	14,3%	0,3	0,03	14,9%	0,4	0,04
A6	13,9%	-0,1	-0,01	14,4%	-1,1	-0,10	15,6%	1,1	0,11	16,6%	3,4	0,35	16,3%	0,7	0,07	17,8%	2,7	0,30
ECONOMIC	**22,4%**			**22,4%**			**22,4%**			**22,4%**			**22,4%**			**22,4%**		
EQ1	6,6%	2,9	0,04	6,6%	2,5	0,04	6,6%	3,6	0,05	6,6%	3,2	0,05	6,6%	1,8	0,03	6,6%	1,8	0,03
EQ2	17,1%	-0,7	-0,03	17,1%	-0,4	-0,01	17,1%	0,0	0,00	17,1%	-0,4	-0,01	17,1%	-0,4	-0,01	17,1%	-1,1	-0,04
EQ3	17,1%	0,7	0,03	17,1%	0,0	0,00	17,1%	0,0	0,00	17,1%	1,1	0,04	17,1%	-0,4	-0,01	17,1%	0,4	0,01
EQ4	59,3%	2,5	0,33	59,3%	2,5	0,33	59,3%	4,3	0,57	59,3%	4,3	0,57	59,3%	3,9	0,52	59,3%	3,6	0,47
POLITICAL	**11,2%**			**11,2%**			**11,2%**			**11,2%**			**11,2%**			**11,2%**		
PQ1	45,5%	-0,4	-0,02	45,5%	-0,4	-0,02	45,5%	-0,4	-0,02	45,5%	-0,7	-0,04	45,5%	-0,7	-0,04	45,5%	0,0	0,00
PQ2	9,1%	0,0	0,00	9,1%	-1,1	-0,01	9,1%	-0,4	0,00	9,1%	-0,4	0,00	9,1%	-0,4	0,00	9,1%	0,0	0,00
PQ3	45,5%	2,1	0,11	45,5%	-0,7	-0,04	45,5%	1,4	0,07	45,5%	1,4	0,07	45,5%	2,9	0,15	45,5%	1,4	0,07
Total Score			1,25			0,41			1,81			2,31			0,73			1,68
Rank	4			6			2			1			5			3		

Chapter 3: Results

In this Chapter, the results of the application of the DST evaluation method are presented, analyzed and reviewed. The results of the Evaluation method are illustrated in Table 2, which ranks the technologies per domain.

Table 2: Results of the Delphi Method, ranked by category

Technology	Rank	Total Score	Research Groups in EU	Industry in EU
Metallic microlattice	1st	2,03	x	
Ceramic composite structures	2nd	1,52	x	x
Cathodic arc application of amorp. boron coatings	3rd	1,49	x	
Highly Conductive graphite epoxy composites	4th	1,42		
Nanocrystaline diamond aerogel	5th	1,38		x
Chalcogenide-based reconfigurable memory electronics	1st	1,29	x	x
Holographic data storage	2nd	0,89	x	x
Multicarrier signals	3rd	0,89	x	x
Super/ultra capacitors	1st	2,31	x	x
Silicon nanowire lithium ion-battery	2nd	1,81	x	
UltraFlex solar panels	3rd	1,68	x	x
Aluminium-celmet for li-ion batteries	4th	1,25		x
Quantum-dot solar cells	5th	0,73	x	x
Bacterial nanowire	6th	0,41		
Micro-electric space propulsion MEP/NanoFET	1st	1,07	x	x
Alternative solid propellant CL-20	2nd	0,90	x	
Transpiration cooling	3rd	0,83	x	
Magnetoplasmadynamic thruster	4th	0,57	x	x
Aerospike engine	5th	0,21		

1 Introduction

The main purpose of Work Package 5000 of the Technology Evaluation of Project 4000101818/10/NL/GLC is the evaluation of the technologies resulting from the DST search and pre-selection. It fits within the overall research as the evaluation of potential Disruptive Space Technologies (DSTs) part, highlighted in the overall structure of the research, depicted in Figure 1-1. In this TN, the pre-selected technologies are evaluated through a Delphi Method and ranked through a Concept Scoring Matrix. The technologies with the highest disruptive potential are subjected to a roadmapping process in WP5300, which is documented in the final report.

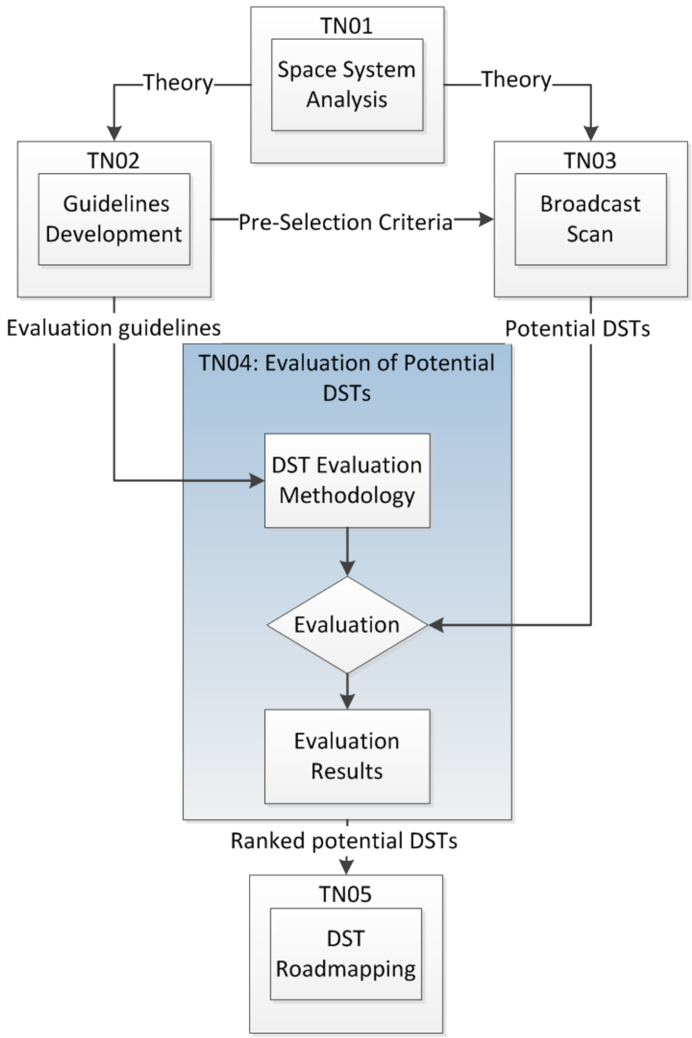


Figure 1-1: Overall structure of research.

This TN describes the evaluation method in a practical way, while the theoretical part was covered by TN02. This separation is caused by the evolutionary design of the method, which caused the method to be only describable after application. Chapter 2 describes the practical application of the method and chapter 3 explains the implementation, shows the results and gives recommendations for future evaluations.

2 DST Evaluation Methodology

In the following, the customized method is described that is used to identify the space technology concepts with the highest potential for disruptiveness. The overall method consists of a combination of the following methodologies: AHP [RD 1], Delphi Method [RD 2] and Concept Scoring [RD 3]. The overall method is explained in TN02 and a high level (preliminary) version of AHP is already applied in TN03. This chapter provides more details on how the evaluation method for DSTs is constructed and how the potential for disruptiveness is measured. Figure 2-1 illustrates the evaluation guidelines discussed in TN02.

The first part focuses on the customization of the Delphi Method for space technologies by elaborating on the questions of the Delphi Method. The second part focuses on the questions that are used in the Delphi Method. In the third part, the weighting for the Concept Scoring is determined, using the pairwise comparison method of the AHP.

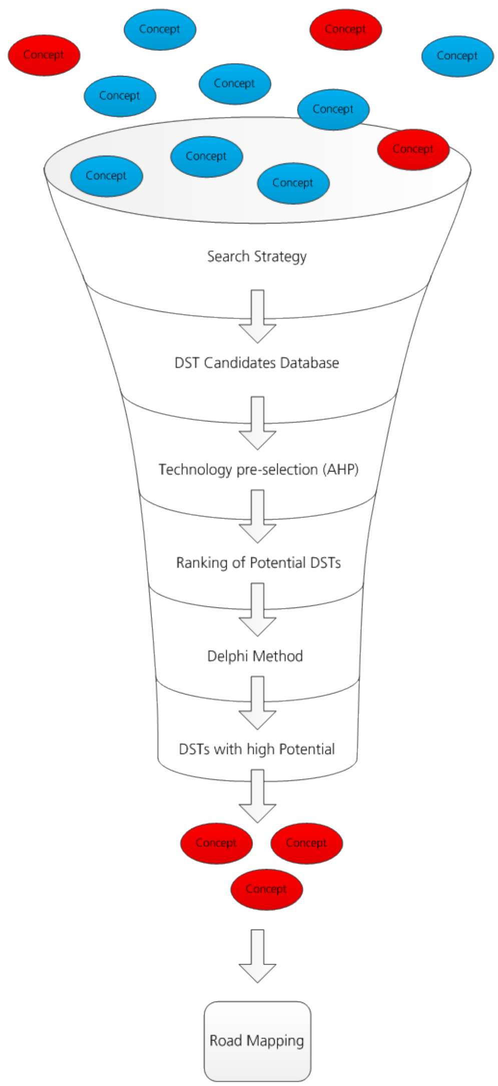


Figure 2-1: Overview of the evaluation method (described in more detail in TN02)

2.1 DST Evaluation Method

The Delphi Method is combined with the AHP and Concept Scoring method to form a customized evaluation method for the disruptive potential of DSTs. The Delphi Method is designed as an online questionnaire with three rounds. Häder and Häder [RD 4] argue that three rounds are sufficient for most Delphi surveys. After three rounds, no new arguments can be expected and the dropout rate increases as the motivation of the interviewees diminishes [RD 4]. The method is illustrated in the flowchart depicted in Figure 2-2 and is explained in more detail in the subsections below.

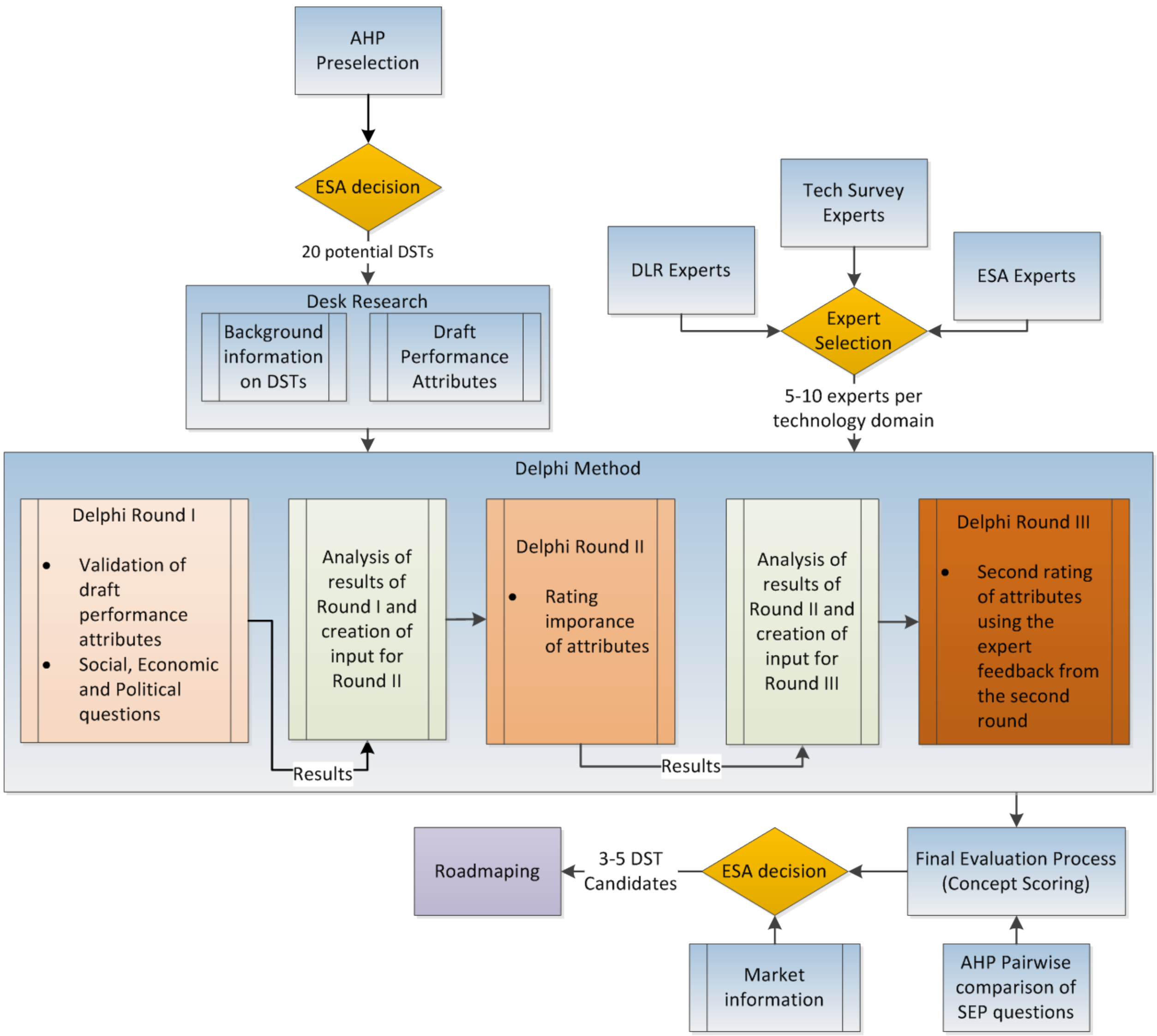


Figure 2-2: Delphi overview

2.1.1 Desk Research

The first step involves the gathering of information concerning the concept. This serves as an information source for experts throughout the different rounds. In addition to a general description, the following background information concerning the concept is collected:

- Maturity
- Technology domain
- Benefits
- Issues
- Field of application
- Media attention
- Research groups
- Industry
- Relevant papers
- Fit with the European Space Policy
- Spin-off possibilities
- Market size

This information is partially shared with the experts throughout different Delphi rounds. The fact sheets which list the information per technology are listed in Annex 1. In addition, a draft of the performance attributes, which is presented to the experts, is created by means of a workshop, utilizing internal German Aerospace Center (DLR) experts.

2.1.2 First Delphi Round

The first round covers the validation of the selected performance attributes by asking the experts to choose the most important attributes and by providing them with the option to suggest additional attributes. In addition, the experts are asked to answer the questions from the Social, Economic and Political (SEP) domain, which are listed in Section 2.2.

2.1.3 Second Delphi Round

In the second round of the Delphi Method, the experts are asked to rate the technologies on the six most important performance attributes that the DST project team selected based on the answers the experts gave in the first round. The rating scale measures from -5 to +5, where a negative score represents an under-performance and a positive score an over-performance of the DST candidate compared to the state of the art. The experts are also asked to rate the importance of each attribute on a scale of 1 to 5. This method has the advantage that the experts do not have to pay attention to give the attributes a total sum of weights of 100%, which would be an unnecessary challenge considering there are six attributes. The ratings are transformed to percentages via the following formula:

$$AP_1 = \frac{AR_1 \cdot 100}{n} \div \sum_{i=1}^{n} \frac{AR_i}{n}$$

Where,

$$AP_1 = Attribute\ 1\ Percentile$$
$$AR_1 = Attribute\ 1\ Rating$$

$$n = number\ of\ attributes$$

2.1.4 Third Delphi Round

In the third round of the Delphi Method, the experts receive a record of the answers given in the second round (attribute rating and attribute weight) including a mean score for each attribute. They are asked to reevaluate their answers and change it towards the mean if they agree with the assessment of the other experts. This round is performed via email and each expert is contacted personally.

2.1.5 Concept Scoring

In the Concept Scoring phase, the input of the Delphi Method is measured according to the weight per question. These weights and the process to derive them are elaborated in Section 2.3. The weights are determined by means of the AHP, which involves a pairwise comparison of all the questions. More specifically, this process compares the questions with each other and checks the consistency of the weights. This pairwise comparison is performed for the overall factors of the STEP analysis and the sub-questions within the SEP domain, which are explained in Section 2.2.

2.2 Delphi Questions

For the part that applies the Delphi Method, questions are selected, which allow the experts to give input to the Concept Scoring method. The questions are based on the criteria described in TN02 and these criteria are identified as high potential indicators of disruptiveness. The questions are elaborated in the subsections below.

2.2.1 Social Questions

Social Question 1 (SQ1): Compare the potential DST) to the existing dominant technology (state of the art) with respect to environmental benefits.

Environmental aspects have become increasingly important in today's society [RD 5]. Using a technology might be beneficial or detrimental to the Earth's environment. Society's opinion on the benefits of space technologies is partially governed by these benefits or drawbacks. A good example of how an environmental issue influenced a space program is the launch of Cassini-Huygens. The spacecraft had a radioisotope thermoelectric generator onboard and, due to fear of nuclear contamination in case of launch failure, a major civil movement against the program was formed. (Criterion 1.6 of TN02)

Social Question 2 (SQ2): Are you aware of any ethical dilemmas or social problems associated with *the potential DST*?

Since the beginning of the space era in the 1950's, ethical dilemmas have played a big role in the formation of space policy. Examples of ethical issues can be found in almost all manned spaceflight programs where the risk of a failure and the subsequent loss of life has to be weighed against the benefits of a manned mission. Other examples include the development of technologies that can be used for military purposes (dual-use) or the use of high resolution optical devices in satellites with regard to the invasion of privacy. If the usage of the technology creates any ethical dilemmas, public opinion might shift and decrease the technology's likelihood of application and thus, disruptiveness. (Criterion 1.5 of TN02)

2.2.2 Technical Questions

In the technical domain, each technology is evaluated on its six most important performance attributes in comparison to the existing dominant (state of the art) technology. The attributes named A1 through A6 are different for each technology and are determined during the course of the Delphi Method. Examples of performance attributes are efficiency, reliability, lifetime and mass. An example question would be: *What is the efficiency of technology X compared to the state of the art?* (Criterion 2.2 of TN02)

2.2.3 Economic Questions

Economic Question 1 (EQ1): Compare the new technology (technology X) to the existing dominant technology (state of the art) with respect to the potential for spin-off.

The term *spin-off* (also sometimes referred to as *spin-out*) was formed in the context of space technologies in the 1950's and describes the usage of space technologies or space technology byproducts in commerce and thus outside their main field of application [RD 9]. Technologies that have a potential for spin-off have potential for gains beyond their application as space technology and can therefore benefit from favored development incentive. (Criterion 3.6 of TN02)

Economic Question 2 (EQ2): Compare the new technology (technology X) to the existing dominant technology (state of the art) with respect to production complexity and material cost.

The development of a technology is linked to its production complexity and material cost. If either of these two is too high, the gain in performance might not justify the increase in cost and the technology might not get developed or used. (Criterion 3.3 of TN02)

Economic Question 3 (EQ3): Compare the new technology (technology X) to the existing dominant technology (state of the art) with respect to operation complexity and maintenance cost.

High maintenance or operating cost might also have the same results as production complexity and material cost. An example of a technology that was discontinued because of its operation complexity and the therewith associated cost is the Space Shuttle Program of the National Aeronautics and Space Administration (NASA) [RD 6]. (Criterion 3.3 of TN02)

Economic Question 4 (EQ4): Will the market (area of application) of the potential DST increase or decrease in the coming years?

A factor determining the success of a technology development is the potential market size or the number of potential applications of a technology. If this is high, then the technology development costs can be shared over a wide range of areas. If it is small, then it could be that the development costs do not outweigh the benefits the technology (potentially) has to offer. Markets and areas of application can be affected by policy changes, mission types or technology advancements. For example, plans for the colonization of the Moon or Mars will increase the market and area of application of life support systems and radiation shielding technologies. (Criterion 3.6 of TN02)

2.2.4 Political Questions

Political Question 1 (PQ1): Do you know or can you think of any restrictions or regulations that can hinder the entry of technology X into the space sector?

Regulations/restrictions can be laws, directives, technical regulations, existing patterns or any other kind of restriction that goes against the development or usage of this technology. (Criterion 4.1 of TN02)

Political Question 2 (PQ2): In what timeframe do you anticipate this technology to be ready to be used in a space environment?

If the level of maturity of a technology is too low and the expected timeframe for its development is too large, another technology might advance in the same domain and take its place before the technology is fully developed. This can decrease the disruptive potential of a technology. The relative importance of this question is determined by the scope of the respective research and the context it is used in. (Criterion 4.3 of TN02)

Political Question 3 (PQ3): Are you aware of any political incentive to promote or prevent the development of the potential DST (or its field of application)?

Decisions to promote or prevent a technology are often made with regard to political aspects and not only on the basis of the actual performance of a technology. Political decisions can be influenced, for example, by the need to secure employment, the existence of (trade) agreements, public pressure or lobby work. Govindarajan & Kopalle identified that commitments to existing technologies might limit the use of the potential disruptive technology [RD 7]. Within the space sector this phenomenon is especially strong as technologies require an extensive investment in human capital and equipment. This initial investment and the common reluctance to cannibalize existing technology development is an inhibiting factor against technology development [RD 8]. (Criterion 4.2 of TN02)

2.3 Weighting & Scoring

As mentioned before, the weights of the questions are determined by a pairwise comparison process. The details of this comparison, the resulting matrix normalization and the consistency check are listed in Annex 3: AHP results. In Figure an overview of the priorities per factor and per question is provided. (Note the Technical questions are technology depended, so in this picture just an example is given with 5 attributes and equal weight)

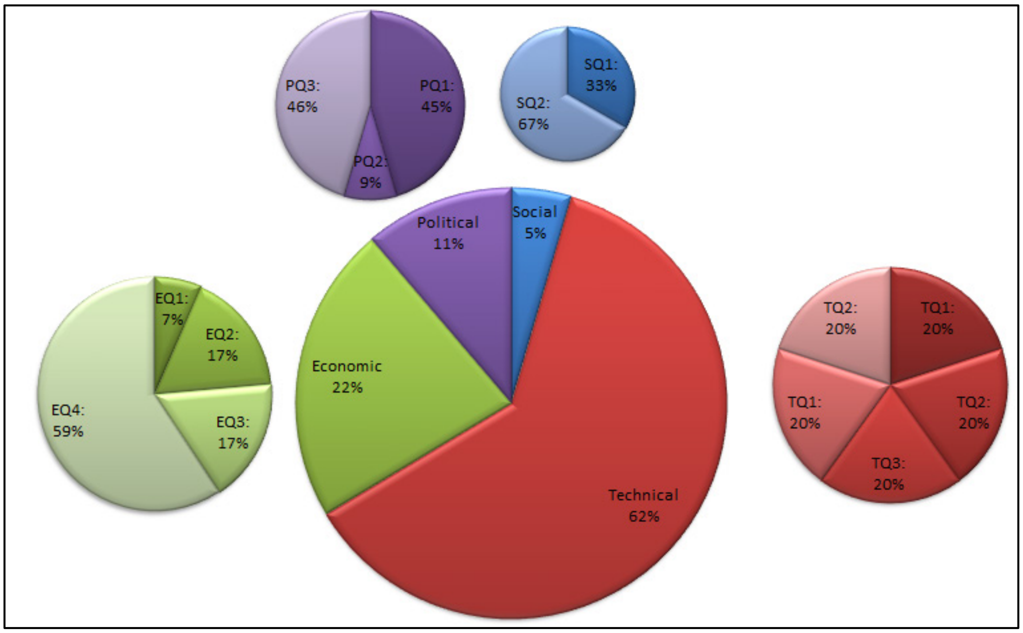


Figure 2-3: Overview of weights per factor and per question

For the scoring of the performance attributes of the technical factor, a scale of -5 to +5 is used (modified zero to ten scale) where a negative score indicates that the new technology is worse compared to the state of the art technology and a positive score means that the new technology is better. Zero means that both the new and the state of the art technologies perform equally.

2.4 Selection of Experts

For the Delphi Method, the expert selection is carried out on a global scale. A database of experts in each of the four technology domains is created. As a start, all participants of the technology survey that expressed interest in the participation in further studies are contacted. Those who confirmed their participation for the Delphi Method are inserted into the database. In order to expand this database, a second search for experts is conducted. Persons in managing and supervising positions in the world's leading technology corporations, universities, research institutes and space agencies are contacted and asked for their cooperation. Value is placed on a balanced distribution of experts among different organizations and different countries in order to reduce bias. A total of 45 experts (at least ten in each category) are acquired for the Delphi method.

3 Results

In this chapter, the results of the application of the DST evaluation method are presented, analyzed and reviewed. The first objective is to rank the pre-selected technologies from TN03 according to their domains: materials and processes, data handling, spacecraft electrical power, and propulsion. The second objective is to apply the theoretically developed evaluation method in practice and thereby illustrate its feasibility and give the proof of concept. This includes the identification of weak spots and improvement points of the method in future applications as well as the drawing out of implications for future research.

3.1 Presentation of the Results

The evaluation starts with the preselected technologies: three out of the data handling domain, six out of the power domain, five out of the propulsion domain and five out of the materials domain. These 19 technologies go into four different Delphi surveys, one for each domain and corresponding expert group. The ranked Delphi Method results are shown in Table 3-1. The presence of research groups and industry has been added to the table, in order to facilitate the selection of technologies for the roadmapping phase, which is documented upon in TN05. In Delphi Results , the results and calculations of the survey can be found.

Especially the comments of the experts on several questions are interesting. They provide further information on the technologies, illustrate the reasoning behind the experts voting and are a strong indicator for the experts' motivation and knowledge level. The end calculation of the method is illustrated in Annex 4: Concept Scoring, which involves the expert rating and the weights elaborated in Chapter 2.

Table 3-1: Results of the Delphi Evaluation Method

Technology	Rank	Total Score	Research Groups in EU	Industry in EU
Metallic microlattice	1st	2,03	x	
Ceramic composite structures	2nd	1,52	x	x
Cathodic arc application of amorp. boron coatings	3rd	1,49	x	
Highly Conductive graphite epoxy composites	4th	1,42		
Nanocrystaline diamond aerogel	5th	1,38		x
Chalcogenide-based reconfigurable memory electronics	1st	1,29	x	x
Holographic data storage	2nd	0,89	x	x
Multicarrier signals	3rd	0,89	x	x
Super/ultra capacitors	1st	2,31	x	x
Silicon nanowire lithium ion-battery	2nd	1,81	x	
UltraFlex solar panels	3rd	1,68	x	x
Aluminium-celmet for li-ion batteries	4th	1,25		x
Quantum-dot solar cells	5th	0,73	x	x
Bacterial nanowire	6th	0,41		
Micro-electric space propulsion MEP/NanoFET	1st	1,07	x	x
Alternative solid propellant CL-20	2nd	0,90	x	
Transpiration cooling	3rd	0,83	x	
Magnetoplasmadynamic thruster	4th	0,57	x	x
Aerospike engine	5th	0,21		

3.2 *Analysis of the Results*

The total score indicates the performance of the technology with respect to the performance of the state of the art technology. The scale ranges from -5 to +5, where zero indicates an equal performance of both technologies. So, in a sense, the total scores quantify the comparison of the state of the art technology to the DST candidate. A comparison of the technologies over multiple domains, however, would be misleading. For example, the incremental increase in performance of a propulsion system over the state of the art has a high impact on the space sector and can be very disruptive. In contrast to this, a high over-performance of a material over the state of the art has a small impact on the space sector. Because of this, results cannot be compared across different domains. The technologies with the highest scores and research groups and industry present in Europe are candidate for the roadmapping process, because European investments cannot go to institutions outside Europe. The final decision of the technologies which are roadmapped within this project is reserved for ESA, who choose the technologies based on the results of the Delphi and their own interests. The roadmapping phase is documented in TN05.

3.3 Assessment of the Evaluation Process and Recommendations

A limitation of this evaluation method is the broad scope of technology concepts. The heterogeneity of these technology concepts requires an evaluation of highly specialized experts which were not available at the scope of this research. Because of this, the research needed to settle with experts in the broad technology domain who often lacked a fundamental understanding of the technology and the surrounding market dynamics. This was made evident by some experts, who stated that they knew only little about a specific technology because it was too specialized. This could be countered by focusing on only one technology domain.

The formation of subcategories inside this one domain and the selection of dedicated experts for each subcategory will increase the accuracy and quality of the evaluation method. Additionally, it increases the motivation of the experts as all technologies will be of interest to them.

Important lessons learned from the Delphi Method are summarized below:

- The expert selection is the most important element of the Delphi Method. Large discrepancies regarding motivation and knowledge were observed among the experts. The selection of the right experts guarantees not only a lower dropout rate but also a much higher quality of the answers. A noticeable difference was observed between the quality of answers from experts that were randomly acquired and those that participated in the study based on recommendations. The latter provided the highest quality of evaluations and took much more time to write comments.
- A second selection process of experts based on their performance in the first round of the Delphi forum is advisable. During the course of the survey some experts excelled while others delivered only mediocre results. A reevaluation of the experts could be done according to the quality of the comments and explanations provided with their answers and/or the time they spend to complete the survey.

Technology Fact Sheets (Annex 1)

1 Materials

1.1 Cathodic Arc Application of Amorphous Boron Coatings

Domain	Materials and Processes	Benefits	Issues	
Subdomain	Novel Materials	▪ High performance	▪ Still has to be developed	
Group	Material assessment	▪ Small and cheap electrical devices	▪ No mass production	
TRL	2 to 3			

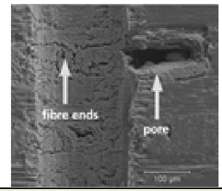
Description

Boron is an attractive hard coating for a variety of applications. It has the highest hot-hardness of the known materials at temperatures around 800 degrees Celsius. It has excellent properties, e.g. impact resistance and adhesion, salt pitting corrosion resistance, refractory nature and non-combustibility, nontoxicity, robustness of process, and a strong tendency to bond with most substrates. Moreover, Boron has very high lubricity, and thermal and chemical stability. Nevertheless, Boron is a material, whose favorable properties have not previously been widely recognized. Therefore, the deposition technique is essentially an extension of the well-established and economical cathodic arc or vacuum arc technique of coatings deposition to include elemental boron, because it has been difficult to deposit it in the form of coatings. The development of a boron vacuum arc is an important technological achievement, because it finally allows for the deposition of boron in an economically viable way. Boron is otherwise very intractable with respect to both synthesis of coatings and fabrication of products. It does not sputter well and it cannot be electroplated. Any boron-containing volatile compounds for use in chemical vapor deposition are toxic and/or explosive. As with any other vacuum arc deposition, the source produces a supersonic plume of plasma fully ionized gas out of solid feedstock, which is used as the cathode in the arc discharge. In this case, the cathode is made of consolidated boron powders, and is heated, in order to achieve the necessary electrical conductivity. This is because Boron is a semiconductor and has a very poor conductivity at room temperature. The discharge, once initiated, operates without added gas and at a very low background pressure. The primary source of material is the cathode, which is consumed in the process. As with vacuum arcs using metal cathodes, all the activity on the cathode is concentrated on small, non-stationary spots. However, these high current densities produce tremendous local stresses on the cathode, which can lead to fracture in the case of consolidated powder cathodes. A successful boron source

depends largely on the quality of its cathode consolidation technology. The source and deposition region are separated by means of a gate valve, so that the substrate may be replaced, while maintaining the heated cathode under good vacuum. A cryogenic pump is used to reach base pressures. Low impurity content in the film is important to achieve high hardness. The current is fixed by the power supply. The arc is initiated by a specially designed trigger that involves electrical breakdown across an insulator, separating a trigger-pin from the cathode.
Fields of application
Boron coatings have potentially excellent prospects regarding for several metallurgical coating applications, including space vehicle components, turbine blades of aircrafts and combustion chamber of aircraft engines.
Media Attention
The technology received slight attention in media, such as in online technology magazines or journals so far. Difficult to find papers for this technology.
Information Links
Wikipedia, 2012: http://en.wikipedia.org/wiki/Cathodic_arc_deposition Wikipedia, 2012: http://en.wikipedia.org/wiki/Boron
Research Attention and Prominent Research Groups
Marie-Paule Delplancke-Ogletree, Department of Industrial Chemistry, Universite Libre de Bruxelles, Brussels, Belgium http://www.ulb.ac.be/rech/inventaire/chercheurs/3/CH4223.html USA: Hazelton, R. C.; Yadlowsky, E. J.: HY-Tech Research Corporation http://hytechresearch.com/
Papers
Monteiro, O. R., Delplancke-Ogletree, M.-P., Klepper, C. C. (2003) Boron carbide coatings prepared by cathodic arc deposition. Journal of Materials Science 38, 3117 – 3120. C.C. Klepper, J. Niemel, R.C. Hazelton, J. Yadlowsky and O.R. Monteiro (2001) Vacuum arc deposited boron carbide films for fusion plasma facing components. Published in Fusion Technology, Vol. 39, Number 2 (Mar 2001) pp. 910 – 915.
Industry
USA: AMG Advanced Metallurgical Group N.V.: http://www.amg-nv.com/
Fit with European Space Policy
Technology meets Europe's security needs. Ceramic Composite Structures fit with the European

Space Policy.
Potential areas for Spin-off
Potential Spin-off application may find in healthcare industries (e.g. biomedical implants), in automotive (e.g. die-casting dies for aluminum alloys or brake pads) turbine blades for military and/or civil helicopter.
Market Size
The market for this technology is still undeveloped. Difficult to acquire market data for this technology. In some cases, the technology will require significant research efforts.

1.2 Ceramic Composite Structures

Domain	Materials and Processes	Benefits	Issues	
Subdomain	Novel Materials	▪ Large tensile strength	▪ Requires novel manufacturing	
Group	Advanced Materials Manufacturing	▪ Corrosive resistant		
TRL	7 to 8			

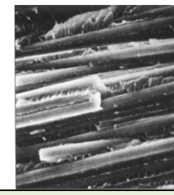
Description

Ceramics can be described as solid materials which exhibit very strong ionic bonding in general and in few cases covalent bonding. High melting points, good corrosion resistance, stability at elevated temperatures and high compressive strength, render ceramic-based matrix materials a favorite for applications requiring a structural material that doesn't give way at temperatures above 1500 degree Celsius. 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. Ceramic matrix composites (CMCs) are separated into two categories: discontinuous reinforced and continuous fiber reinforced CMCs. Discontinuous reinforced CMCs include particulate, platelet, whisker, fiber and in situ reinforced composites. CMCs containing discontinuous second phases are, in general, processed by shaping techniques commonly used for monolithic ceramics, i.e. injection molding, slip casting, and tape casting, followed by sintering to densify the composite. By contrast continuous fiber ceramic composites (CFCCs) have required the development of infiltration methods that enable the densification of various ceramic matrices in continuous fiber lay-ups and/ or net shape woven fiber preforms. Ceramic fibers in ceramic matrix composites can have a polycrystalline structure, as in conventional ceramics. They can also be amorphous or have inhomogeneous chemical composition, which develops upon pyrolysis of organic precursors. The high process temperatures required for making ceramic matrix composites preclude the use of organic, metallic or glass fibers. Only fibers stable at temperatures above 1000 °C can be used, such as fibers of alumina, mullite, SiC, zirconia or carbon. Amorphous SiC fibers have an elongation capability above 2%, which is much larger than in conventional ceramic materials (0.05 to 0.10%). The reason for this property of SiC fibers is that most of them contain additional elements like oxygen, titanium and/ or aluminum yielding a tensile strength above 3 GPa.

Fields of application
Ceramic composite materials reinforced with continuous fibers may find use thermal-structural application in turbine and rocket engines where metallic alloys cannot meet the performance and/or durability requirements. Aircraft turbine engine, divert propulsion and attitude control nozzles for missile rocket engines are some examples. The next generation reusable launch vehicle will likely use ceramic composite materials for the thrust cells and the ramp of the Aerospike engine. Ceramic composites are presently being evaluated for leading edges, nose section, inlet cowlings, and the nozzle of future hypersonic vehicles. Future turbine engine applications may include combustors, shrouds, stators, and vanes. Heat shields to protect metallic structures are also being considered in many aircraft and space applications.
Media Attention
Ceramic Composite Structures are receiving an average attention in media so far. This technology was published in several prominent materials journals. Various papers are available for this technology.
Information Links
Wikipedia, 2012: http://en.wikipedia.org/wiki/Ceramic_matrix_composite DLR: http://www.dlr.de/en/Portaldata/35/Resources/dokumente/Flyer_Ceramic_Composite_Structures.pdf
Research Attention and Prominent Research Groups
Prof. Dr.-Ing. Kurosch Rezwan, head of the Advanced Ceramics group at the University of Bremen http://www.ceramics.uni-bremen.de/ Prof. Dr.-Ing. Walter Krenkel at the department of Ceramic Materials Engineering at the University of Bayreuth http://www.cme-keramik.uni-bayreuth.de/weblication/englisch/matrix.html Fraunhofer-Institut für Silicatforschung ISC: There are also close ties to the University of Bayreuth through the Fraunhofer Project Group Ceramic Composites affiliated to the Institute. Prof. Dr.-Ing. Walter Krenkel, who heads the Fraunhofer Project Group, also holds the chair for Ceramic Materials at the University of Bayreuth http://www.isc.fraunhofer.de/Composite-Materials.540.0.html?&L=1#c1687 Fraunhofer Institute for Ceramic Technologies and Systems (IKTS) http://www.ikts.fraunhofer.de/en/research_fields/materials/
Papers
Kuntz, M.: „Ceramic Matrix Composites“, cfi/Bericht der DKG, Band 49, Nr. 1, 1992, S. 18. M. Dogigli, H. Weihs, K. Wildenrotter, H. Lange: New High-Temperature Ceramic Bearing for Space Vehicles. 51st International Astronautical Congress, Rio de Janeiro, Brasilien, Oktober 2000,

Paper IAF-00-I.3.04
Industry
MT Aerospace AG: http://www.mt-aerospace.de/ Snecma: http://www.snecma.com/ Pritzkow Spezialkeramik: http://www.keramikblech.com/ (worked with DLR)
Fit with European Space Policy
Technology meets Europe's security needs. Ceramic Composite Structures fit with the European Space Policy.
Potential areas for Spin-off
Ceramic Composite Structures have potentially excellent prospects regarding several fields of applications including aeronautic, automotive (e.g. brake pads), construction and mechanical engineering. Ceramic Composite Structures may find potential applications as thrust control flaps for military jet engine or as components for fusion and fission reactors, and may also friction systems for various applications.
Market Size
The greatest potential for composite ceramics is in the range of mobility such as aerospace and automotive technology. The entire area provides a wide range of applications for high-tech ceramic composites: Alone on the automotive market, for instance brakes for cars and rail vehicles, which are equipped with ceramic composites, made millions in sales today.

1.3 Highly Conducting Graphite Epoxy Composite

Domain	Materials and Processes	Benefits	Issues	
Subdomain	Mechanism Engineering	▪ Lightweight	▪ High production costs	
Group	Engineering Tools	▪ High performance		
TRL	7 to 8			

Description

Graphite Epoxy Composite is a superhybrid resin matrix composite with a high epoxy content which is reinforced with graphite or carbon particles. The process by which most carbon-fiber-reinforced polymer is made varies, depending on the piece being created, the finish required, and how many of this particular piece is going to be produced. Composite fibre materials satisfy all of the given requirements by using an epoxy resin matrix material reinforced with high strength fibres. The properties of both materials determine the behavior of the composite. The fibres have high strength due to a very uniform structure and the absence of surface flaws, thus their strength approaches the theoretical strength of the fibre material, determined by molecular bond strengths. Currently used materials are boron, graphite, glass, Kevlar and various hybrids, each of these is best suited to some particular application. The matrix material is an epoxy resin. These polymers are very stable and have excellent bonding properties, especially with graphite. Epoxies decompose rather than melt and are inert to most solvents. They are very stable, and this practically eliminates corrosion/weathering problems. A composite of high strength fibres and an epoxy resin exhibits a combination of properties of both components. 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 lightweight than monolithic materials such as steel and aluminum, which make it attractive for numerous weight critical applications.

Fields of application

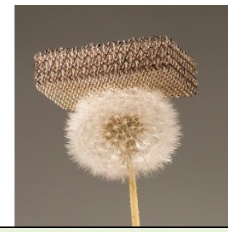
Graphite composites are ideally suited for applications where high stiffness and lightweight is required, for example in satellite antenna, space- and aircraft structures, scanning and imaging machines, and in precision optical devices used in space environment. In addition, it might have some application in electromagnetic interference shielding covers and grounding planes if the conductivity can be improved.

Media Attention

Graphite Epoxy Composite received less attention in the past years in media so far. Difficult to

find information for this technology.
Information Links
Wikipedia, 2012: http://en.wikipedia.org/wiki/Carbon-fiber-reinforced_polymer Nondestructive Testing (NDT): http://www.ndt.net/article/v04n03/ntiac/ntiac.htm
Research Attention and Prominent Research Groups
No research group found in Europe.
Papers
Han, J. H.; Kang, S. G. and Kim, C. G. (2003) Space Environmental Characteristics of Graphite/Epoxy Composites. KASA 1st International Sessions, Kyung-ju, South Korea. Predecki, P. and Barret, C. S. (2001) Stress Measurement in Graphite/Epoxy Composites By X-Ray Diffraction from Fillers. Journal of Composite Materials June 1, 2001 35: 972-998.
Industry
No manufacturer for this technology found in Europe.
Fit with European Space Policy
Technology meets Europe’s security needs. Graphite Epoxy Composite fit with the European Space Policy.
Potential areas for Spin-off
Spin-off areas of composites abound and continue to expand. They can include aircraft, automotive, shipbuilding, energy, infrastructure, military, and biomedical and recreational (sports) applications.
Market Size
Difficult to find manufacturers in Europe which are producing this technology. Therefore it can be safely stated that the market is undeveloped at the moment.

1.4 Metallic Microlattice

Domain	Materials and Processes	Benefits	Issues	
Subdomain	Novel Materials	▪ Ultra lightweight	▪ Limited number of space applications	
Group	Material assessment	▪ Recovery of previous state after pressure		
TRL	4 to 5			

Description

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. Metallic microlattices are composed of a network of interconnecting hollow struts. In the least-dense microlattice sample reported, each strut is about 100 micrometres in diameter, with a wall 100 nanometres thick. The completed structure is about 99.99% air by volume, and by convention, the mass of air is excluded when the microlattice density is calculated. Allowing for the mass of the interstitial air, the true density of the structure is approximately 2.1 mg/cm3 (2.1 kg/m3), which is only about 1.76 times the density of air itself at 25 degrees Celsius. The material is described as being 100 times lighter than Styrofoam. Metallic microlattices are characterized by very low densities, with the current record of 0.9 mg/cm3 being the lowest value for any solid yet discovered. Mechanically, the microlattices are behaviorally similar to elastomers and almost completely recover their shape after significant compression. This gives them a significant advantage over current aerogels, which are brittle, glass-like substances. This elastomeric property in metallic microlattices furthermore results in efficient shock absorption.

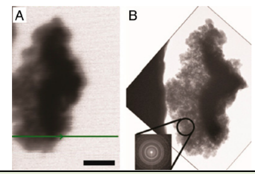
Fields of application

Metallic microlattice may find potential applications as thermal and vibration insulators such as shock absorbers, and may also prove useful as battery electrodes and catalyst supports. Additionally, the microlattices' ability to return to their original state after being compressed may make them suitable for using in spring-like energy storage devices.

Media Attention
After announcing the development of "world's lightest" material by its researchers on the HRL Laboratories website in November 2011, the metallic microlattice received a huge media attention from prominent journals, magazines and technology newspaper so far.
Information Links
HRL Laboratories, LLC: http://www.hrl.com/hrlDocs/pressreleases/2011/prsRls_111117.html BBC Technology: http://www.bbc.com/news/technology-15788735 Chemistry World: http://www.rsc.org/chemistryworld/News/2011/November/17111103.asp Wikipedia, 2012: http://en.wikipedia.org/wiki/Metallic_microlattice
Research Attention and Prominent Research Groups
No research group could find in Europe.
Papers
Schaedler, T. A.; Jacobsen, A. J.; Torrents, A.; Sorensen, A. E.; Lian, J.; Greer, J. R.; Valdevit, L.; Carter, W. B. (2011) Ultralight Metallic Microlattices. Science 334 (6058): 962. Mines, R. A. W. (2008) On the Characterisation of Foam and Micro-lattice Materials used in Sandwich Construction. Strain, Vol. 44, No. 1, pages 71–83, February 2008. Jacobsen, A.J.; Barvosa-Carter, W.B.; Nutt, S. (2007) Micro-scale Truss Structures formed from Self-Propagating Photopolymer Waveguides. Advanced Materials 19 (22): 3892–3896.
Industry
No manufacturer available for this technology.
Fit with European Space Policy
Technology meets Europe's security needs. Metallic Microlattices fit with the European Space Policy.
Potential areas for Spin-off
The material could find use in a range of applications, from aircraft structural components to acoustic damping and shock absorption. Bill Carter, manager of architected materials group at HRL, told Ward's AutoWorld, an automobile trade magazine, that a key focus for the metallic microlattice material will be its potential application in automotive technologies. By replacing primary structures in cars and airplanes with micro-lattice, manufacturers will be able to produce lighter and more fuel-efficient products, he said.
Market Size
The metallic microlattice was developed by a team of scientists from HRL Laboratories, in collaboration with researchers at University of California, Irvine and California Institute of

Technology, and was first announced in November 2011. Some prototype samples were made from a nickel-phosphorus alloy. A similar ultra-lightweight material consisting of an electrodeposited nanocrystalline nickel layer over a polymeric truss was created by researchers at the University of Toronto. A market or rather manufacturer for this technology still doesn’t exist.

1.5 Nanocrystalline diamond Aerogel

Domain	Materials and Processes	Benefits	Issues	
Subdomain	Materials and Processes	▪ Large intrinsic surface area	▪ Decreases the potential of insulation	
Group	Advanced Materials Manufacturing	▪ Ultralow density		
TRL	1 to 2			

Description

Aerogels are a novel class of high surface-area continuous solids with a broad range of both commercial and fundamental scientific applications. Both crystalline and amorphous structures have been synthesized. Aerogel materials have myriad scientific and technological applications due to their large intrinsic surface areas and ultralow densities. Amorphous carbon aerogel in particular has received a considerable amount of attention in recent years owing to its low cost, electrical conductivity, mechanical strength, and thermal stability. The carbon aerogel is placed in a diamond cell cavity where it is infused with neon gas, to keep the pores from collapsing. Then it is encased in a diamond shell and pressurized followed by a blasting from a laser that heats it; once again to simulate the way that diamonds are formed naturally at great geological depths. The key to the process is keeping the pores from collapsing. The supercritical neon gas is used because at pressures greater than 5GPa, it becomes a solid, thereby holding the walls of the pores in place as pressure and heat are added. The result is a new form crystalline diamond with a very low density similar to that of the precursor of around 40 milligrams per cubic centimeter, which is only about 40 times denser than air and about 200 microns wide.

Fields of application

The new material opens up a wide range of potential application, including water desalination, electrochemical supercapacitors, as well as both thermal and optical insulation. Flat panel television screens to components in a quantum computer are possible applications for the new material. The diamond aerogel could have applications in antireflection coatings, a type of optical coating applied to the surfaces of lenses and other optical devices to reduce reflection. It can be applied to telescopes, binoculars, eyeglasses or any other device that may require reflection reduction.

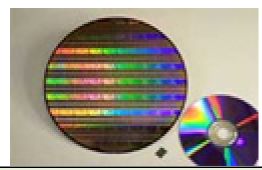
Media Attention

In March 2011, the diamond aerogel research published in PNAS, featured in Nature, Nature Chemistry and in other technology journals and magazines.

Information Links
Science Daily: http://www.sciencedaily.com/releases/2011/05/110517132646.htm Physorg.com: http://www.physorg.com/news/2011-05-team-diamond-aerogel-lab-emulating.html MSNBC: http://www.msnbc.msn.com/id/42977366/ns/technology_and_science-tech_and_gadgets/t/frozen-diamond-smoke-rich-possibilities/#.T0dtSvFRa5I Royal Society of Chemistry: http://www.rsc.org/chemistryworld/News/2011/May/10051101.asp Nanodiamond aerogel hammered out on anvil (Video): http://www.youtube.com/watch?feature=player_embedded&v=Z9IlCzvEryQ
Research Attention and Prominent Research Groups
Research groups found in US: Assistant Professor of Materials Science & Engineering; Peter J. Pauzauskie; Pauzauskie Group at the University of Washington: http://faculty.washington.edu/peterpz/wordpress/. Related companies in Europe: Pcas: http://www.pcas.com/ Active Space Technologies: http://activespacetech.com/EN/home.htm
Papers
Pauzauskie et al. (2011) Synthesis and characterization of a nanocrystalline diamond aerogel. Proceedings of the National Academy of Sciences of the United States of America, May 24, 2011 vol. 108 no. 21 8550-8553.
Industry
No manufacturer available for this technology at the moment.
Fit with European Space Policy
Technology meets Europe's security needs. Nanocrystalline diamond aerogel fit with the European Space Policy.
Potential areas for Spin-off
The nanocrystalline diamond aerogel could have potential applications in enhanced or modified biocompatibility, using it for example as a part of medical implants. The diamond aerogel may find potential applications in chemical doping, thermal conduction and electrical field emission.
Market Size
Technology is still in research phase. Therefore a marketplace or rather manufacturer doesn't exist.

2 Data Handling

2.1 Chalcogenide-Based Reconfigurable Memory Electronics

Domain	On-board Data Systems	Benefits	Issues	
Subdomain	On-board Data Management	▪ High speed	▪ Still in early stage of research	
Group	Data Storage	▪ Large memory electronics in small device		
TRL	5 to 6			

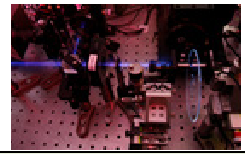
Description

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 Random Access Memory (RAM) 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 Dynamic random-access memory (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 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. 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.
Fields of application
The different applications of this technology are still in early stage of research. Chalcogenide-based compounds are candidates for a variety of reconfigurable applications in data storage, radio frequency circuitry, antenna, analog circuits, and even as reconfigurable wiring harnesses.
Media Attention
Chalcogenide-Based Reconfigurable Memory Electronics have received significant attention over the past years. A few research papers are published.
Information Links
Wikipedia, 2012: http://en.wikipedia.org/wiki/Phase-change_memory
Research Attention and Prominent Research Groups
Prof. Ing. Miloslav Frumar at the University Pardubice – Faculty of Chemical Technology http://www.upce.cz/en/fcht/index.html Activities: Study of chalcogenide memories for multilevel storage.
Papers
Mehta, N. (2006) Application of chalcogenide glasses in electronics and optoelectronics: A review. Journal of Scientific & Industrial Research, Vol. 65, pp. 777-786. Raoux, S.; Burr, G. W.; Breitwisch, M. J.; Rettner, C. T.; Chen, Y.-C.; Shelby, R. M.; Salinga, M.; Krebs, D.; Chen, S.-H.; Lung, H.-L. and Lam, C. H. (2008) Phase-change random access memory: A scalable technology. IBM Journal of Research and Development, Vol. 52 No. 4/5.
Industry
Hewlett-Packard Hitachi IBM Samsung

Fit with European Space Policy
Technology meets Europe's security needs. Chalcogenide-Based Reconfigurable Memory Electronics fit with the European Space Policy.
Potential areas for Spin-off
Potential Spin-off areas are automotive, information and communication technologies and radio and telecommunication terminal equipment.
Market Size
IBM announced in June 2011 that they have produced a stable, reliable, high-performance multi-bit PCRAM. The technology is still in its infancy and will require significant research efforts, however, scientists and industry alike see potential in its development.

2.2 Holographic Data Storage

Domain	On-board Data Systems	Benefits	Issues	
Subdomain	On-board Data Management	▪ Higher capacity	▪ No mass production	
Group	Data Storage	▪ Faster storage		
TRL	7 to 8			

Description

Holographic data storage is a potential technology in the area of high-capacity data storage that overcomes the limitation of magnetic and conventional optical data storage by going beyond recording only on the surface to recording through the full depth of the medium. Holographic data storage record information throughout the volume of the medium and is capable of recording multiple images in the same area utilizing light at different angles, unlike other technologies that record one data bit at a time. In holographic storage, light from a coherent laser source is split into two beams, the reference beam and the signal beam. The reference beam contains no information whereas the signal beam carries data to be stored that it has picked up by being passed through a spatial light modulator (SLM). SLMs are used in holographic data storage systems to encode information into a laser beam. At the point of intersection of the reference beam and the signal beam, the hologram is recorded in a light sensitive storage medium. These two beams are spatially overlapped through the volume of a photosensitive storage medium producing an optical interference pattern that is imaged within the medium. The result is a hologram, which can be read by applying a beam equivalent to the original reference. This produces a replica of the original data. The advantage of holography is that a huge number of holographic files can be stored in an overlapping manner in the same volume of photosensitive material. Rather than conventional optical storage, the holographic storage promises fast capacity and high data rates.

Fields of application

Holographic data storage could find use in on-board data application such as data storage on space mission which require faster storage and higher capacity.

Media Attention

Holographic data storage has received considerable attention over the past 20 years. Vast number of paper and articles are published in prominent journals, magazines and technology newspaper.

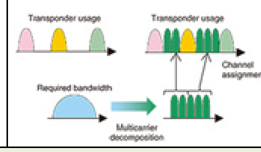
Information Links

Wikipedia, 2012: http://en.wikipedia.org/wiki/Holographic_data_storage

Technology Review: http://www.technologyreview.com/computing/21507/ Howstuffworks: http://computer.howstuffworks.com/holographic-memory.htm
Research Attention and Prominent Research Groups
Prof. Dr. Cornelia Denz at the University of Münster: http://www.uni-muenster.de/Physik.AP/Denz/Forschung/Forschungsaktivitaeten/Datenspeicherung/datenspeicherung.html Activities: Research into holographic and optoelectronic recording materials. Prof. Germano Montemezzani at the University of Metz and Supélec - Laboratoire Matériaux Optiques Photoniques et Systèmes (LMOPS) http://www.lmops.supelec.fr/. Dr. John Sheridan (Deputy Director of the Optoelectronic Research Centre) at University College Dublin - Department of Electronic and Electrical Engineering. Activities: Research into optical signal processing, holographic materials and optical devices/components for holographic data storage.
Papers
Hesselink, L.; Orlov, S.S.; Bashaw, M.C. (2004) Holographic data storage systems. Proceedings of the IEEE, Vol. 92, No. 8. Ashley, J.; Bernal, M.-P; Burr, G. W.; Coufal, H.; Guenther, H.; Hoffnagle, J. A.; Jefferson, C. M.; Marcus, B.; Macfarlane, R. M.; Shelby, R. M.; Sincerbox, G. T. (2000) Holographic data storage technology. IBM Journal of Research and Development, Vol. 44, No. 3. Psaltis, D.; Burr, G.W. (1998) Holographic data storage. IEEE Journals & Magazines, Vol. 31, No. 2.
Industry
In 1999, the research institute European Media Laboratory from Heidelberg and the Tesa-manufacturer (Beiersdorf AG) from Hamburg signed a cooperation agreement for the development of a so-called "T-ROM". JENOPTIK Laser, Optik, Systeme GmbH http://www.jenoptik-los.de Activities: Optical, opto-electronic & photonic functional components for holographic data storage. Daewoo Electronics: http://sine.ni.com/cs/app/doc/p/id/cs-685 General Electric Global Research: http://www.crn.com/news/storage/217200230/ge-unveils-500-gb-holographic-disc-storage-technology.htm Hitachi Maxell, Ltd.: http://www.maxell.eu/
Fit with European Space Policy
Technology meets Europe’s security needs. Holographic data storage fit with the European Space Policy.
Potential areas for Spin-off

Potential areas for Spin-off could be radio and telecommunication equipment, and information and communication technologies.
Market Size
Holographic data storage isn't a market yet, but several companies devoted to the commercialization continue the race to develop storage media technology. In the area of holographic data storage, there have been a variety of projects. Due to technical problems, especially in the field of material development, the release date for this technique, however, moved further and further into the future. Some Japanese, US and also European (Ecma International) research companies move toward a holographic data storage product and accelerate the holographic data storage market development. The first commercial instrument was introduced only in 2007 by the company InPhase.

2.3 Multicarrier signals

Domain	On-board Data Systems	Benefits	Issues	
Subdomain	Telecommunication Sub-Systems	▪ Signal-to-noise ratio (SNR) can be discarded	▪ High peak to mean envelop power ratio	
Group	Wave Interaction	▪ Faster storage		
TRL	6 to 7			

Description

Multicarrier signals or transmission, also known as multi tone transmission, has seen application in recent years as an approach to the problem of transmitting data over channels which are severely distorted and may suffer from additive or impulsive noise, distorting crosstalk, or multipath fading.

The basic concept of multicarrier transmission is to divide the channel bandwidth into sub-channels, assigning a carrier to each of them, and distributing the information stream between subcarriers, for example by filtering, or in effect, for example using orthogonal vector coding. 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 sub-channel exhibits a flat frequency response, thus making frequency-domain equalization easier. Each sub-stream 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. Since each data symbol occupies a much wider bandwidth than the data rate, a signal-to-noise-plus-interference ratio of less than 0 dB is feasible.

Fields of application

Multicarrier signals could be used in on-board telecommunication system of space vehicles.

Media Attention

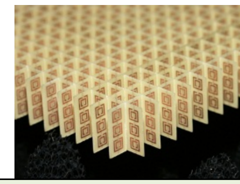
The technology received marginal or rather scarce attention in media so far. Difficult to find further information for this technology.

Information Links

Wikipedia, 2012: http://en.wikipedia.org/wiki/Multi-carrier_code_division_multiple_access

Research Attention and Prominent Research Groups
No research group found for this technology.
Papers
Nakhai, M.R. (2007) Multicarrier transmission. Published in IET Signal Processing.
Industry
Difficult to find manufacturers in Europe which are producing this technology.
Fit with European Space Policy
Technology meets Europe's security needs. Multicarrier signals fit with the European Space Policy.
Potential areas for Spin-off
Potential Spin-off areas for Multicarrier signals are automotive, aeronautic, information and communication technologies, and radio and telecommunication equipment.
Market Size
Difficult to find usable data this technology. Therefore it can be safely stated that the market is undeveloped at the moment.

2.4 Light slowing Metamaterials

Domain	On-board Data Systems	Benefits	Issues	
Subdomain	Wave Interaction and Propagation	▪ Faster transfer of information	▪ Higher complexity	
Group	Wave Interaction	▪ More orderly traffic flow	▪ Still in research phase	
TRL	2 to 3			

Description

Metamaterials are artificial materials which exhibit properties not easily achieved using naturally occurring materials. They usually gain their properties from structure rather than composition, using small inhomogeneities to create effective macroscopic behavior. Metamaterials have periodic structures spaced at a distance comparable to the wavelength of light propagating through them, and have unusual optical properties, such as the ability to bend light contrary to the direction of normal refraction. Previous negative refraction approaches have been demonstrated in the microwave region of the spectrum, and have depended on resonances within the metamaterials' structure that lead to high losses of the incident light. Light pulses can be decelerated and stopped within an optical waveguide containing a negative refractive-index metamaterial. One of the features of such waveguides is the possibility of supporting forward and backward modes, which may be of the same order and exist simultaneously, in the same frequency region, inside the waveguide, but with different propagation characteristics. An advantage of the negative refractive-index structures as compared to their single-negative permittivity or permeability counterparts is that they can slow light propagation for both polarizations. This slow-light producing method turns is remarkably simple and bears a number of serious advantages compared to previously proposed ways of decelerating optical signals. The hetero structures investigated here can be designed for mono mode operation in the desired frequency range, while the control of the group velocity can be achieved by appropriate tuning of the micro photonic structure, e.g. through gain to locally modify the refractive index, or via optically-induced attractive/repulsive forces exerted on the hetero structures to manipulate the thickness of its core.

Fields of application

The ability to slow light opens up a wide range of potential applications, including random access memories, optical delay lines, enhanced light-matter interactions and network buffering. Also, optical switches controlled by slow light could cut power requirements a million-fold compared to switches now operating everything from telephone equipment to supercomputers. Slowing light

could lead to a more orderly traffic flow in networks.
Media Attention
Light slowing metamaterials received considerable attention in media so far. Several numbers of paper and article are published in prominent journals, magazines and technology newspaper.
Information Links
Wikipedia, 2012: http://en.wikipedia.org/wiki/Slow_light Wikipedia, 2012: http://en.wikipedia.org/wiki/Metamaterial BBC NEWS, Technology: 'Slow' light to speed up the net: http://news.bbc.co.uk/2/hi/7557280.stm Harvard Gazette: http://news.harvard.edu/gazette/1999/02.18/light.html
Research Attention and Prominent Research Groups
Professor Ortwin Hess holds the Leverhulme Chair in Metamaterials in the Department of Physics at Imperial College London and is Co-Director of the Centre for Plasmonics & Metamaterials: http://www3.imperial.ac.uk/people/o.hess Centre for Plasmonics & Metamaterials, a cross-faculty grouping at Imperial College London covering a broad range of research in plasmonics and metamaterials. The Centre is jointly administered by Professor Stefan Maier, Professor Ortwin Hess and Professor Sir John Pendry. http://www3.imperial.ac.uk/plasmonmeta http://epubs.surrey.ac.uk/1556/1/fulltext.pdf Kosmas L. Tsakmakidis http://www.ati.surrey.ac.uk/profiles?s_id=4701
Papers
Valentine et. al. (2008) Three-dimensional optical metamaterial with a negative refractive index. Nature Vol 455. Savatore Savo, Wentao T. Lu; B. Didier F. Casse, Srinivas Sridhar (2011). "Observation of slow-light in a metamaterials waveguide at microwave frequencies". Applied Physics Letters 98 (17): 1719079.
Industry
Technology is still under development, therefore difficult to find manufacturers in Europe for this technology.
Fit with European Space Policy
Technology meets Europe’s security needs. Light slowing metamaterials fit with the European Space Policy.

Potential areas for Spin-off
Potential areas for Light slowing metamaterials are information and communication technologies, radio and telecommunication equipment, and electrical engineering industries.
Market Size
Difficult to find usable data for this technology. Therefore it can be safely stated that the market is undeveloped at the moment.

3 Propulsion

3.1 Ceramic Combustion chamber concept based on transpiration cooling

Domain	Propulsion	Benefits	Issues	
Subdomain		▪	▪	
Group		▪	▪	
TRL				

Description

Compared with metals, ceramic shows properties like low specific mass, high temperature stability, damage tolerance, among others. These properties make ceramic highly attractive for use in a thrust chamber environment. The transpiration/effusion cooling is well known over decades. However, if a porous and permeable metallic wall material based on platelet technology created by sintering processes is used, a critical situation may occur during operation when local overheating melts the porous surface resulting in rapid further damage due to the interrupted local cooling. Today, ceramics with either no melting phase or very high operational temperature limits offer the potential to establish transpiration/effusion cooled concepts which avoid such disadvantages and associated operational risks inherent to metals. Furthermore, the significant pressure loss occurring in the regenerative cooling channels can be avoided or reduced when using a transpiration/effusion cooled system. The principle of effusion or transpiration cooling consists of two mechanisms. First, coolant comes from the reservoir flows through the porous wall towards the hot gas side wall surface. Passing through the porous structure the coolant absorbs the heat flux conducted into the solid material of the wall. Since the absorbed heat flux is transported backwards into the hot gas with the coolant flow, the porous wall becomes a counter flow heat exchanger. At steady state a thermal equilibrium between the coolant and the solid wall is reached. Second, having passed through the porous wall the coolant forms a film on the hot gas side surface. The coolant film partially absorbs the convective wall heat flux and thus reduces the heat flux conducted into the wall to a certain amount, just like actual film cooling. The heated coolant at the film surface is transported downstream by the momentum of the hot gas flow, continuously replaced with fresh coolant flowing out of the wall.

Fields of application

The need of continued fundamental research in the fields of ceramic materials, cooling strategy, injectors, etc. is required for applying the new ceramic combustion chamber technology in vehicles. Cooling options such as transpiration or effusion cooling have the potential to reduce heat loads on hypersonic vehicles, allowing thinner leading edges and sharper noses. Moreover, the aerodynamic performance of such vehicles can thus be greatly improved.

Media Attention
The technology received slight attention in media so far. Only few papers were published by some research institutes. No further information found in technology magazines and newspaper.
Information Links
Ultramet: http://www.ultramet.com/propulsionsystem_components_liquid_rocket.html Flightglobal: http://www.flightglobal.com/news/articles/transpiration-cooling-offers-protection-for-spaceplanes-213860/ Martin Kurz & Company, Inc.: http://www.mkicorp.com/a-t-transpiration.asp
Research Attention and Prominent Research Groups
Research groups at DLR. Transpiration Cooling: Institute of Aerospace Thermodynamics at the University of Stuttgart http://www.uni-stuttgart.de/itlr/forschung/waerme/index.php?open=u&lang=en
Papers
Kirchberger, C.; Soller, S.; Kuhn, M.; Steelant, J. (2009) Cooling of Ceramic Combustion Chambers. 19th ISABE Conference, 2009-09-07 - 2009-09-11, Montréal, Canada. ISBN 9781600867361. Cheuret, F.; Steelant, J.; Langener, T.; von Wolfersdorf, J. (2011) Transpiration Cooling Modelling for Ceramic Combustion Chambers. 20th International Symposium on Air Breathing Engines, ISABE 2011-1126, Gothenburg, Sweden.
Industry
See DLR cooperation partner.
Fit with European Space Policy
Technology meets Europe’s security needs. Ceramic Combustion chamber concept based transpiration cooling fit with the European Space Policy.
Potential areas for Spin-off
Potential Spin-off areas for transpiration cooling can be the automotive and aeronautic industries.
Market Size
Difficult to find manufacturers which are producing this technology. Therefore it can be safely stated that the market is undeveloped at the moment.

3.2 Aerospike engine

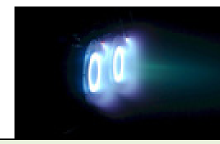
Domain	Propulsion	Benefits	Issues	
Subdomain	Chemical Propulsion Technologies	▪ Less fuel consumption	▪ Extra weight for the spike	
Group	Liquid Propulsion Systems	▪ Optimal thrust	▪ Larger cooled area can reduce performance	
TRL	6 to 7			

Description

The aerospike engine is a type of rocket engine that maintains its aerodynamic efficiency across a wide range of altitudes through the use of an aerospike nozzle. The aerospike engine is a member of the class of altitude compensating nozzle engines. A vehicle with an aerospike engine uses 25 to 30% less fuel at low altitudes, where most missions have the greatest need for thrust. Aerospike engines have been studied for a number of years and are the baseline engines for many single-stage-to-orbit (SSTO) designs and were also a strong contender for the Space Shuttle Main Engine. No aerospike engine is in commercial production. The best large-scale aerospikes are still only in testing phases. The basic concept of any engine bell is to efficiently expand 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. Instead of firing the exhaust out of a small hole in the middle of a bell, an aerospike engine avoids this random distribution by firing along the outside edge of a wedge-shaped protrusion, the "spike". The spike forms one side of a virtual bell, with the other side being formed by the outside air - thus the "aerospike". The idea behind the aerospike design is that at low altitude the ambient pressure compresses the wake against the nozzle. The recirculation in the base zone of the wedge can then raise the pressure there to near ambient. Since the pressure on top of the engine is ambient, this means that base gives no overall thrust. It also means that this part of the nozzle doesn't lose thrust by forming a partial vacuum, thus the base part of the nozzle can be ignored at low altitude. As the spacecraft climbs to higher altitudes, the air pressure holding the exhaust against the spike decreases, but the pressure on top of the engine decreases at the same time, so this is not detrimental. Further, although the base pressure drops, the recirculation zone keeps the pressure on the base up to a fraction of 1 bar, a pressure that is not balanced by the near vacuum on top of the engine; this difference in pressure gives extra thrust at altitude, contributing to the altitude compensating effect. This produces an effect like that of a bell that grows larger as air pressure falls, providing altitude compensation. The main disadvantages of aerospike engines seem to be extra weight for the spike, and increased cooling requirements due to the extra heated area. Further, the larger cooled area can reduce performance below theoretical levels by reducing the pressure against the

nozzle. Also, aerospikes work relatively poorly between Mach 1-3, where the airflow around the vehicle has reduced pressure, and this reduces the thrust.
Fields of application
The Aerospike engine represents the first application of this type of nozzle to the field of rocket propulsion. Typical propellants are liquid hydrogen (fuel) and liquid oxygen.
Media Attention
The Aerospike engine received marginal or rather scarce attention in media so far. Difficult to find further information for this technology.
Information Links
Wikipedia, 2012: http://en.wikipedia.org/wiki/Aerospike_engine Aerospike nozzle FAQ: http://www.hq.nasa.gov/office/pao/History/x-33/aero_faq.htm NASA: http://www.nasa.gov/centers/marshall/news/background/facts/aerospike.html
Research Attention and Prominent Research Groups
No research groups available in Europe so far.
Papers
Kumakawa, A., Onodera, T., Yoshida, M., Atsumi, M., and Igarashi, I. (1998) A Study of Aerospike-Nozzle Engines, AIAA Paper 98-3526, 1998. Fick, M. and Schmucker, R. H. (1997) Linear Aerospike Performance Evaluation, AIAA Paper 97-3305, 1997.
Industry
Boeing: www.boeing.com
Fit with European Space Policy
Technology meets Europe's security needs. Aerospike engines fit with the European Space Policy.
Potential areas for Spin-off
The aerospike engine may find potential in military application such as in rocket-powered aircrafts or in rocket planes is an aircraft that uses a rocket for propulsion, sometimes in addition to airbreathing jet engines.
Market Size
Aerospike engines have been studied for a number of years and are the baseline engines for many single-stage-to-orbit designs and were also a strong contender for the Space Shuttle Main Engine. However, no engine is in commercial production. The best large-scale aerospikes are still only in testing phases.

3.3 *Nanoparticle Field Extraction Thruster (NanoFET)*

Domain	Propulsion	Benefits	Issues	
Subdomain	Electric Propulsion Technologies	▪ Lightweight	▪ Transportation of the particles	
Group	Electrostatic Systems	▪ High-efficiency		
TRL	4 to 6			

Description

The micro electric space propulsion (MEP) or most commonly called nanoparticle field extraction thruster (NanoFET) is a high-speed electrostatic thruster technology that uses nanoparticles as propellant and utilizes micro- and nano-electromechanical system technologies, known as MEMS and NEMS, to transport, charge, extract, and accelerate the nanoparticles. NanoFET technology provides conductive nanoparticles to be transported to a small liquid-filled reservoir by a micro-fluidic flow transport system. Nanoparticles that come into contact with the bottom conducting plate would become charged and pulled to the liquid surface by the imposed electric field. If the electrostatic force near the surface can cause charged nanoparticles to break through the surface tension, field focusing would quickly accelerate the particles through the surface. Once extracted, the charged nanoparticles would be accelerated by the vacuum electric field and ejected, thus generating thrust. MEMS/NEMS technology is used in nanoparticle field extraction thruster concept where a multi-layer grid establishes the critical electric fields to charge, extract, accelerate, and eject conducting nanoparticles from the surface of an insulating liquid used to transport these particles. These nanoparticles will likely have diameters ranging from 1 nm to over 10 nm. NanoFET concepts potentially have the performance and integration flexibility to be employed on a diverse set of missions. NanoFETs have a high thrust-to-power ratio for electric propulsion systems. They can adjust specific impulse over a large range from 100s to 10.000s. Today used chemical propulsion systems have a maximum specific impulse of around 500 s. In addition, nanoFETs would be able achieve nearly constant acceleration and show a high efficiency range of over 90% over the entire specific impulse range.

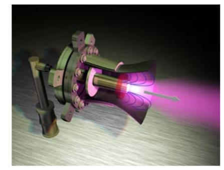
Fields of application

The Nanoparticle Field Extraction Thruster is being developed as a high thrust-to-power, highly compact, variable specific impulse electric propulsion. The Nanoparticle Field Extraction Thruster could be capable of propelling spacecraft at up to 90% the speed of light.

Media Attention
Due to the research efforts of the University of Michigan, the Nanoparticle Field Extraction Thruster got attention in a plenty of magazines and technology websites so far. The research results of this technology were published in prominent journals, for example in the American Institute of Physics.
Information Links
Wikipedia, 2012: http://en.wikipedia.org/wiki/Nano-particle_field_extraction_thruster MSNBC: http://www.msnbc.msn.com/id/31665236/ns/technology_and_science-innovation/t/near-lightspeed-nano-spacecraft-might-be-close/#.T0eLXvFRa5I Nanowerk: http://www.nanowerk.com/spotlight/spotid=1668.php Discover Magazine: http://blogs.discovermagazine.com/sciencenotfiction/2009/07/16/would-an-electric-rocket-ship-have-zero-emmissions-if-it-goes-90-of-the-speed-of-light-do-we-care/ Test of a Nanoparticle Field Extraction Thruster by students from Zero-g ElectroStatic Thruster Testbed (ZESTT) at NASA's Reduced Gravity Office during summer 2010 (Video): http://www.youtube.com/watch?v=b8l7UauqpO8
Research Attention and Prominent Research Groups
No research group available in Europe. USA: Dr. Thomas Liu at the University of Michigan is currently doing developmental research on the Nanoparticle Field Extraction Thruster http://pepl.engin.umich.edu/projects/NanoFET.html
Papers
Musinski, L.; Liu, T.; Gilchrist, B.; Gallimore, A.; Keidar, M. (2007) Nanoparticle Field Extraction Thruster (nanoFET): Design and Results of the Microparticle Emitter Prototype. Presented at the 30th International Electric Propulsion Conference, Florence, Italy. Musinski, L.; Liu, T.; Eu, I.; Gilchrist, B.; Gallimore, A.; Mirecki-Millunchick, J.; Morris, D. (2008) Nanoparticle Field Extraction Thruster (nanoFET): Introduction to, Analysis of, and Experimental Results from the "No-liquid" Configuration. 44th AIAA/ASME/SAE/ASEE Joint Propulsion Conference & Exhibit, Hartford, CT. Liu, Thomas M.; Brittany D. Drenkow, Louis D. Musinski, Alec D. Gallimore, Brian E. Gilchrist, Joanna Mirecki-Millunchick, David P. Morris, Alexandra L. Doan, Joseph L Munski, Allison M. Muldoon (2008) Developmental Progress of the Nanoparticle Field Extraction Thruster.
Industry
USA: ElectroDynamic Applications, Inc. (EDA) is a research and development firm principally focused on technologies for space and other severe environment applications, Michigan, USA.

http://www.edapplications.com/nanofet.html
Fit with European Space Policy
Technology meets Europe's security needs. Nanoparticle Field Extraction Thrusters fit with the European Space Policy.
Potential areas for Spin-off
The Nanoparticle Field Extraction Thruster propulsion system may find particular value in satellites attached to high value military assets. The NanoFET propulsion system can also support other propulsion applications beyond military satellites. As a scalable technology, NanoFET could provide its variable thrust and Isp benefits to a wide range of civilian and research satellites in many size categories. For example, in material processing it can be used to implant materials in accurately controlled quantities to specific depths and precise locations.
Market Size
The Nanoparticle field extraction thruster (NanoFET) is still under development by the University of Michigan.

3.4 *Magnetoplasmadynamic thruster (MPDT)*

Domain	Propulsion	Benefits	Issues	
Subdomain	Electric Propulsion Technologies	▪ High specific impulse	▪ Power requirements	
Group	Electrostatic Systems	▪ High thrust	▪ Degradation of cathodes	
TRL	4 to 6			

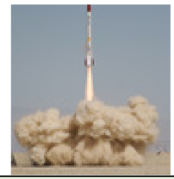
Description

The Magnetoplasmadynamic thruster (MPDT) is a form of electromagnetic spacecraft propulsion that uses the Lorentz force to generate thrust. A magnetoplasmadynamic thruster has two metal electrodes: a central rod-shaped cathode and a cylindrical anode that surrounds the cathode. A high-current electric arc is struck between the anode and cathode. As the cathode heats up, it emits electrons that collide with and ionize a propellant gas to create plasma. A magnetic field is created by the electric current returning to the power supply through the cathode, just like the magnetic field that is created when electrical current travels through a wire. This self-induced magnetic field interacts with the electric current flowing from the anode to the cathode (through the plasma) to produce an electromagnetic (Lorentz) force that pushes the plasma out of the engine, creating thrust. An external magnet coil may also be used to provide additional magnetic fields to help stabilize and accelerate the plasma discharge. Unlike chemical propulsion, there is no combustion of fuel. There are two main types of magnetoplasmadynamic thrusters: the applied-field and the self-field. The applied-field thrusters have magnetic rings surrounding the exhaust chamber to produce the magnetic field, while the self-field thrusters have a cathode extending through the middle of the chamber. Applied fields are necessary at lower power levels, where self-field configurations are too weak. Various propellants such as xenon, neon, argon, hydrazine, and lithium have been used, with lithium generally achieved the best results. With its high exhaust velocities, MPDTs offer advantages over conventional types of propulsion for each of these mission applications. MPDTs expel plasma to create propulsion. MPDTs can process more power and create more thrust than any other type of electric propulsion currently available while maintaining the high exhaust velocities associated with ion propulsion. A disadvantage is that power requirements on the order of hundreds of kilowatts are required for optimum performance. Current interplanetary spacecraft power systems and solar arrays are incapable of producing that much power. Another disadvantage with MPDT has been the degradation of cathodes due to evaporation driven by high current densities. Performance data: Exhaust velocity: 80.000 m/s; Specific impulse: 2.500-8.000s; Thrust: several hundred Newton are possible.

Fields of application
The MPDT is a very powerful electric propulsion system, which could make interplanetary manned flights possible. With a huge amount of electric energy, the MPDT can provide an efficient, megawatt-class electromagnetic thruster capable of several thousand hours of continuous operation.
Media Attention
The Magnetoplasmadynamic thruster has received a lot of attention over the past few years so far. Several papers from the US are published in prominent journals and presented in conferences.
Information Links
Wikipedia, 2012: http://en.wikipedia.org/wiki/Magnetoplasmadynamic_thruster Search engine for a large archive of technical papers on MPD thruster research: http://alfven.princeton.edu/publications.htm Glenn Research Center: http://www.nasa.gov/centers/glenn/pdf/105909main_FS-2004-11-022.pdf
Research Attention and Prominent Research Groups
Dr.-Ing. Georg Herdrich at the Institute of Space Systems at the University of Stuttgart, also working group leader of the International PPT & iMPD working group http://impd.irs.uni-stuttgart.de Professor of Aerospace Propulsion Mariano Andrenucci at the Aerospace Engineering Department of the University of Pisa: http://www.dia.unipi.it
Papers
Dan, L. (2012) Investigation of Efficiency in Applied Field MagnetoPlasmaDynamic Thrusters. A Dissertation Presented to the Faculty of Princeton University in Candidacy for the Degree of Doctor of Philosophy. Andrenucci M. Magnetoplasmadynamic Thrusters. Encyclopedia of Aerospace Engineering. Department of Aerospace Engineering, University of Pisa, Pisa, Italy. Andrenucci M., et. al. (2002) Magneto-plasma-dynamic Thrusters for Space Applications. AIAA 2002-111.
Industry
Alta SpA is the leading European small company in the aerospace propulsion sector. They operate in research and development on space electric propulsion, chemical propulsion and aerothermodynamics: http://www.alta-space.com/ EADS Astrium Ion Propulsion Systems: http://cs.astrium.eads.net/sp/

Qinetiq: http://www.qinetiq.com/
Fit with European Space Policy
Technology meets Europe's security needs. Magnetoplasmadynamic Thruster fit with the European Space Policy.
Potential areas for Spin-off
The primary application for Magentoplasmadynamic thruster is in the area of aeronautics.
Market Size
The MPDT is realized up to now only in prototype form and has so far been tested only on the ground. Initially investigated in the 1960s and funded periodically over the last few decades, MPDTs have achieved slow but steady improvements and developments. A variety of thruster geometries have been investigated using different types of gas propellants, with lithium vapor propellant providing the most efficient performance to date. Lithium-fed MPDTs developed in Russia have operated at power levels of 100 kilowatts, with efficiencies of up to 45% and plasma exhaust velocities approaching 50.000 meters per second (over 160.000 km/h). Facilities to investigate lithium-fed MPDTs have been established in the United States at the NASA Jet Propulsion Laboratory and Princeton University.

3.5 *Alternative Solid Propellants: CL-20*

Domain	Propulsion	Benefits	Issues	
Subdomain	Supporting Propulsion Technologies and Tools	▪ High performance	▪ Production costs	
Group	Propellants	▪ High energy content	▪ Sensitive to both impact and friction	
TRL	7 to 8			

Description

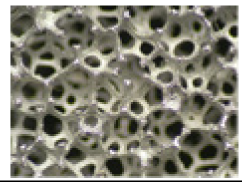
Hexanitrohexaazaisowurtzitane (HNIW) more commonly called CL-20 is a novel high-density cyclic nitramine that is 20 percent more powerful than HMX nitramines. CL-20 is considered the most powerful non-nuclear explosive today. It has a higher energy content, higher heat of formation and better oxidizer-to-fuel ratio and detonation properties, but lower impact and friction sensitivity than the conventionally used high-energy propellants and explosives such as HMX or RMX. The molecular structure of CL-20 consists of a rigid isowurtzitane cage with a nitro group attached to each of the six bridging nitrogen atoms within the cage. In contrast to HMX and RDX nitramines that have no C-C bonds in their structures, CL-20 bears three slightly elongated C-C bonds. There are four polymorphs of CL-20: α-HNIW, β-HNIW, γ-HNIW and HNIW-ε. The ε-HNIW is the polymorph with the highest crystal density and stability. The first step in CL-20 synthesis involves creation of the basic cage structure through condensation of glyoxal with benzylamine, which is leading to HBIW. Conversion of HBIW to CL-20 poses a major challenge. Direct debenzylation of HBIW by nitrolysis is unsuccessful due to competing nitration of phenyl rings. Thereby, debenzylation precedes the nitration as a necessary step. The removal of N-benzyl groups is usually achieved by catalytic hydrogenation. However hexaaza isowurtzitane itself being unstable, it is necessary that six secondary amine groups be protected during the transformations. The reductive debenzylation of HBIW under a wide variety of hydrogenation conditions to get tetraacetyl derivative of isowurtzitane with palladium catalyst has been investigated by various researchers. Intermediates are converted to CL-20 by reacting with nitrosonium salt followed by nitronium salt. 98% HNO3 also produces CL-20 at high temperature. As an explosive, CL-20 is about 14% stronger than HMX. Its detonation velocity is maximum 10.3 km s-1, so that the substance of the most explosive mixtures of tetranitromethane and toluene is not superior to smaller densities, and lead block compression tests significantly more energy than HMX. Cl-20's explosive force is 1.9 and TNT equivalent. The thermal stability as well as the vapor pressure of CL-20 is significantly lower than that of octogen. CL20 is a polyazapolycyclic caged polynitramine. The new propellant has been successfully developed and tested in tactical rocket motors. The propellant is non-polluting: acid free, solid particulates free, and lead free. It is also smoke free and has only a faint shock diamond pattern that is visible in the otherwise transparent exhaust. Without the bright flame and dense smoke trail produced by the burning of aluminized propellants, these smokeless

propellants all but eliminate the risk of giving away the positions from which the missiles are fired. The new CL-20 propellant is shock-insensitive (hazard class 1.3) as opposed to current HMX smokeless propellants which are highly detonable (hazard class 1.1). CL-20 is considered a major breakthrough in solid rocket propellant technology but has yet to see widespread use because costs remain high.
Fields of application
CL-20 has numerous applications. It was primarily developed to be used in propellants.
Media Attention
CL-20 receives more and more attention over the past years so far. Vast number of paper and articles are published in prominent journals, magazines and technology newspaper.
Information Links
Wikipedia, 2012: http://en.wikipedia.org/wiki/Hexanitrohexaazaisowurtzitane PhysOrg: www.physorg.com/news/2011-09-university-chemists-stabilize-explosive-cl-.html ScienceNews: http://www.sciencenews.org/view/generic/id/334051/title/Explosive_goes_boom,_but_not_too_soon
Research Attention and Prominent Research Groups
Chair of Inorganic Chemistry – Energetic Materials Prof. Dr. Thomas M. Klapötke at Ludwig-Maximilian University (LMU) Munich http://www.chemie.uni-muenchen.de/ac/klapoetke/ Dr. Klaus Menke at the Fraunhofer Institute for Chemical Technology ICT in Pfinztal http://www.ict.fraunhofer.de/EN/coreco/EM/Ex/rp/index.jsp USA: Matzger Research Group of Prof. Adam Matzger at University of Michigan http://www.umich.edu/~ajmgroup/energeticmaterials.html
Papers
M. Geetha, U. R. Nair, D. B. Sarwade, G. M. Gore, S. N. Asthana and H. Singh (2003) Studies on CL-20: The most powerful high energy material. Journal of Thermal Analysis and Calorimetry, Vol. 73 (2003) 913-922 Turcotte, R.; Vachon, M.; Kwok, Q. S. M.; Wang, R. and Jones, D. E. G. (2005) Thermal study of HNIW (CL-20) in Thermochimica Acta. Bolton, O. and Matzger, A. J. (2011) Improved Stability and Smart-Material Functionality Realized in an Energetic Cocrystal. Angewandte Chemie, Volume 123, Issue 38, pages 9122–9125.
Industry
No manufacturer found for this technology in Europe for this technology so far.

Fit with European Space Policy
In terms of its dangerousness, the substance CL-20 was not classified by the European Union. There can be some issues with Europe’s security needs.
Potential areas for Spin-off
CL-20 has a potential use in defence/military applications. The explosive could also find use in aeronautic and mining industries.
Market Size
CL-20 was discovered in 1987 by researchers at the Naval Air Warfare Center Weapons Division in China Lake, California. Due to the complicated synthesis and the associated high production costs the CL-20 is far too expensive for commercial use. Therefore, the market is still undeveloped.

4 Power

4.1 Aluminum-Celmet for Lithium-Ion Batteries

Domain	Spacecraft Electrical Power	Benefits	Issues	
Subdomain	Energy Storage Technologies	▪ Higher energy density	▪ Has been not tested in Space	
Group	Electro chemical Technologies for Energy Storage	▪ High corrosion resistance		
TRL	7 to 8			

Description

Standard lithium-ion batteries are often made by aluminum and copper foils. Celmet is made from nickel or nickel chromium and is created through a combination of electro conductive coating, plastic foam, nickel plating and plastic foam. The airflow resistance of celmet is very low. Therefore, fluid can be treated at low pressure drop. Celmet has good workability; it can be cut, pressed and piped easily. Replacing the aluminum foil in a conventional lithium-ion battery with aluminum-celmet increases the amount of positive active material per unit area and thus increases battery capacity 1.5 to 3 times. With up to 98 percent porosity, aluminum-celmet is about one-third the weight of nickel, offers greater electrical conductivity and is corrosion-resistant. In conventional capacitors, both positive and negative current collectors are made from aluminum foil. The use of aluminum-celmet instead can improve the capacity and reduce the footprint, as with lithium-ion batteries. The aluminum-celmet material is suitable for use in lithium-ion and other secondary batteries operating at high charge and discharge voltages.

Fields of application

The Aluminum-Celmet material is suitable for use in lithium-ion and other secondary batteries operating at high charge and discharge voltages.

Media Attention

Aluminum-Celmet for Lithium-Ion Batteries received considerable attention in the media. A few articles are published in prominent magazines and technology newspaper.

Information Links

Electronics News: http://www.electronicsnews.com.au/features/tripling-lithium-battery-capacity-with-aluminium-c

Sumitomo Electric Industries, Ltd.: http://global-sei.com/products/energy/celmet/index.html

Research Attention and Prominent Research Groups
No research group found in Europe for this technology so far.
Papers
Inazawa, S.; Hosoe, A.; Majima, M. and Nitt, K. (2010) Novel Plating Technology for Metallic Foam. Sei Technical Review, Number 71, October 2010. Okuno, K.; Kato, M.; Harada, K.; Park, J.; Emura, K.; Yao, M.; Iwaki, T.; Tanase, S. and Sakai, T. (2007) Discharge Property of High Power Ni-MH Battery Using New Celmet. Sei Technical Review, Number 64, April 2007.
Industry
Sumitomo Electric Industries, Ltd.: http://global-sei.com/
Fit with European Space Policy
Technology meets Europe's security needs. Aluminum-Celmet for Lithium-Ion Batteries fit with the European Space Policy.
Potential areas for Spin-off
Potential Spin-off areas are Automotive (e.g. hybrid vehicles or structure of batteries), Construction, Mechanical Engineering, and Aeronautic & Defence industries. Some examples of application: Vaporization element of kerosene fan heater; Carrier of industrial deodorizer catalysts; Oil mist separators.
Market Size
In May 2010, the Japan Aerospace Exploration Agency (JAXA) launched the Small Solar Power Sail Demonstrator IKAROS from the Tanegashima Space Center. To prevent liquid motion inside the IKAROS tank, celmet was selected as material, which features high porosity and continuous pores. Nevertheless, the Aluminum-Celmet market is still in its infancy and will require significant research. Scientists and industry alike see potential in its further development.

4.2 Super-/ Ultracapacitors

Domain	Spacecraft Electrical Power	Benefits	Issues	
Subdomain	Power Conditioning and Distribution	▪ High efficiency	▪ High self-discharge	
Group	Power Conditioning	▪ Long lifetime	▪ Low maximum voltage	
TRL	7 to 8			

Description

A supercapacitor, also known as ultracapacitor, or electric double-layer capacitor (EDLC), is an electrochemical capacitor with relatively high energy density. In conventional capacitors, energy is stored by the removal of charge carriers, typically electrons, from one metal plate and depositing them on another. This charge separation creates a potential between the two plates, which can be harnessed in an external circuit. The total energy stored in this fashion increases with both the amount of charge stored and the potential between the plates. The amount of charge stored per unit voltage is essentially a function of the size, the distance, and the material properties of the plates and the material in between the plates, while the potential between the plates is limited by the breakdown field strength of the dielectric. The dielectric controls the capacitor's voltage. Optimizing the material leads to higher energy density for a given size of capacitor. Supercapacitors do not have a conventional dielectric. Rather than two separate plates separated by an intervening insulator, these capacitors use virtual plates that are in fact two layers of the same substrate. Their electrochemical properties result in the effective separation of charge despite the vanishingly thin physical separation of the layers. The lack of need for a bulky layer of dielectric, and the porosity of the material used, permits the packing of plates with much larger surface area into a given volume, resulting in high capacitances in practical-sized packages. Each layer of supercapacitors by itself is quite conductive, but the physics at the interface where the layers are effectively in contact means that no significant current can flow between the layers. However, the double layer can withstand only a low voltage, which means that supercapacitors rated for higher voltages must be made of matched series-connected individual supercapacitors, much like series-connected cells in higher-voltage batteries. Supercapacitors have much higher power density (10 to 100 times) than conventional batteries. Power density combines the energy density with the speed that the energy can be delivered to the load. Batteries, which are based on the movement of charge carriers in a liquid electrolyte, have relatively slow charge and discharge times. Supercapacitors can be charged or discharged at a rate that is typically limited by current heating of the electrodes. 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).

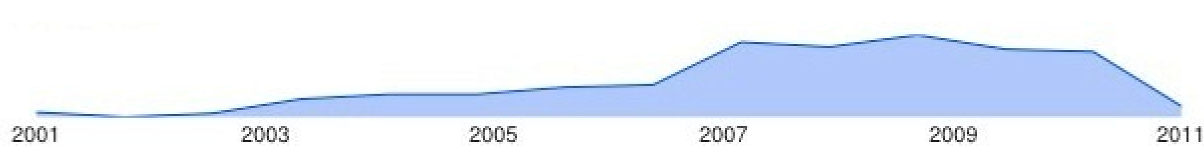
Fields of application

Supercapacitors find primary application in electrical energy matters of space vehicles/ spacecraft's.

Media Attention

Supercapacitors received considerable attention over the past 10 years in media. Vast number of paper and articles are published in prominent journals, magazines and technology newspaper.

Tag usage "supercapacitors" for paper on www.mendeley.com:



Information Links

Wikipedia, 2012: http://en.wikipedia.org/wiki/Electric_double-layer_capacitor

GigaOM, Garthwaite, Josie (12 July 2011): http://gigaom.com/cleantech/how-ultracapacitors-work-and-why-they-fall-short/

Electronics Weekly: http://www.electronicsweekly.com/Articles/03/03/2006/37810/Supercapacitors-see-growth-as-costs-fall.htm

UltraCapacitors.org: http://www.ultracapacitors.org

Office of Energy Efficiency and Renewable Energy: http://www1.eere.energy.gov/vehiclesandfuels/technologies/energy_storage/ultracapacitors.html

Research Attention and Prominent Research Groups

Project leader Bernd Willer at Fraunhofer Institute for Wind Energy and Energie Systems Technology in Kassel, Germany: http://www.iset.uni-kassel.de/pls/w3isetdad/www_iset_new.main_page?p_name=7241015&p_lang=eng

Research team of Dr. Rüdiger Kötz at Paul Scherrer Institut in Switzerland: http://ecl.web.psi.ch/supercap/index.html#project

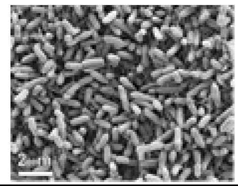
Papers

Kötz, R. and Carlen, M. (2000) Principles and applications of electrochemical capacitors. Electrochimica Acta, Volume 45, Issues 15–16, 3 May 2000, Pages 2483–2498.

Halper, M. S. and Ellenbogen, J. C. (2006) Supercapacitors: A Brief Overview. In Mitre Corporation (MITRE), March 2006.

Industry
Siemens AG, Transportation Systems Group Technology: http://www.mobility.siemens.com/en/data/pdf/ts_internet/sonstiges/siemens_ts_innovation_sibac_en.pdf WIMA SuperCaps: http://www.wima.com/DE/products_super.htm Maxwell Technologies GmbH/Maxwell Technologies SA EMEA: http://www.maxwell.com/ Tavrima Canada Ltd.: http://www.tavrima.com/
Fit with European Space Policy
Technology meets Europe's security needs. Super- or Ultracapacitors fit with the European Space Policy.
Potential areas for Spin-off
Supercapacitors have a variety of commercial applications, notably in energy smoothing and momentary-load devices. They have applications as energy-storage and KERS devices used in vehicles, and for smaller applications like home solar energy systems where extremely fast charging is a valuable feature. Supercapacitors are used in some concept prototype vehicles, in order to keep batteries within resistive heating limits and extend battery life. They can also be used to operate low-power equipment such as PC Cards, photographic flash, flashlights, portable media players, and automated meter reading equipment.
Market Size
According to Innovative Research and Products, supercapacitor market growth will continue during 2009 to 2014. Worldwide business, over US $ 275 million in 2009, will continue to grow at an Average Annual Growth Rate of 21.4% through 2014.

4.3 Bacterial Nanowires

Domain	Spacecraft Electrical Power	Benefits	Issues	
Subdomain	Energy Storage Technologies	▪ High performance	▪ Has been not tested in Space	
Group	Electro chemical Technologies for Energy Storage	▪ Small and cheap electrical devices	▪ Method of application unknown	
TRL	2 to 3			

Description

Bacterial nanowires, also known as microbial nanowires, are electrically conductive appendages with nanowire architectures produced by a number of bacteria most notably from the Geobacter sulfurreducens and Shewanella oneidensis genera. Bacterial Nanowires are a new kind of bacteria that produces long stringy filaments outside its body that conduct electrons better than some metals. The strings of nanowires, which are called pili, allow the bacteria to get rid of electrons which are a by-product of its digestive process. Bacterial Nanowires conduct electrons along their length. These are produced by some bacteria and are 3-5 nm wide and up to tens of micrometers long. The filaments bind bacteria together into clumps called microbial films. The electrical conductivity in the wires is comparable to those of synthetic organic metallic nanostructures that commonly used in the electronics industry.

Fields of application

Bacterial Nanowires could lead to very small and cheap conductive materials using microorganism, high performance batteries as well as conductors or sensors. In addition, Bacterial Nanowires could lead to the development of new electronic materials and could influence the design of energy-capture strategies, such as conversion of biomass and wastes to methane or electricity. Bacterial nanowires are seen as a next generation of conductive materials with a multitude of possible applications in nanoelectronic devices.

Media Attention

Bacterial nanowires received considerable attention in media. In addition, several numbers of paper and article are published in prominent journals, magazines and technology newspaper.

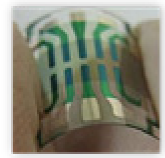
Information Links

Wikipedia, 2012: http://en.wikipedia.org/wiki/Bacterial_nanowires

Nature Reviews: http://www.nature.com/nrmicro/journal/v3/n8/pdf/nrmicro1216.pdf

Discovery News: http://news.discovery.com/tech/bacterial-nanowires-electronics-110811.html
Research Attention and Prominent Research Groups
Prof. Derek Lovley; Research Groups in Microbiology of the University of Massachusetts at Amherst; http://www.bio.umass.edu/micro/research_groups.html Geobacter.org is a website with contacts of people who are working on the topic of bacterial nanowires: http://www.geobacter.org/contacts
Papers
Leung, Kar Man (2011) Exploring Bacterial Nanowires: From Properties to Functions and Implications. The School of Graduate and Postdoctoral Studies. The University of Western Ontario London, Ontario, Canada. Reguera et al. (2005) Extracellular electron transfer via microbial nanowires. Nature 435, 1098-1101. Malvankar, N. S.; Vargas, M.; Nevin, K. P.; Franks, A. E.; Leang, C.; Kim, B.-C.; Inoue, K.; Mester, T.; Covalla, S. F.; Johnson, J. P.; Rotello, V. M.; Tuominen, M. T. and Lovley, D. R. (2011) Tunable metallic-like conductivity in microbial nanowire networks. Nature Nanotechnology 6, 573–579.
Industry
Technology is still under development and method of application unknown. Difficult to find manufacturers in Europe for this technology.
Fit with European Space Policy
Technology meets Europe's security needs. Bacterial nanowires fit with the European Space Policy.
Potential areas for Spin-off
Bacterial nanowires may find potential application in medical and healthcare devices, information and communication technologies as well as in radio and telecommunication equipment.
Market Size
Difficult to find usable data this technology. Therefore it can be safely stated that the market is undeveloped at the moment.

4.4 UltraFlex Solar Panels

Domain	Spacecraft Electrical Power	Benefits	Issues	
Subdomain	Power Generation Technologies	▪ Very lightweight	▪ Lower lifetime	
Group	Photovoltaic Generator Technology	▪ Low volume due to foldability		
TRL	6 to 7			

Description

The UltraFlex Solar Panel is a lightweight, low volume, triple junction solar array which provides 5% higher efficiency and increased foldability compared with traditional triple junction Gallium Arsenide cells. UltraFlex solar cells have 25% less mass than conventional solar panels, which allow reduced launch costs. In addition, UltraFlex solar panels have a compact and extremely low stowage volume (25% less volume of standard solar arrays) that enables spacecraft and launch vehicle flexibility. The UltraFlex solar array is an accordion fanfold flexible-blanket solar array comprised of interconnected triangular shaped lightweight substrates/gores. During deployment, each interconnected triangular substrate/gore unfolds in a rotational fan fashion. Upon full deployment, the structure becomes tensioned into a rigid shallow umbrella-shaped structure. Lightweight composite radial spar elements attached to each substrate/gore provide structural support for the gores during deployment and in the deployed state. When fully deployed, the UltraFlex gores are maintained in a preloaded and tensioned state via the elastic deflection of in-plane spring flexures, forming a high-stiffness structural platform for the solar cells. The UltraFlex solar panel provides less mass, higher efficiency, compact stowage volume, exceptional deployed structural performance, high reliability, scalability, and operational capability.

Fields of application

UltraFlex Solar Panels could be used for solar energy generation in space. Solar energy can be harvested around the clock, the satellites which are in orbit never obscured by clouds and bad weather.

Media Attention

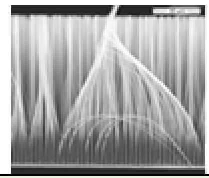
The technology received slight attention in media so far. Only the UltraFlex Solar Panel research by the NASA has received more significant attention. Articles or research papers are difficult to find on this technology.

Information Links

NASA Jet Propulsion Laboratory: http://nmp.nasa.gov/st8/tech/solar_array1.html

ATK: http://www.atk.com/capabilities_multiple/cs_ss_subsys_sasps.asp
Research Attention and Prominent Research Groups
No research group found for this technology in Europe.
Papers
Semke, W.; Webster, A.; Spence, B.; and White, S.: The Dynamic Characteristics of a Lightweight Deployable Solar Array.
Industry
A few companies are existing in the US. Alliant Techsystems Inc.: http://www.atk.com/ Emcore Corporation: http://www.emcore.com/
Fit with European Space Policy
Technology meets Europe's security needs. UltraFlex Solar Panels fit with the European Space Policy.
Potential areas for Spin-off
UltraFlex Solar Panels may find application in ground photovoltaic plants and can be used for solar energy generation. Areas for Spin-off could be the automotive and aeronautic market.
Market Size
Difficult to find manufacturers in Europe which are producing this technology. Therefore it can be safely stated that the market is undeveloped at the moment.

4.5 Silicon Nanowire Lithium-Ion Battery

Domain	Spacecraft Electrical Power	Benefits	Issues	
Subdomain	Energy Storage Technologies	▪ High efficiency	▪ Improvement of cathode needed	
Group	Electro chemical Technologies for Energy Storage	▪ Clean power generation	▪ High irreversible capacity loss	
TRL	7 to 8			

Description

Nanowires of silicon just a few atoms across can function as high-capacity electrodes, absorbing and releasing about 10 times more lithium ions than the graphite electrodes that are commonly used today. To overcome expand/shrink cycle typically causes the silicon to pulverize and degrading the performance of the battery, researchers used nanotechnology methods. 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 lithium. With this method, the silicon is not collapsing but it maintains its size when the lithium atoms are being positively charged and when being electrically discharged when used. Morphological changes occur in Si during electrochemical cycling. The volume of silicon anodes changes by about 400% during cycling. As a result, Si films and particles tend to pulverize during cycling. Nanowires grown directly on the current collector do not pulverize or break into smaller particles after cycling.

Fields of application

The Silicon Nanowire is suitable for use in lithium-ion and other secondary batteries operating at high charge and discharge voltages in space energy storage technologies.

Media Attention

Silicon Nanowire Lithium-Ion Batteries received considerable attention in media so far. In addition, several numbers of paper and article are published in prominent journals, magazines and technology newspaper.

Information Links

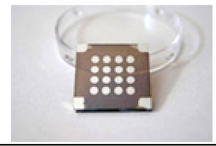
Wikipedia, 2012: http://en.wikipedia.org/wiki/Nanowire_battery

Stanford News Service: http://news.stanford.edu/news/2008/january9/nanowire-010908.html

Royal Society of Chemistry:

http://www.rsc.org/chemistryworld/News/2007/December/17120702.asp Physorg: http://www.physorg.com/news117212815.html
Research Attention and Prominent Research Groups
DFG Priority Programme 1165; Nanowires and Nanotubes: From Controlled Synthesis to Function; Dr. Valeriy Stepanyuk and Dr. Peter Werner at the Max Planck Institute of Microstructure Physics in Halle; http://www.mpi-halle.mpg.de/department2/research-topics/major-research-collaborations/spp-1165-nanowires-and-nanotubes/abstract/ Riccardo Ruffo at the University of Milan Bicocca; Research line devoted mainly to the investigation of electrode and electrolyte materials for lithium ion batteries http://www.mater.unimib.it/uploads/MAE-3_relazione_annuale_07.pdf
Papers
Chan, C. K.; Peng, H.; Liu, G.; McIlwrath, K.; Zhang, X. F.; Huggins, R. A.; Cui, Y. (2008) High-performance lithium battery anodes using silicon nanowires. Nature Nanotechnology 3, 31 – 35. Park, M.-S. et al. (2007) Preparation and electrochemical properties of SnO2 nanowires for application in lithium-ion batteries. Angewandte Chemie International Edition 46, 750– 753. Green, M., Fielder, E., Scrosati, B., Wachtler, M. & Moreno, J. S. (2003) Structured silicon anodes for lithium battery applications. Electrochemical and Solid-State Letters 6, A75-A79.
Industry
No manufacturer found for this technology in Europe so far.
Fit with European Space Policy
Technology meets Europe's security needs. Silicon Nanowires Lithium-Ion Batteries fit with the European Space Policy.
Potential areas for Spin-off
Potential Spin-off areas are automotive and aeronautic and defence industries.
Market Size
The market for silicon nanowire lithium-Ion batteries is still undeveloped. In some cases, the technology will require significant research efforts. Nevertheless, scientists and industry alike see a huge potential in its further development.

4.6 Quantum-Dot Solar Cell

Domain	Spacecraft Electrical Power	Benefits	Issues	
Subdomain	Energy Storage Technologies	▪ High potential efficiency	Untill now, low levels of efficiency	
Group	Mechanical Technology for Energy Storage	▪ Clean power generation		
TRL	5			

Description

As opposed to conventional photovoltaic solar cells based on bulk semiconductors, such as silicon, copper indium gallium selenide or cadmium telluride, quantum dot solar cells use quantum dots as photovoltaic material. Quantum dots are nano-scale particle of semiconductor materials whose excitons are confined in all three spatial dimensions. Semiconductor quantum dots typically have diameters from about 2 to 10 nanometers and contain only hundreds to thousands of atoms. In contrast to bulk materials, which have larger crystals and more atoms than nanomaterials and where the bandgap is fixed by the choice of material composition, quantum dots have bandgaps that are tunable across a wide range of energy levels by changing the quantum dot size. The ability to tune the bandgap makes quantum dots desirable for solar cell use, where a variety of different energy levels are used to extract more power from the solar spectrum. The conversion process works by multiple exciton generation (MEG) while a single photon of light of sufficient energy is absorbed by the quantum dot. It produces more than one bound electron-hole pair per absorbed photon. The extra efficiency comes from harvesting energy that would otherwise be lost as heat. Quantum dots used in third-generation solar cells have the potential to increase the efficiency of converting sunlight to electricity up to 66%, exceeding the limits of about 31% of first-generation (silicon) and second-generation (thin-film silicon, cadmium telluride, and copper indium gallium diselenide) solar cells. Quantum dot solar cells can reduce wasteful heat and maximize the amount of the sun's energy that is converted to electricity.

Fields of application

Quantum-Dot Solar Cells find primary application in energy harnessing and converting in space environment.

Media Attention

Quantum-Dot Solar Cells received considerable attention in media, especially in the past few years, because quantum dot based photovoltaics may offer advantages such as mechanical flexibility as well as low cost, clean power generation and an efficiency of 65% in future. Several

numbers of paper and article are published in prominent journals, magazines and technology newspaper.
Information Links
Wikipedia, 2012: http://en.wikipedia.org/wiki/Quantum_dot_solar_cell Physorg: http://www.physorg.com/news/2011-08-tiny-tech-big-results-quantum.html Cnet: http://news.cnet.com/8301-11386_3-57344421-76/two-for-one-quantum-dot-solar-cells-boost-power/ Scientific American: http://www.scientificamerican.com/article.cfm?id=quantum-dots-and-more-use
Research Attention and Prominent Research Groups
Dr. Krügers Nanoscience Research Group: The nanoscience group of Dr. Michael Krueger is a subgroup of the Sensor Lab of the Institute for Microsystems Technology (IMTEK) at the University of Freiburg, which is headed by Prof. Dr. G. Urban. The research is focussed on fundamental and applied aspects of nanoscience and nanotechnology: http://www.fmf.uni-freiburg.de/projects/pg_anorg_en/AKKrueger Prof. Kleinermanns: Functional nanosystems research group at Heinrich-Heine-Universität Düsseldorf: http://www-public.rz.uni-duesseldorf.de/~pc1/kleinermanns.htm
Papers
Schaller, R.; Klimov, V. (2004) High Efficiency Carrier Multiplication in PbSe Nanocrystals: Implications for Solar Energy Conversion. Physical Review Letters 92. Nozik, A. J. (2001) Quantum Dot Solar Cells: Preprint. Physica E 14 (2002) 115 – 120. Hanna, M. C.; Beard, M. C.; Johnson, J. C.; Murphy, J.; Ellingson, R. J.; and Nozik, A. J. (2005) Quantum Dot Solar Cells with Multiple Exciton Generation. Presented at the 2005 DOE Solar Energy Technologies Program Review Meeting, Denver, Colorado. Martí, A.; López, N.; Antolín, E.; Cánovas, E.; Stanley, C. R.; Farmer, C.; Cuadra, L.; Luque, A. (2006) Novel semiconductor solar cell structures: The quantum dot intermediate band solar cell. Elsevier, Vol. 511-512, pp. 638-644.
Industry
Fraunhofer Institute: http://www.ise.fraunhofer.de/en/areas-of-business-and-market-areas/alternative-photovoltaic-technologies/novel-solar-cell-concepts-and-photon-management/profile-of-business-unit Infineon: http://www.infineon.com Solvoltaics: http://www.solvoltaics.com/Company/

QuNano: http://www.qunano.se/
Fit with European Space Policy
Technology meets Europe's security needs. Quantum-Dot Solar Cell fit with the European Space Policy.
Potential areas for Spin-off
Quantum-Dot Solar Cell could find use in a range of areas, from automotive technology to aeronautic and defence industries.
Market Size
A Quantum-Dot Solar Cell market doesn't exist yet, but several solar energy based companies started with research that is at a pre-commercialization stage at the moment. In some cases, the technology will require significant research efforts. Nevertheless, scientists and industry alike see a huge potential in its further development.

Delphi Results (Annex 2)

1 General Notes / Table legends

Tables show the answers of the experts on each question of the Delphi survey. Answers and comments are given anonymously.

Under *Selection of attributes* the last line of the table shows total number of nominations. Red marked attributes are selected on the count of the nominations.

Under *Social, Economic and Political (SEP) questions* the last line of the table shows mean score of answers according to the following keys:

- Both are the same = 0; New technology is better = 2,5; New technology is far better = 5; Old technology is better = -2,5; Old technology is far better = -5
- The market will stay the same = 0; The market will increase marginally = 2,5; The market will increase substantially = 5; The market will decrease marginally = -2,5; The market will decrease substantially = -5
- I am not aware of any restrictions/regulations concerning this technology = 0; There are some minor regulations/restrictions concerning this technology = -2,5; There are major regulations/restrictions concerning this technology = -5
- In the next 10 years = 0; In 10 to 20 years = 0; Longer than 20 years = -2,5
- I am not aware of any political incentive concerning this technology = 0; There is political incentive to promote this technology = 5; There is political incentive to prevent this technology = -5
- I am not aware of any ethical or social problems concerning this technology = 0; There are some minor ethical or social problems concerning this technology = -2,5; There are major ethical or social problems concerning this technology = -5

Under *Rating* the last line of the table shows mean score of attributes.

Under *Weighting* the last line of the table shows mean weight of the attributes in %.

2 Materials

2.1 *Cathodic arc application of amorphous boron coatings (CAAABC)*

2.1.1 Technology description

Boron is an attractive hard coating for a variety of applications. It has the highest hot-hardness of all known materials with hardness at temperatures around 800 degrees Celsius. It has excellent properties, e.g. impact resistance and adhesion, salt pitting corrosion resistance, refractory nature and non-combustibility, nontoxicity, robustness of process, and a strong tendency to bond with most substrates. Moreover, boron has very high lubricity and thermal and chemical stability. Nevertheless, boron is a material, whose favorable properties have not previously been widely recognized. Therefore, the deposition technique is essentially an extension of the well-established and economical cathodic arc or vacuum arc technique of coatings deposition to include elemental boron, because it has been difficult to deposit it in the form of coatings.

The development of a boron vacuum arc is an important technological achievement, because it finally allows for the deposition of boron in an economically viable way. Boron is otherwise very intractable with respect to both synthesis of coatings and fabrication of products. It does not sputter well and it cannot be electroplated. Any boron-containing volatile compounds for use in chemical vapor deposition are toxic and/or explosive. As with any other vacuum arc deposition, the source produces a supersonic plume of plasma fully ionized gas out of solid feedstock, which is used as the cathode in the arc discharge. In this case, the cathode is made of consolidated boron powders, and is heated, in order to achieve the necessary electrical conductivity. This is because boron is a semiconductor and has a very poor conductivity at room temperature. The discharge, once initiated, operates without added gas and at a very low background pressure. The primary source of material is the cathode, which is consumed in the process. As with vacuum arcs using metal cathodes, all the activity on the cathode is concentrated on small, non-stationary spots. However, these high current densities produce tremendous local stresses on the cathode, which can lead to fracture in the case of consolidated powder cathodes. A successful boron source depends largely on the quality of its cathode consolidation technology. The source and deposition region are separated by means of a gate valve, so that the substrate may be replaced while maintaining the heated cathode under good vacuum. A cryogenic pump is used to reach base pressures. Low impurity content in the film is important to achieve high hardness. The current is fixed by the power supply. The arc is initiated by a specially designed trigger that involves electrical breakdown across an insulator, separating a trigger-pin from the cathode.

Boron coatings have potentially excellent prospects regarding several metallurgical coating applications including biomedical implants, die-casting dies for aluminum alloys, combustion chamber components in automotive engines and turbine blades used in corrosive and abrasive environments.

2.1.2 Social, Economic and Political (SEP) questions

Compare the new technology (CAAABC) to the existing dominant technology (state of the art) in respect to:				
Environmental benefits	Potential for spin-off	Production complexity and material cost	Operation complexity and maintenance cost	Comment
Both are the same	New technology is better	Both are the same	Old technology is far better	
New technology is far better	New technology is better	New technology is better	New technology is better	
Both are the same	Both are the same	Both are the same	Both are the same	
Old technology is better	New technology is better	Old technology is better	Old technology is better	
New technology is better	New technology is better	Both are the same	Both are the same	#1
Both are the same	New technology is better	Both are the same	Old technology is better	
0,83	2,08	0,00	-1,25	

#1: All these are difficult to judge, market growth if technology allows it will drive price eventually. Only the production remains the same as we have limits with this process about the same as those of the old technology

Will the market (area of application) of coating materials increase or decrease in the coming years?		Do you know or can you think of any restrictions or regulations that can hinder the entry of CBRME into the space sector?	
	Comment		Comment
The market will increase marginally		I am not aware of any restrictions/regulations concerning this technology	
The market will increase substantially		I am not aware of any restrictions/regulations concerning this technology	
The market will increase substantially		I am not aware of any restrictions/regulations concerning this technology	
The market will increase substantially		I am not aware of any restrictions/regulations concerning this technology	
The market will increase substantially	#2	I am not aware of any restrictions/regulations concerning this technology	
The market will increase substantially		I am not aware of any restrictions/regulations concerning this technology	
4,58		0,00	

#2: Speaking about overall coating technologies

In what timeframe do you anticipate this technology to be ready to be used in a space environment?		Are you aware of any political incentive to promote or prevent the development of CBRME (or their field of application)?	
	Comment		Comment
In 10 to 20 years		I am not aware of any political incentive concerning this technology	
In 10 to 20 years		I am not aware of any political incentive concerning this technology	
In the next 10 years		I am not aware of any political incentive concerning this technology	
In 10 to 20 years		I am not aware of any political incentive concerning this technology	
In the next 10 years	#3	I am not aware of any political incentive concerning this technology	
In the next 10 years		I am not aware of any political incentive concerning this technology	
0,00		0,00	

#3: all depends on what is the foreseen application and the dimension of hardware

Are you aware of any ethical dilemmas or social problems associated with CBRME?	
	Comment
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
0,00	

2.1.3 Technical questions (performance attributes)

2.1.3.1 Selection of attributes (1st round)

Select or name the 5 most important performance attributes of coating materials.							
Corrosion resistance	Conductivity	Manufacturability	Density	Wear resistance	Temperature stability	Toxicity	Other
Yes	Yes	Yes	Yes	No	Yes	No	
Yes	No	Yes	No	Yes	Yes	No	oxidation stability
Yes	No	No	No	Yes	No	No	hardness
Yes	No	Yes	Yes	Yes	Yes	No	
No	Yes	Yes	No	No	No	Yes	hadness
Yes	No	Yes	Yes	Yes	No	No	high temperature stability
5	2	5	3	4	3	1	

2.1.3.2 Rating (2nd & 3rd round)

Compare the technology to the state of the art on each attribute on a scale from -5 to +5.						
Corrosion resistance	Manufacturability	Wear resistance	Temperature stability	Hardness	Density	Comment
0	0	3	2	2	3	*1 *2 *3
0	1	1	2	1	4	
1	1	1	0	0	1	
2	1	3	2	2	2	
2	1	2	2	0	1	
1,00	0,80	2,00	1,60	1,00	2,20	

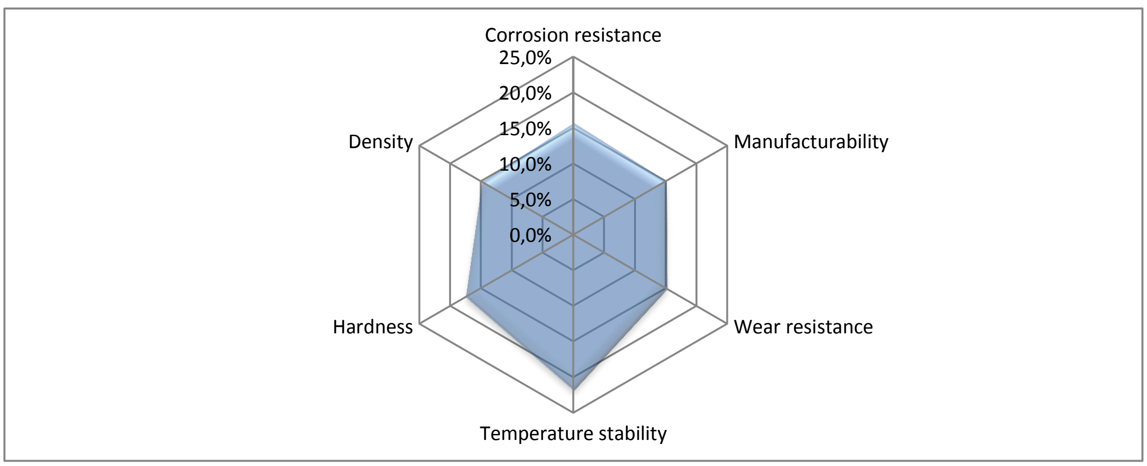
*1: The compatibility with the substrate is the main issue. From corrosion resistance, we need to ensure no cracking of the coating while thermo-cycling. Main advantages are low density and high hardness. With respect to density, all depends on the overall surface. We can imagine replacing tungsten carbide

*2: Comment on manufacturability rating: Reconsider marking as from geometrical viewpoint, limits are the same as other coating techniques. However, compatibility with substrate is not known.

*3: Comment on hardness rating: All depends on thickness. A very thin coating will not make the overall system hard.

2.1.3.3 Weighting (2nd & 3rd round)

Rate the importance of the attributes on a scale of 1 to 5. Rate each attribute independently.					
Corrosion resistance	Manufacturability	Wear resistance	Temperature stability	Hardness	Density
2	3	4	3	4	3
3	3	2	5	4	5
2	3	3	3	2	1
3	3	3	5	4	4
5	2	2	5	3	2
15,7%	15,0%	15,1%	21,8%	17,5%	14,9%



2.2 *Ceramic composite structures*

2.2.1 Technology description

Ceramics can be described as solid materials that exhibit very strong ionic bonding in general and in few cases covalent bonding. High melting points, good corrosion resistance, stability at elevated temperatures and high compressive strength, render ceramic-based matrix materials a favorite for applications requiring a structural material that doesn't give way at temperatures above 1500 degrees Celsius.

Fiber reinforced ceramics are a new class of materials that 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. Ceramic matrix composites (CMCs) are separated into two categories: discontinuous reinforced and continuous fiber reinforced CMCs. Discontinuous reinforced CMCs include particulate, platelet, whisker, fiber and in situ reinforced composites. CMCs containing discontinuous second phases are, in general, processed by shaping techniques commonly used for monolithic ceramics, i.e. injection molding, slip casting, and tape casting, followed by sintering to densify the composite. By contrast continuous fiber ceramic composites (CFCCs) have required the development of infiltration methods that enable the densification of various ceramic matrices in continuous fiber lay-ups and/or net shape woven fiber preforms.

Ceramic fibers in ceramic matrix composites can have a polycrystalline structure as in conventional ceramics. They can also be amorphous or have inhomogeneous chemical composition, which develops upon pyrolysis of organic precursors. The high process temperatures required for making ceramic matrix composites preclude the use of organic, metallic or glass fibers. Only fibers stable at temperatures above 1000 °C can be used, such as fibers of alumina, mullite, SiC, zirconia or carbon. Amorphous SiC fibers have an elongation capability above 2%, which is much larger than in conventional ceramic materials (0.05 to 0.10%). The reason for this property of SiC fibers is that most of them contain additional elements like oxygen, titanium and/or aluminum yielding a tensile strength above 3 GPa.

Ceramic composite materials reinforced with continuous fibers may find use thermal-structural application in turbine and rocket engines where metallic alloys cannot meet the performance and/or durability requirements. Aircraft turbine engine, divert propulsion and attitude control nozzles for missile rocket engines are some examples. Next generation reusable launch vehicles will likely use ceramic composite materials for thrust cells and the ramp of aerospike engines. Ceramic composites are presently being evaluated for leading edges, nose section, inlet cowlings, and the nozzle of future hypersonic vehicles. Future turbine engine applications may include combustors, shrouds, stators, and vanes. Heat shields to protect metallic structures are also being considered in many aircraft and space applications.

2.2.2 Social, Economic and Political (SEP) questions

Compare the new technology (ceramic composite structures) to the existing dominant technology (state of the art) in respect to:				
Environmental benefits	Potential for spin-off	Production complexity and material cost	Operation complexity and maintenance cost	Comment
New technology is far better	New technology is better	Both are the same	New technology is better	
Both are the same	New technology is better	Both are the same	New technology is better	
Both are the same	New technology is better	Old technology is better	Both are the same	
New technology is better	New technology is better	New technology is better	Both are the same	
Both are the same	New technology is better	Old technology is better	Old technology is better	#4
Both are the same	New technology is better	Both are the same	New technology is better	
1,25	2,50	-0,42	0,83	

#4: We are dealing with a difficult to process material. If successful, then we will have spin-off as those for metals are already many. We need to make trade-offs vs. applications to answer the questions thoroughly

Will the market (area of application) of thermal protection materials increase or decrease in the coming years?		Do you know or can you think of any restrictions or regulations that can hinder the entry of ceramic composite structures into the space sector?	
	Comment		Comment
The market will increase marginally		I am not aware of any restrictions/regulations concerning this technology	
The market will increase marginally		I am not aware of any restrictions/regulations concerning this technology	
The market will stay the same		I am not aware of any restrictions/regulations concerning this technology	
The market will increase substantially		I am not aware of any restrictions/regulations concerning this technology	
The market will increase marginally	#5	I am not aware of any restrictions/regulations concerning this technology	
The market will increase substantially		There are some minor regulations/restrictions concerning this technology	
2,92		-0,42	

#5: Thermal barriers are developing based on ceramic systems - any gain in temperature will lead to massive saving is fuel

In what timeframe do you anticipate this technology to be ready to be used in a space environment?		Are you aware of any political incentive to promote or prevent the development of ceramic composite structures (or their field of application)?	
	Comment		Comment
In the next 10 years		There is political incentive to promote this technology	
In the next 10 years		I am not aware of any political incentive concerning this technology	
In the next 10 years		I am not aware of any political incentive concerning this technology	
In 10 to 20 years		I am not aware of any political incentive concerning this technology	
In the next 10 years	#6	I am not aware of any political incentive concerning this technology	
In the next 10 years		I am not aware of any political incentive concerning this technology	
0,00		0,83	

#6: Many are used already - we need to find applications vs. ceramic system

Are you aware of any ethical dilemmas or social problems associated with ceramic composite structures?	
	Comment
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
0,00	

2.2.3 Technical questions (performance attributes)

2.2.3.1 Selection of attributes (1st round)

Select or name the 5 most important performance attributes of thermal protection materials.							
Density	Corrosion resistance	Temperature resistance	Impact resistance	Plasticity / elasticity	Manufacturability / handling	Toxicity / environmental agreeableness	Other
Yes	Yes	Yes	Yes	No	No	Yes	
Yes	Yes	Yes	Yes	No	Yes	No	
No	No	Yes	Yes	Yes	No	No	
Yes	Yes	Yes	Yes	No	Yes	No	
Yes	Yes	Yes	No	No	Yes	No	joining assembly
No	Yes	Yes	Yes	Yes	Yes	No	
4	5	6	5	2	4	1	

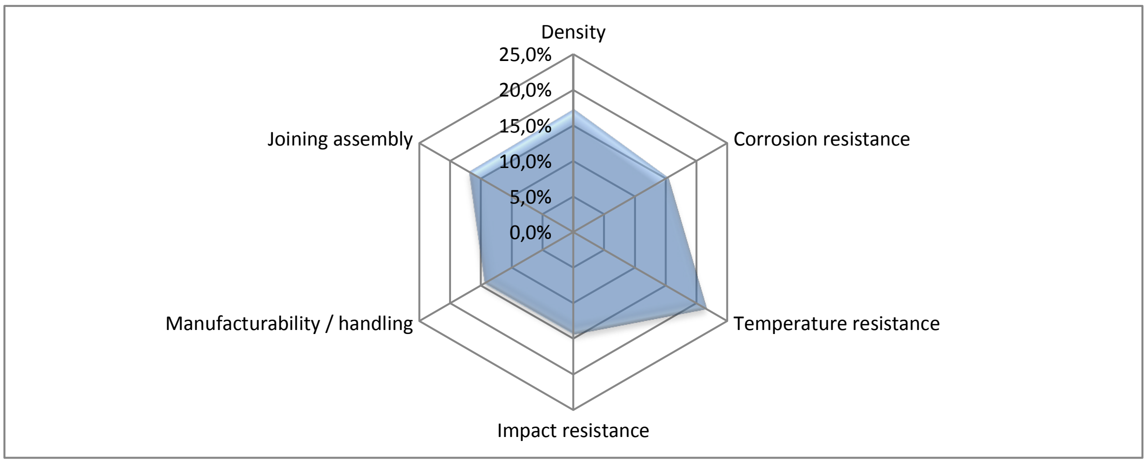
2.2.3.2 Rating (2nd & 3rd round)

Compare the technology to the state of the art on each attribute on a scale from -5 to +5.						
Density	Corrosion resistance	Temperature resistance	Impact resistance	Manufacturability / handling	Joining assembly	Comment
4	2	3	-2	-3	-3	*4
3	1	4	1	-2	-2	
2	0	4	2	2	2	
2	0	3	1	2	3	
3	2	3	3	3	3	
2,80	1,00	3,40	1,00	0,40	0,60	

*4: With this respect, either we consider metallic materials as the state of the art or other CMCs. With metallics, the gain in density is very high and we increase the maximum temperature. However, we need to address the oxidation of CMCs where we can co from forming a protective film of oxide or reach a temperature at which this oxide is not protecting anymore. For impact resistance, manufacturing and joining, CMC are more difficult. If state of the art is CMCs, we have fewer benefits and fewer drawbacks

2.2.3.3 Weighting (2nd & 3rd round)

Rate the importance of the attributes on a scale of 1 to 5. Rate each attribute independently.					
Density	Corrosion resistance	Temperature resistance	Impact resistance	Manufacturability / handling	Joining assembly
5	4	4	2	2	3
4	4	5	4	3	2
2	2	4	2	2	4
4	4	5	4	4	4
3	2	4	3	4	4
17,3%	15,3%	21,5%	14,3%	14,4%	17,0%



2.3 Graphite epoxy composites

2.3.1 Technology description

The process by which most carbon-fiber-reinforced polymers are made varies, depending on the piece being created, the finish required and how many of this particular piece is going to be produced. Composite fibre materials satisfy all of the given requirements by using an epoxy resin matrix material reinforced with high strength fibres. The properties of both materials determine the behavior of the composite. The fibres have high strength due to a very uniform structure and the absence of surface flaws, thus their strength approaches the theoretical strength of the fibre material, determined by molecular bond strengths. Currently used materials are boron, graphite, glass, Kevlar and various hybrids; each of these is best suited to some particular application. The matrix material is an epoxy resin. These polymers are very stable and have excellent bonding properties, especially with graphite. Epoxies decompose rather than melt and are inert to most solvents. They are very stable, and this practically eliminates corrosion/weathering problems. A composite of high strength fibres and an epoxy resin exhibits a combination of properties of both components.

Graphite composites are extremely versatile and have exceptional mechanical properties that are unequaled by other materials. Graphite composites have an extremely low coefficient of thermal expansion. The material is strong, stiff, and 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, they might have some application in electromagnetic interference shielding covers and grounding planes if the conductivity can be improved.

2.3.2 Social, Economic and Political (SEP) questions

Compare the new technology (graphite epoxy composites) to the existing dominant technology (state of the art) in respect to:				
Environmental benefits	Potential for spin-off	Production complexity and material cost	Operation complexity and maintenance cost	Comment
Both are the same	New technology is far better	New technology is better	Both are the same	
Both are the same	New technology is better	New technology is better	Both are the same	
Old technology is better	New technology is far better	Old technology is better	Old technology is better	
New technology is better	New technology is far better	New technology is better	Old technology is better	
Both are the same	New technology is better	Old technology is better	Old technology is better	#7
Old technology is better	New technology is better	Both are the same	New technology is better	
-0,42	3,75	0,42	-0,83	

#7: We have to compare the state of the art and the overall hardware. CFRP are far better in simple shapes while metals would be more performing in complex ones. Manufacturing of CFRP for space often relies on highly skilled operators and the space technologies are difficult to spin-off as such.

Will the market (area of application) of structural materials increase or decrease in the coming years?		**Do you know or can you think of any restrictions or regulations that can hinder the entry of graphite epoxy composites into the space sector?**	
	Comment		Comment
The market will increase marginally		There are some minor regulations/restrictions concerning this technology	Nanotubes
The market will increase substantially		I am not aware of any restrictions/regulations concerning this technology	
The market will increase substantially		I am not aware of any restrictions/regulations concerning this technology	
The market will increase marginally		I am not aware of any restrictions/regulations concerning this technology	
The market will increase marginally		There are some minor regulations/restrictions concerning this technology	#8
The market will increase substantially		There are some minor regulations/restrictions concerning this technology	
3,75		-1,25	

#8: Procurement of raw material may be difficult as main players are in Japan and USA.

In what timeframe do you anticipate this technology to be ready to be used in a space		Are you aware of any political incentive to promote or prevent the development of graphite epoxy composites (or their field of application)?	
	Comment		Comment
In the next 10 years		There is political incentive to promote this technology	
In the next 10 years		I am not aware of any political incentive concerning this technology	
In the next 10 years		I am not aware of any political incentive concerning this technology	
In 10 to 20 years		I am not aware of any political incentive concerning this technology	
In the next 10 years	it is flying daily	There is political incentive to promote this technology	#9
In the next 10 years		I am not aware of any political incentive concerning this technology	
0,00		1,67	

#9: lightweight is a driver for transport industry

Are you aware of any ethical dilemmas or social problems associated with graphite epoxy composites?	
	Comment
There are some minor ethical or social problems concerning this technology	#10
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
-0,42	

#10: Health issues nanomaterials

2.3.3 Technical questions (performance attributes)

2.3.3.1 Selection of attributes (1st round)

Select or name the 5 most important performance attributes of structural materials.											
Strength	Density	Hardness	Plasticity / elasticity	Thermal conductivity	Electric conductivity	Temperature resistance	Toxicity / environmental agreeableness	Corrosion resistance	Manufacturability / handling	Wear resistance	Other
Yes	Yes	No	Yes	No	Yes	No	No	No	Yes	No	
Yes	Yes	No	No	Yes	No	No	No	Yes	Yes	No	
Yes	Yes	No	No	No	No	No	No	No	Yes	No	
Yes	Yes	Yes	Yes	No	No	No	No	No	Yes	No	
No	No	No	No	Yes	Yes	No	No	No	Yes	No	specific stiffness
Yes	Yes	No	Yes	No	No	Yes	No	No	Yes	No	
5	5	1	3	2	2	1	0	1	6	0	

2.3.3.2 Rating (2nd & 3rd round)

Compare the technology to the state of the art on each attribute on a scale from -5 to +5.						
Strength	Density	Plasticity / elasticity	Thermal conductivity	Manufacturability / handling	Specific stiffness	Comment
3	2	-1	-3	-2	4	*5 *6 *7
3	3	-3	1	-1	1	
2	2	0	0	1	3	
2	2	1	2	1	3	
3	3	1	3	0	1	
2,60	2,40	-0,40	0,60	-0,20	2,40	

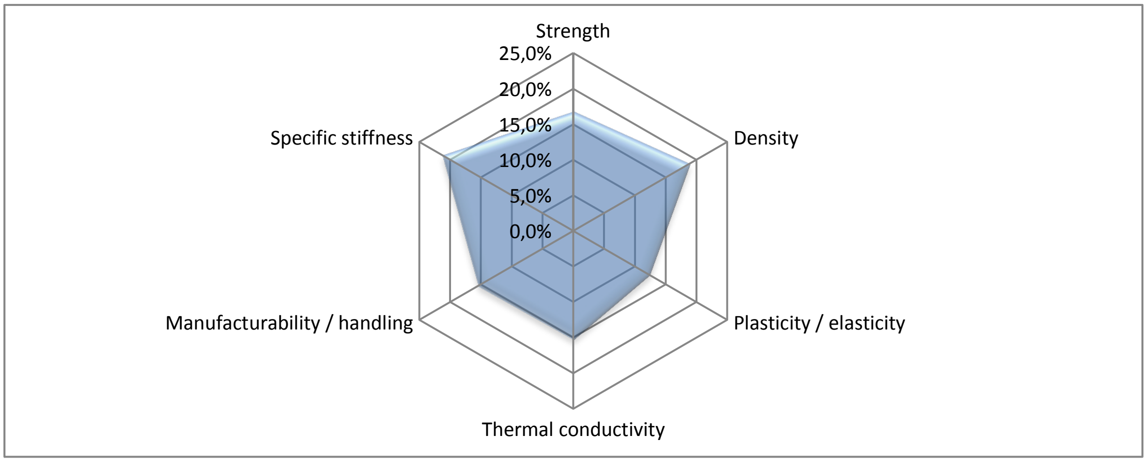
*5: We need to address the specific strength for launchers and specific stiffness for satellites, these are application dependent. Then we need to address the design freedom and the manufacturability compared with other solutions (e.g. metallics). In any case, unless we go for coatings or for thermally conductive resins, the anisotropy will remain an issue on these materials. The design will be highly impacted by the desired properties of the final hardware

*6: Comment on density rating: When considering e.g. aluminum panels, we still gain. We need to better define state of the art as we already have many CFRP made hardware

*7: Comment on thermal conductivity rating: This is a very well-known issue with CFRP. Today with carbon nanotubes, the resin can be doped and TC improved a lot.

2.3.3.3 Weighting (2nd & 3rd round)

Rate the importance of the attributes on a scale of 1 to 5. Rate each attribute independently.					
Strength	Density	Plasticity / elasticity	Thermal conductivity	Manufacturability / handling	Specific stiffness
3	4	2	2	4	4
2	4	2	3	3	4
3	3	2	1	2	4
3	4	2	4	3	4
4	2	3	4	2	3
16,8%	18,9%	12,3%	15,2%	15,4%	21,3%



2.4 Nanocrystaline diamond aerogel

2.4.1 Technology description

Aerogels are a novel class of high surface-area continuous solids with a broad range of both commercial and fundamental scientific applications. Both crystalline and amorphous structures have been synthesized. Aerogel materials have myriad scientific and technological applications due to their large intrinsic surface areas and ultralow densities. Amorphous carbon aerogel in particular has received a considerable amount of attention in recent years owing to its low cost, electrical conductivity, mechanical strength, and thermal stability.

The carbon aerogel is placed in a diamond cell cavity where it is infused with neon gas to keep the pores from collapsing. Then it is encased in a diamond shell and pressurized followed by a blasting from a laser that heats it; once again to simulate the way that diamonds are formed naturally at great geological depths. The key to the process is keeping the pores from collapsing. The supercritical neon gas is used because at pressures greater than 5GPa, it becomes a solid, thereby holding the walls of the pores in place as pressure and heat are added. The result is a new form crystalline diamond with a very low density similar to that of the precursor of around 40 milligrams per cubic centimeter, which is only about 40 times denser than air and about 200 microns wide.

2.4.2 Social, Economic and Political (SEP) questions

Compare the new technology (nanocrystaline diamond aerogel) to the existing dominant technology (state of the art) in respect to:				
Environmental benefits	Potential for spin-off	Production complexity and material cost	Operation complexity and maintenance cost	Comment
Both are the same New technology is better Both are the same New technology is better Both are the same Old technology is better	New technology is better New technology is far better New technology is better New technology is far better New technology is far better Old technology is better	Both are the same New technology is better Both are the same Both are the same Both are the same Old technology is better	Both are the same New technology is better Both are the same Both are the same Both are the same Old technology is better	#11
0,42	2,92	0,00	0,00	

#11: These diamond aerogels are fillers of reinforcement it seems. To get it bulk would be interesting. As reinforcement particles, the composite would need to be studied.

Will the market (area of application) of structural materials increase or decrease in the coming years?	
	Comment
The market will increase marginally	
The market will increase substantially	
The market will increase substantially	
The market will increase marginally	
The market will increase marginally	
The market will increase substantially	
3,75	

Do you know or can you think of any restrictions or regulations that can hinder the entry of nanocrystaline diamond aerogel into the space sector?	
	Comment
I am not aware of any restrictions/regulations concerning this technology	
I am not aware of any restrictions/regulations concerning this technology	
I am not aware of any restrictions/regulations concerning this technology	
I am not aware of any restrictions/regulations concerning this technology	
I am not aware of any restrictions/regulations concerning this technology	
There are some minor regulations/restrictions concerning this technology	
-0,42	

In what timeframe do you anticipate this technology to be ready to be used in a space		**Are you aware of any political incentive to promote or prevent the development of nanocrystaline diamond aerogel (or their field of application)?**	
	Comment		Comment
In 10 to 20 years		I am not aware of any political incentive concerning this technology	
In 10 to 20 years		I am not aware of any political incentive concerning this technology	
In 10 to 20 years		I am not aware of any political incentive concerning this technology	
In 10 to 20 years		I am not aware of any political incentive concerning this technology	
In the next 10 years	#12	I am not aware of any political incentive concerning this technology	
In 10 to 20 years		I am not aware of any political incentive concerning this technology	
0,00		0,00	

#12: matrix + reinforcement has to be looked at. Diamond based composites are used in high thermal application today already - Aerogel could bring high specific stiffness to matrices.

Are you aware of any ethical dilemmas or social problems associated with nanocrystaline diamond aerogel?	
	Comment
I am not aware of any ethical or social problems concerning this technology I am not aware of any ethical or social problems concerning this technology I am not aware of any ethical or social problems concerning this technology I am not aware of any ethical or social problems concerning this technology I am not aware of any ethical or social problems concerning this technology There are some minor ethical or social problems concerning this technology	
-0,42	

2.4.3 Technical questions (performance attributes)

2.4.3.1 Selection of attributes (1st round)

Select or name the 5 most important performance attributes of structural materials.											
Strength	Density	Hardness	Plasticity / elasticity	Thermal conductivity	Electric conductivity	Temperature resistance	Toxicity / environmental agreeableness	Corrosion resistance	Manufacturability / handling	Wear resistance	Other
Yes	Yes	No	Yes	No	Yes	No	No	No	Yes	No	
Yes	Yes	No	No	Yes	No	No	No	Yes	Yes	No	
Yes	Yes	No	No	No	No	No	No	No	Yes	No	
Yes	Yes	Yes	Yes	No	No	No	No	No	Yes	No	
No	No	No	No	Yes	Yes	No	No	No	Yes	No	specific stiffness
Yes	Yes	No	Yes	No	No	Yes	No	No	Yes	No	
5	5	1	3	2	2	1	0	1	6	0	

2.4.3.2 Rating (2nd & 3rd round)

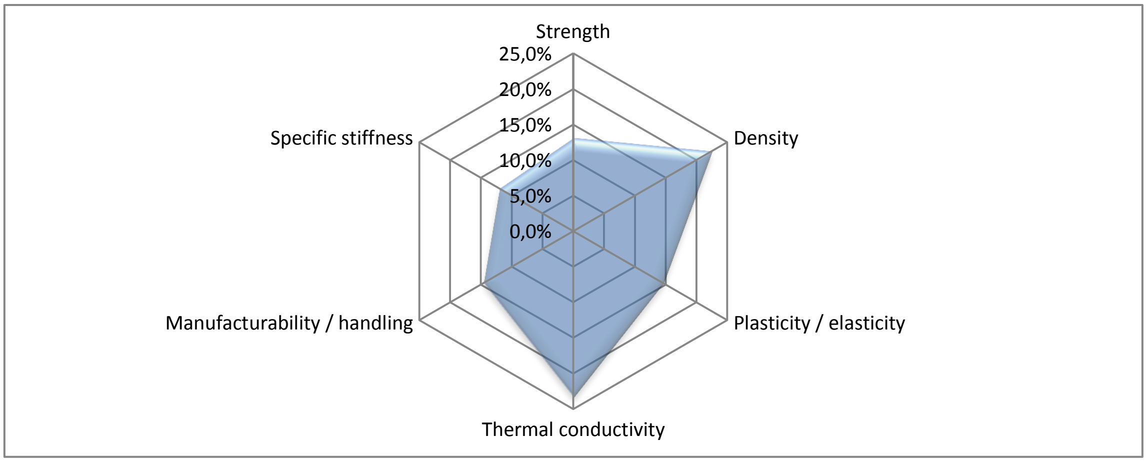
Compare the technology to the state of the art on each attribute on a scale from -5 to +5.						
Strength	Density	Plasticity / elasticity	Thermal conductivity	Manufacturability / handling	Specific stiffness	Comment
1	3	-1	4	0	1	*8 *9
-1	2	-1	2	-1	0	
1	3	1	3	1	0	
1	3	1	3	1	1	
0	2	0	3	-2	2	
0,40	2,60	0,00	3,00	-0,20	0,80	

*8: The issue is the matrix and the means to incorporate the particles in it. We have difficulties judging on filler only.

*9: Comment on plasticity/elasticity rating: Plasticity can be still improved due to matrix deformation

2.4.3.3 Weighting (2nd & 3rd round)

Rate the importance of the attributes on a scale of 1 to 5. Rate each attribute independently.					
Strength	Density	Plasticity / elasticity	Thermal conductivity	Manufacturability / handling	Specific stiffness
2	3	3	4	4	2
2	4	2	3	2	2
1	4	2	4	2	1
2	4	2	4	3	2
4	3	3	4	1	3
13,1%	22,4%	14,5%	23,3%	14,6%	12,0%



2.5 Metallic microlattice

2.5.1 Technology description

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.

Metallic microlattices are composed of a network of interconnecting hollow struts. In the least-dense microlattice sample reported, each strut is about 100 micrometres in diameter, with a wall 100 nanometres thick. The completed structure is about 99.99% air by volume, and by convention, the mass of air is excluded when the microlattice density is calculated. Allowing for the mass of the interstitial air, the true density of the structure is approximately 2.1 mg/cm3 (2.1 kg/m3), which is only about 1.76 times the density of air itself at 25 degrees Celsius. The material is described as being 100 times lighter than Styrofoam. Metallic microlattices are characterized by very low densities, with the current record of 0.9 mg/cm3 being the lowest value for any solid yet discovered. Mechanically, the microlattices are behaviorally similar to elastomers and almost completely recover their shape after significant compression. This gives them a significant advantage over current aerogels, which are brittle, glass-like substances. This elastomeric property in metallic microlattices furthermore results in efficient shock absorption.

2.5.2 Social, Economic and Political (SEP) questions

Compare the new technology (metallic microlattice) to the existing dominant technology (state of the art) in respect to:				
Environmental benefits	Potential for spin-off	Production complexity and material cost	Operation complexity and maintenance cost	Comment
New technology is far better	New technology is far better	New technology is better	Both are the same	
Both are the same	New technology is better	Old technology is better	New technology is better	
Both are the same	New technology is better	Old technology is better	Both are the same	
New technology is far better	New technology is far better	New technology is better	New technology is far better	
New technology is far better	New technology is far better	Both are the same	Both are the same	#13
New technology is better	New technology is better	Old technology is better	Both are the same	
2,92	3,75	-0,42	1,25	

#13: All depends on what we do with it. This new material shape has to be looked at for potential applications. Lightness is an asset, increase temperature range for damping another one, the possibility to grade the damping coefficient a 3rd one. More in depth investigation would be needed.

Will the market (area of application) of damping materials increase or decrease in the coming years?		**Do you know or can you think of any restrictions or regulations that can hinder the entry of metallic microlattice into the space sector?**	
	Comment		Comment
The market will increase marginally		I am not aware of any restrictions/regulations concerning this technology	
The market will increase marginally		I am not aware of any restrictions/regulations concerning this technology	
The market will increase marginally		I am not aware of any restrictions/regulations concerning this technology	
The market will increase substantially		I am not aware of any restrictions/regulations concerning this technology	
The market will increase substantially	#14	I am not aware of any restrictions/regulations concerning this technology	
The market will increase marginally		I am not aware of any restrictions/regulations concerning this technology	
3,33		0,00	

#14: not only as damping material but these lattice like materials will develop

In what timeframe do you anticipate this technology to be ready to be used in a space environment?		Are you aware of any political incentive to promote or prevent the development of metallic microlattice (or their field of application)?	
	Comment		Comment
In the next 10 years		I am not aware of any political incentive concerning this technology	
In 10 to 20 years		I am not aware of any political incentive concerning this technology	
In 10 to 20 years		I am not aware of any political incentive concerning this technology	
In the next 10 years		I am not aware of any political incentive concerning this technology	
In the next 10 years	#15	There is political incentive to promote this technology	#16
In 10 to 20 years		I am not aware of any political incentive concerning this technology	
0,00		0,83	

#15: All depends on what it is for - pads for optical may be ready quite soon but contamination has to be looked at

#16: this is a general trend with new lattice materials

Are you aware of any ethical dilemmas or social problems associated with metallic microlattice?	
	Comment
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
0,00	

2.5.3 Technical questions (performance attributes)

2.5.3.1 Selection of attributes (1st round)

Select or name the 5 most important performance attributes of damping materials.								
Temperature sensitivity	Density	Plasticity / elasticity	Manufacturability / handling	Damping coefficient	Toxicity / environmental agreeableness	Reliability	Shear strength	Other
No	Yes	Yes	Yes	Yes	No	No	Yes	
Yes	Yes	No	Yes	Yes	No	No	Yes	
No	Yes	Yes	No	Yes	No	Yes	No	energy absorption
No	Yes	Yes	Yes	Yes	No	Yes	No	
Yes	No	No	Yes	Yes	No	Yes	No	quality control
Yes	Yes	Yes	Yes	Yes	No	No	No	
3	5	4	5	6	0	3	2	

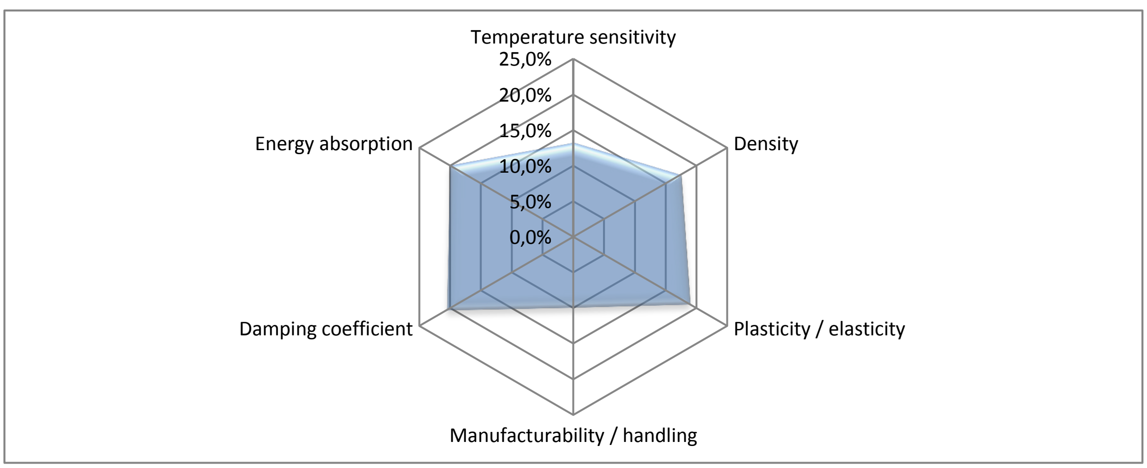
2.5.3.2 Rating (2nd & 3rd round)

Compare the technology to the state of the art on each attribute on a scale from -5 to +5.						
Temperature sensitivity	Density	Plasticity / elasticity	Manufacturability / handling	Damping coefficient	Energy absorption	Comment
0	4	4	-2	3	4	*10
0	3	3	1	4	4	
0	0	1	1	1	1	
2	4	4	2	4	4	
4	1	1	0	2	2	
1,20	2,40	2,60	0,40	2,80	3,00	

*10: The design of the lattices has to be looked at carefully. We have the issue of contamination-cleaning that need to be looked at mainly close to optics. The energy absorption has to be considered as specific to a given available mass or to a given available volume.

2.5.3.3 Weighting (2nd & 3rd round)

Rate the importance of the attributes on a scale of 1 to 5. Rate each attribute independently.					
Temperature sensitivity	Density	Plasticity / elasticity	Manufacturability / handling	Damping coefficient	Energy absorption
2	3	5	2	4	5
2	4	3	2	4	4
2	3	2	2	3	2
2	4	5	2	4	4
4	2	3	1	4	4
13,2%	17,4%	18,9%	9,9%	20,6%	20,1%



3 On-board data

3.1 Chalcogenide-based reconfigurable memory electronics (CBRME)

3.1.1 Technology description

Chalcogenide glasses are materials that contain sulfur (S), selenium (Se) or tellurium (Te), or combinations of them. These materials are characterized by 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 being 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 Random Access Memory (RAM) 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 Dynamic Random-Access Memory (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-Change 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 radio frequency circuitry, antenna, analog circuits, and even as reconfigurable wiring harnesses.

3.1.2 Social, Economic and Political (SEP) questions

Compare the new technology (CBRME) to the existing dominant technology (state of the art) in respect to:				
Environmental benefits	Potential for spin-off	Production complexity and material cost	Operation complexity and maintenance cost	Comment
Both are the same	New technology is better	Old technology is better	New technology is far better	#17
New technology is far better	New technology is far better	Both are the same	Old technology is better	
Both are the same	New technology is far better	Old technology is better	Old technology is better	
Both are the same	New technology is better	Both are the same	New technology is far better	
Old technology is better	Old technology is far better	Old technology is better	Old technology is far better	
0,50	2,00	-1,50	0,00	

#17: It is not easy to provide an evaluation for "future" production and operation complexity for a technology at a very early stage of development. Until a certain "critical mass" is not reached, old technologies always have a better appeal in terms of material and maintenance costs (due to availability) and reduced complexity for production and operations (well known behavior and characteristics). My answer hinges on these considerations.

Will the market (area of application) of data storage devices increase or decrease in the coming years?		**Do you know or can you think of any restrictions or regulations that can hinder the entry of CBRME into the space sector?**	
	Comment		Comment
The market will increase substantially	#18	I am not aware of any restrictions/regulations concerning this technology	
The market will increase substantially		I am not aware of any restrictions/regulations concerning this technology	
The market will increase substantially		I am not aware of any restrictions/regulations concerning this technology	
The market will decrease substantially		I am not aware of any restrictions/regulations concerning this technology	
The market will increase substantially		There are some minor regulations/restrictions concerning this technology	
3,00		-0,50	

#18: As far as I know the trend is solidly increasing and there is no sign of slow-down.

In what timeframe do you anticipate this technology to be ready to be used in a space environment?		**Are you aware of any political incentive to promote or prevent the development of CBRME (or their field of application)?**	
	Comment		Comment
In the next 10 years		I am not aware of any political incentive concerning this technology	
In the next 10 years		I am not aware of any political incentive concerning this technology	
In the next 10 years		I am not aware of any political incentive concerning this technology	
In 10 to 20 years		I am not aware of any political incentive concerning this technology	
In the next 10 years		I am not aware of any political incentive concerning this technology	
0,00		0,00	

Are you aware of any ethical dilemmas or social problems associated with CBRME?	
	Comment
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
0,00	

3.1.3 Technical questions (performance attributes)

3.1.3.1 Selection of attributes (1st round)

Select or name the 5 most important performance attributes of data storage devices.										
Mass specific capacity	Volume specific capacity	Error rate	Lifetime	Energy consumption	Addressability	Latency	Throughput	Accessibility	Mutability	Other
No	Yes	Yes	Yes	Yes	No	No	No	No	No	number of chips for Capacity
No	No	Yes	No	No	Yes	Yes	Yes	No	No	
Yes	Yes	Yes	Yes	No	No	Yes	No	No	No	
No	No	Yes	Yes	No	Yes	Yes	Yes	No	No	
No	Yes	Yes	Yes	Yes	No	No	No	No	No	radiation tolerance
1	3	5	4	2	2	3	2	0	0	

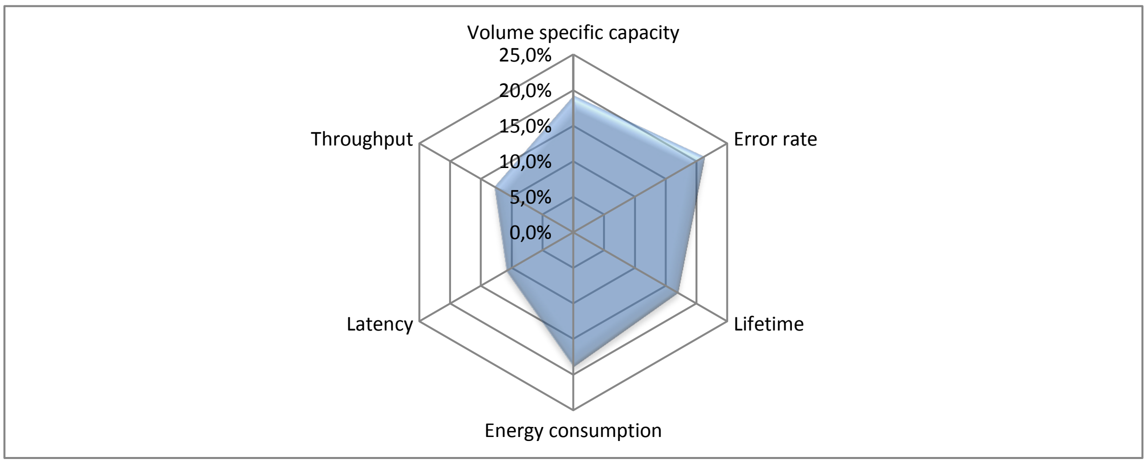
3.1.3.2 Rating (2nd & 3rd round)

Compare the technology to the state of the art on each attribute on a scale from -5 to +5.						
Volume specific capacity	Error rate	Lifetime	Energy consumption	Latency	Throughput	Comment
3	4	0	2	1	1	*11
-2	0	3	4	0	4	
0	2	1	2	0	1	
0,33	2,00	1,33	2,67	0,33	2,00	

*11: Chalcogenide-based reconfigurable memory electronics are not radiation sensitive and that is a very important aspect for space mission.

3.1.3.3 Weighting (2nd & 3rd round)

Rate the importance of the attributes on a scale of 1 to 5. Rate each attribute independently.					
Volume specific capacity	Error rate	Lifetime	Energy consumption	Latency	Throughput
3	3	2	2	2	2
3	4	3	4	1	2
3	3	3	3	2	2
19,3%	21,2%	16,9%	18,9%	10,9%	12,9%



3.2 Holographic data storage

3.2.1 Technology description

Holographic data storage is a potential technology in the area of high-capacity data storage that overcomes the limitation of magnetic and conventional optical data storage by going beyond recording only on the surface to recording through the full depth of the medium. Holographic data storage record information throughout the volume of the medium and is capable of recording multiple images in the same area utilizing light at different angles, unlike other technologies that record one data bit at a time.

In holographic storage, light from a coherent laser source is split into two beams, the reference beam and the signal beam. The reference beam contains no information whereas the signal beam carries data to be stored that it has picked up by being passed through a spatial light modulator (SLM). SLMs are used in holographic data storage systems to encode information into a laser beam. At the point of intersection of the reference beam and the signal beam, the hologram is recorded in a light sensitive storage medium. These two beams are spatially overlapped through the volume of a photosensitive storage medium producing an optical interference pattern that is imaged within the medium. The result is a hologram that can be read by applying a beam equivalent to the original reference. This produces a replica of the original data.

The advantage of holography is that a huge number of holographic files can be stored in an overlapping manner in the same volume of photosensitive material. Rather than conventional optical storage, the holographic storage promises fast capacity and high data rates.

3.2.2 Social, Economic and Political (SEP) questions

Compare the new technology (holographic data storage) to the existing dominant technology (state of the art) in respect to:				
Environmental benefits	Potential for spin-off	Production complexity and material cost	Operation complexity and maintenance cost	Comment
Both are the same	New technology is far better	New technology is better	New technology is far better	
Both are the same	New technology is far better	Both are the same	Both are the same	
Both are the same	New technology is far better	Old technology is better	Old technology is better	#19
Both are the same	New technology is better	Old technology is better	Old technology is better	
Both are the same	Old technology is better	Old technology is better	Old technology is better	
0,00	3,00	-1,00	-0,50	

#19: See answer on Chalcogenide memory for a comment on the comparison on Production and Operation complexity and material and maintenance cost.

Will the market (area of application) of data storage devices increase or decrease in the coming years?	
	Comment
The market will increase substantially	
The market will increase substantially	
The market will increase substantially	#18
The market will decrease substantially	
The market will increase substantially	
3,00	

Do you know or can you think of any restrictions or regulations that can hinder the entry of holographic data storage into the space sector?	
	Comment
I am not aware of any restrictions/regulations concerning this technology	
I am not aware of any restrictions/regulations concerning this technology	
I am not aware of any restrictions/regulations concerning this technology	
I am not aware of any restrictions/regulations concerning this technology	
There are major regulations/restrictions concerning this technology	
-1,00	

#18: As far as I know the trend is solidly increasing and there is no sign of slow-down.

In what timeframe do you anticipate this technology to be ready to be used in a space environment?		Are you aware of any political incentive to promote or prevent the development of holographic data storage (or their field of application)?	
	Comment		Comment
In 10 to 20 years		I am not aware of any political incentive concerning this technology	
In the next 10 years		I am not aware of any political incentive concerning this technology	
In 10 to 20 years		I am not aware of any political incentive concerning this technology	
In 10 to 20 years		I am not aware of any political incentive concerning this technology	
In the next 10 years		I am not aware of any political incentive concerning this technology	
0,00		0,00	

Are you aware of any ethical dilemmas or social problems associated with holographic data storage?	
	Comment
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
0,00	

3.2.3 Technical questions (performance attributes)

3.2.3.1 Selection of attributes (1st round)

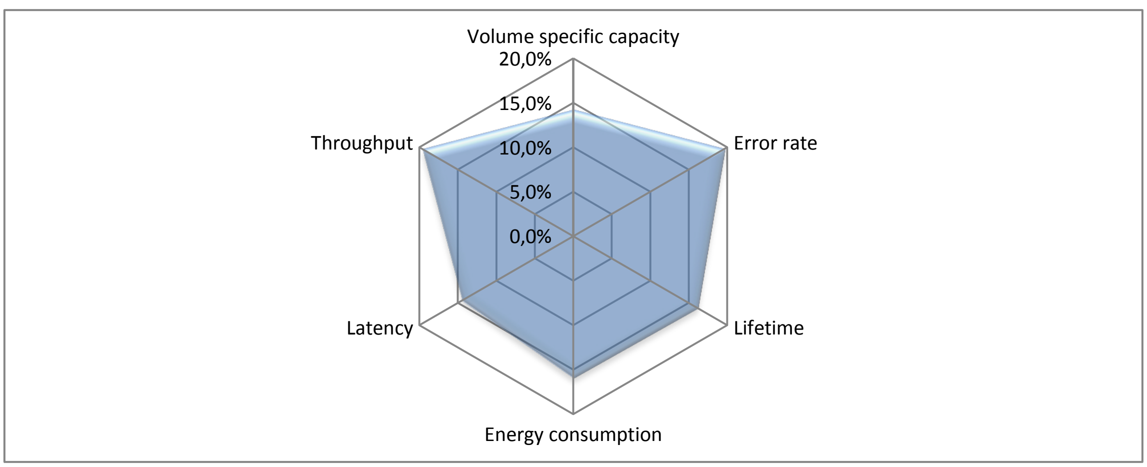
Select or name the 5 most important performance attributes of data storage devices.										
Mass specific capacity	Volume specific capacity	Error rate	Lifetime	Energy consumption	Addressability	Latency	Throughput	Accessibility	Mutability	Other
No	Yes	Yes	Yes	Yes	No	No	No	No	No	number of chips for Capacity
No	No	Yes	No	No	Yes	Yes	Yes	No	No	
Yes	Yes	Yes	Yes	No	No	Yes	No	No	No	
No	No	Yes	Yes	No	Yes	Yes	Yes	No	No	
No	Yes	Yes	Yes	Yes	No	No	No	No	No	radiation tolerance
1	3	5	4	2	2	3	2	0	0	

3.2.3.2 Rating (2nd & 3rd round)

Compare the technology to the state of the art on each attribute on a scale from -5 to +5.						
Volume specific capacity	Error rate	Lifetime	Energy consumption	Latency	Throughput	Comment
4	2	3	4	-4	2	
1	0	0	-1	-2	-2	
4	1	1	3	-2	2	
3,00	1,00	1,33	2,00	-2,67	0,67	

3.2.3.3 Weighting (2nd & 3rd round)

Rate the importance of the attributes on a scale of 1 to 5. Rate each attribute independently.					
Volume specific capacity	Error rate	Lifetime	Energy consumption	Latency	Throughput
2	3	4	3	3	3
3	4	3	4	2	4
3	4	2	2	3	4
14,3%	19,6%	16,1%	15,9%	14,4%	19,6%



3.3 *Multicarrier signals*

3.3.1 Technology description

Multicarrier signals or transmission, also known as multi tone transmission, has seen application in recent years as an approach to the problem of transmitting data over channels that are severely distorted and may suffer from additive or impulsive noise, distorting crosstalk or multipath fading.

The basic concept of multicarrier transmission is to divide the channel bandwidth into sub-channels, assigning a carrier to each of them, and distributing the information stream between subcarriers, for example by filtering, or in effect, for example using orthogonal vector coding. 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 sub-channel exhibits a flat frequency response, thus making frequency-domain equalization easier. Each sub-stream 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.

Since each data symbol occupies a much wider bandwidth than the data rate, a signal-to-noise-plus-interference ratio of less than 0 dB is feasible.

3.3.2 Social, Economic and Political (SEP) questions

Compare the new technology (multicarrier signals) to the existing dominant technology (state of the art) in respect to:				
Environmental benefits	Potential for spin-off	Production complexity and material cost	Operation complexity and maintenance cost	Comment
Both are the same	New technology is better	Old technology is better	New technology is better	
Both are the same	New technology is better	Both are the same	New technology is better	
New technology is better	New technology is better	Both are the same	Both are the same	#20
New technology is better	New technology is better	Old technology is better	New technology is better	
Both are the same	Both are the same	New technology is better	New technology is better	
1,00	2,00	-0,50	2,00	

#20: In this case I do not see significant added complexity or cost associate with the new technology. Moreover, and only as far as I know, we are here considering a new technology at a maturing state (significantly ahead in the development process, if compared to the previous two examples).

Will the market (area of application) of RF communication systems increase or decrease in the coming years?		**Do you know or can you think of any restrictions or regulations that can hinder the entry of multicarrier signals into the space sector?**	
	Comment		Comment
The market will increase substantially		I am not aware of any restrictions/regulations concerning this technology	
The market will increase substantially		I am not aware of any restrictions/regulations concerning this technology	
The market will increase substantially		There are some minor regulations/restrictions concerning this technology	#21
The market will increase substantially		There are major regulations/restrictions concerning this technology	
The market will increase marginally		I am not aware of any restrictions/regulations concerning this technology	
4,50		-1,50	

#21: Power level of RF communication must comply existing and future regulations.

In what timeframe do you anticipate this technology to be ready to be used in a space environment?		Are you aware of any political incentive to promote or prevent the development of multicarrier signals (or their field of application)?	
	Comment		Comment
In the next 10 years		I am not aware of any political incentive concerning this technology	
In the next 10 years		I am not aware of any political incentive concerning this technology	
In the next 10 years		I am not aware of any political incentive concerning this technology	
In 10 to 20 years		I am not aware of any political incentive concerning this technology	
In the next 10 years		I am not aware of any political incentive concerning this technology	
0,00		0,00	

Are you aware of any ethical dilemmas or social problems associated with multicarrier signals?	
	Comment
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
0,00	

3.3.3 Technical questions (performance attributes)

3.3.3.1 Selection of attributes (1st round)

Select or name the 5 most important performance attributes of RF communication systems.						
Interference robustness	Spectral efficiency	SNIR	PAPR	Doppler shift sensitivity	Time synchronization errors	Other
Yes	Yes	No	No	No	Yes	
Yes	No	Yes	No	No	No	
Yes	Yes	Yes	No	Yes	Yes	
Yes	Yes	Yes	No	Yes	No	
Yes	No	Yes	No	No	Yes	intercarrier interference
5	3	4	0	2	3	

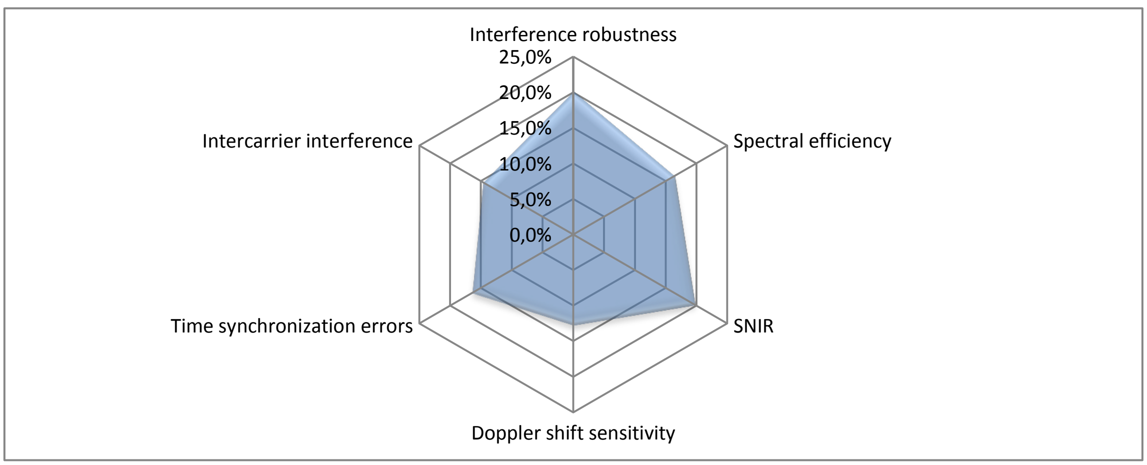
3.3.3.2 Rating (2nd & 3rd round)

Compare the technology to the state of the art on each attribute on a scale from -5 to +5.						
Interference robustness	Spectral efficiency	SNIR	Doppler shift sensitivity	Time synchronization errors	Intercarrier interference	Comment
2	3	2	1	3	0	*12
-2	0	-1	-2	-2	-1	
0	2	2	0	0	0	
0,00	1,67	1,00	-0,33	0,33	-0,33	

*12: This technology was proposed by Bosch about 20 years ago, for digital television... But......

3.3.3.3 Weighting (2nd & 3rd round)

Rate the importance of the attributes on a scale of 1 to 5. Rate each attribute independently.					
Interference robustness	Spectral efficiency	SNIR	Doppler shift sensitivity	Time synchronization errors	Intercarrier interference
3	3	5	3	3	2
4	3	2	2	3	3
4	3	4	2	3	3
20,1%	16,4%	19,7%	12,7%	16,4%	14,7%



4 Power

4.1 Aluminium-celmet for li-ion batteries

4.1.1 Technology description

Standard lithium-ion batteries are often made by aluminum and copper foils. Celmet is made from nickel or nickel chromium and is created through a combination of electro conductive coating, plastic foam, nickel plating and plastic foam. The airflow resistance of celmet is very low. Therefore, fluid can be treated at low pressure drop. Celmet has good workability; it can be cut, pressed and piped easily.

Replacing the aluminum foil in a conventional lithium-ion battery with aluminum-celmet increases the amount of positive active material per unit area and thus increases battery capacity 1.5 to 3 times. With up to 98 percent porosity, aluminum-celmet is about one-third the weight of nickel, offers greater electrical conductivity and is corrosion-resistant.

In conventional capacitors, both positive and negative current collectors are made from aluminum foil. The use of aluminum-celmet instead can improve the capacity and reduce the footprint, as with lithium-ion batteries. The aluminum-celmet material is suitable for use in lithium-ion and other secondary batteries operating at high charge and discharge voltages.

4.1.2 Social, Economic and Political (SEP) questions

Compare the new technology (aluminium-celmet for li-ion batteries) to the existing dominant technology (state of the art) in respect to:				
Environmental benefits	Potential for spin-off	Production complexity and material cost	Operation complexity and maintenance cost	Comments
New technology is better	New technology is better	Both are the same	Both are the same	
New technology is better	New technology is better	Both are the same	Both are the same	
New technology is better	New technology is better	Old technology is better	Both are the same	
New technology is better	New technology is better	New technology is better	New technology is better	
New technology is better	New technology is far	Old technology is far better	Both are the same	
Both are the same	New technology is better	Both are the same	New technology is better	
New technology is better	New technology is better	Both are the same	Both are the same	
2,14	2,86	-0,71	0,71	

Will the market (area of application) of conductors for batteries increase or decrease in the coming years?		**Do you know or can you think of any restrictions or regulations that can hinder the entry of aluminium-celmet for li-ion batteries into the space sector?**	
	Comment		Comment
The market will stay the same		I am not aware of any restrictions/regulations concerning this technology	
The market will increase substantially		I am not aware of any restrictions/regulations concerning this technology	
The market will increase substantially		I am not aware of any restrictions/regulations concerning this technology	
The market will increase substantially		I am not aware of any restrictions/regulations concerning this technology	
The market will decrease substantially		There are some minor regulations/restrictions concerning this technology	
The market will increase marginally		I am not aware of any restrictions/regulations concerning this technology	
The market will increase substantially		I am not aware of any restrictions/regulations concerning this technology	
2,50		-0,36	

In what timeframe do you anticipate this technology to be ready to be used in a space environment?		Are you aware of any political incentive to promote or prevent the development of aluminium-celmet for li-ion batteries (or their field of application)?	
	Comment		Comment
In the next 10 years		I am not aware of any political incentive concerning this technology	
In the next 10 years		I am not aware of any political incentive concerning this technology	
In the next 10 years		I am not aware of any political incentive concerning this technology	
In the next 10 years		There is political incentive to promote this technology	#22
In 10 to 20 years		There is political incentive to promote this technology	
In the next 10 years		I am not aware of any political incentive concerning this technology	
In the next 10 years		There is political incentive to promote this technology	#23
0,00		2,14	

#22: Reduction of heavy metals.

#23: battery technology has a high priority in R&D programs

Are you aware of any ethical dilemmas or social problems associated with aluminium-celmet for li-ion batteries?	
	Comment
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
0,00	

4.1.3 Technical questions (performance attributes)

4.1.3.1 Selection of attributes (1st round)

Select or name the 5 most important performance attributes of conductors for batteries.						
Mass	Lifetime	Conductivity	Corrosion resistance	Temperature sensitivity	Manufacturability	Other
Yes	Yes	Yes	No	Yes	No	capacity
No	Yes	No	No	No	No	
Yes	No	Yes	Yes	No	Yes	
Yes	Yes	Yes	Yes	No	Yes	
Yes	Yes	No	No	No	Yes	
Yes	Yes	Yes	Yes	Yes	No	
Yes	Yes	Yes	Yes	No	Yes	
6	6	5	4	2	4	

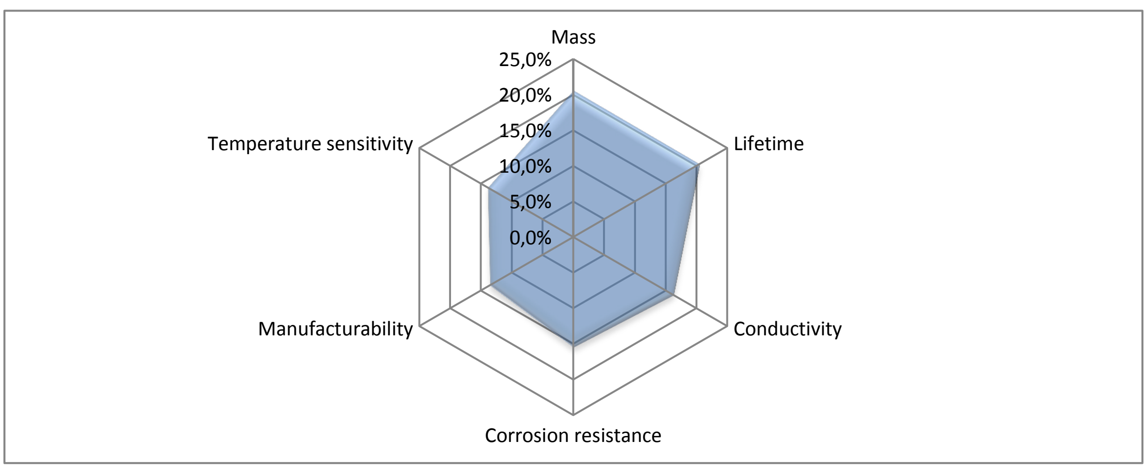
4.1.3.2 Rating (2nd & 3rd round)

Compare the technology to the state of the art on each attribute on a scale from -5 to +5.						
Mass	Lifetime	Conductivity	Corrosion resistance	Manufacturability	Temperature sensitivity	Comment
2	4	2	0	0	0	
4	2	4	3	2	2	
4	1	0	0	0	0	
3	0	1	0	0	0	
2	0	-1	0	-2	-1	
3	3	4	1	-1	-2	*13
3	0	0	1	0	0	
3,00	1,43	1,43	0,71	-0,14	-0,14	

*13: This technology is very important. But, the technology has not been carried out the environmental test for long duration.

4.1.3.3 Weighting (2nd & 3rd round)

Rate the importance of the attributes on a scale of 1 to 5. Rate each attribute independently.					
Mass	Lifetime	Conductivity	Corrosion resistance	Manufacturability	Temperature sensitivity
5	5	3	2	2	3
3	4	5	4	3	4
5	5	4	3	4	2
3	3	2	2	2	2
4	3	3	3	2	4
5	5	3	4	4	2
5	5	4	5	3	3
20,6%	20,4%	16,2%	15,4%	13,5%	13,9%



4.2 *Bacterial nanowire*

4.2.1 Technology description

Bacterial nanowires, also known as microbial nanowires, are electrically conductive appendages with nanowire architectures produced by a number of bacteria most notably from the Geobacter sulfurreducens and Shewanella oneidensis genera.

Bacterial nanowires are a new kind of bacteria that produces long stringy filaments outside its body that conduct electrons better than some metals. The strings of nanowires, which are called pili, allow the bacteria to get rid of electrons which are a by-product of its digestive process. Bacterial nanowires conduct electrons along their length. These are produced by some bacteria and are 3-5 nm wide and up to tens of micrometers long. The filaments bind bacteria together into clumps called microbial films. The electrical conductivity in the wires is comparable to those of synthetic organic metallic nanostructures that commonly used in the electronics industry.

Bacterial nanowires could lead to very small and cheap conductive materials using microorganism, high performance batteries as well as conductors or sensors. In addition, bacterial nanowires could lead to the development of new electronic materials and could influence the design of energy-capture strategies, such as conversion of biomass and wastes to methane or electricity.

4.2.2 Social, Economic and Political (SEP) questions

Compare the new technology (bacterial nanowire) to the existing dominant technology (state of the art) in respect to:				
Environmental benefits	Potential for spin-off	Production complexity and material cost	Operation complexity and maintenance cost	Comments
New technology is better	New technology is better	New technology is better	Both are the same	
Both are the same	Both are the same	Both are the same	Both are the same	
Old technology is better	New technology is better	Old technology is better	Old technology is better	
New technology is better	New technology is better	Old technology is better	Both are the same	
Both are the same	New technology is far	Old technology is better	Old technology is better	
New technology is better	New technology is better	Both are the same	New technology is better	
Both are the same	New technology is better	New technology is better	New technology is better	#24
0,71	2,50	-0,36	0,00	

#24: real functionality is quite speculative and far from application in a larger scale

Will the market (area of application) of conductors for batteries increase or decrease in the coming years?	
	Comment
The market will stay the same	
The market will increase substantially	
The market will increase substantially	
The market will increase substantially	
The market will decrease substantially	
The market will increase marginally	
The market will increase substantially	
2,50	

Do you know or can you think of any restrictions or regulations that can hinder the entry of bacterial nanowire into the space sector?	
	Comment
I am not aware of any restrictions/regulations concerning this technology	
I am not aware of any restrictions/regulations concerning this technology	
I am not aware of any restrictions/regulations concerning this technology	
I am not aware of any restrictions/regulations concerning this technology	
I am not aware of any restrictions/regulations concerning this technology	
I am not aware of any restrictions/regulations concerning this technology	
There are some minor regulations/restrictions concerning this technology	#25
-0,36	

#25: contamination due to bacteria unknown

In what timeframe do you anticipate this technology to be ready to be used in a space environment?		Are you aware of any political incentive to promote or prevent the development of bacterial nanowire (or their field of application)?	
	Comment		Comment
In the next 10 years		I am not aware of any political incentive concerning this technology	
Longer than 20		I am not aware of any political incentive concerning this technology	
In 10 to 20 years		I am not aware of any political incentive concerning this technology	
In 10 to 20 years		I am not aware of any political incentive concerning this technology	
Longer than 20		I am not aware of any political incentive concerning this technology	
Longer than 20		There is political incentive to prevent this technology	
In 10 to 20 years		I am not aware of any political incentive concerning this technology	
-1,07		-0,71	

Are you aware of any ethical dilemmas or social problems associated with bacterial nanowire?	
	Comment
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
There are some minor ethical or social problems concerning this technology	#26
-0,36	

#26: bacteria might have impacts on environment

4.2.3 Technical questions (performance attributes)

4.2.3.1 Selection of attributes (1st round)

Select or name the 5 most important performance attributes of conductors for batteries.						
Mass	Lifetime	Conductivity	Corrosion resistance	Temperature sensitivity	Manufacturability	Other
Yes	Yes	Yes	No	Yes	No	capacity
No	Yes	No	No	No	No	
Yes	No	Yes	Yes	No	Yes	
Yes	Yes	Yes	Yes	No	Yes	
Yes	Yes	No	No	No	Yes	
Yes	Yes	Yes	Yes	Yes	No	
Yes	Yes	Yes	Yes	No	Yes	
6	6	5	4	2	4	

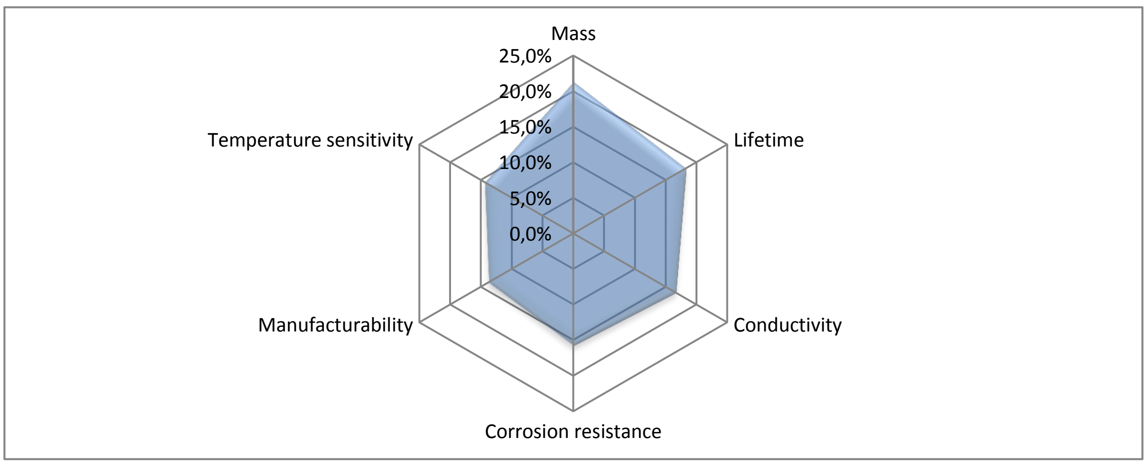
4.2.3.2 Rating (2nd & 3rd round)

Compare the technology to the state of the art on each attribute on a scale from -5 to +5.						
Mass	Lifetime	Conductivity	Corrosion resistance	Manufacturability	Temperature sensitivity	Comment
2	0	1	-1	-2	-3	
4	3	2	3	2	3	
2	-1	1	-1	-2	-2	
0	-1	0	0	-2	0	
0	-3	-2	-2	1	-3	*14
3	3	2	1	-3	-2	
2	-2	5	-2	-3	-1	
1,86	-0,14	1,29	-0,29	-1,29	-1,14	

*14: since there is not yet a real prove a concept for a device rating is very speculative. For lifetime self-healing mechanism would be essential

4.2.3.3 Weighting (2nd & 3rd round)

Rate the importance of the attributes on a scale of 1 to 5. Rate each attribute independently.					
Mass	Lifetime	Conductivity	Corrosion resistance	Manufacturability	Temperature sensitivity
5	3	4	4	2	2
3	3	3	4	3	3
4	3	4	2	3	2
3	3	2	2	2	2
4	4	3	3	3	3
4	3	2	2	2	3
5	5	4	4	3	4
21,3%	18,2%	16,5%	15,7%	13,7%	14,4%



4.3 *Silicon nanowire lithium ion-battery*

4.3.1 Technology description

Nanowires of silicon just a few atoms across can function as high-capacity electrodes, absorbing and releasing about 10 times more lithium ions than the graphite electrodes that are commonly used today.

To overcome expand/shrink cycle typically causes the silicon to pulverize and degrading the performance of the battery, researchers used nanotechnology methods. 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 lithium.

With this method, the silicon is not collapsing but it maintains its size when the lithium atoms are being positively charged and when being electrically discharged when used.

4.3.2 Social, Economic and Political (SEP) questions

Compare the new technology (silicon nanowire lithium ion-battery) to the existing dominant technology (state of the art) in respect to:				
Environmental benefits	Potential for spin-off	Production complexity and material cost	Operation complexity and maintenance cost	Comments
New technology is better	New technology is better	New technology is better	Both are the same	
New technology is better	New technology is far	Both are the same	Both are the same	
Both are the same	New technology is better	Old technology is better	Both are the same	
New technology is better	New technology is better	Old technology is better	Old technology is better	
Both are the same	New technology is far	Old technology is better	Old technology is better	
New technology is better	New technology is better	New technology is better	New technology is far	
New technology is better	New technology is far	New technology is better	Both are the same	
1,79	3,57	0,00	0,00	

Will the market (area of application) of energy storage devices increase or decrease in the coming years?		**Do you know or can you think of any restrictions or regulations that can hinder the entry of silicon nanowire lithium ion-battery into the space sector?**	
	Comment		Comment
The market will stay the same		I am not aware of any restrictions/regulations concerning this technology	
The market will increase substantially		There are some minor regulations/restrictions concerning this technology	
The market will increase substantially		I am not aware of any restrictions/regulations concerning this technology	
The market will increase substantially		I am not aware of any restrictions/regulations concerning this technology	
The market will increase substantially		I am not aware of any restrictions/regulations concerning this technology	
The market will increase substantially		I am not aware of any restrictions/regulations concerning this technology	
The market will increase substantially		I am not aware of any restrictions/regulations concerning this technology	
4,29		-0,36	

In what timeframe do you anticipate this technology to be ready to be used in a space environment?		**Are you aware of any political incentive to promote or prevent the development of silicon nanowire lithium ion-battery (or their field of application)?**	
	Comment		Comment
In the next 10 years		I am not aware of any political incentive concerning this technology	
In 10 to 20 years		I am not aware of any political incentive concerning this technology	
In 10 to 20 years		I am not aware of any political incentive concerning this technology	
In 10 to 20 years		I am not aware of any political incentive concerning this technology	
Longer than 20		There is political incentive to promote this technology	
In 10 to 20 years		I am not aware of any political incentive concerning this technology	
In the next 10 years		There is political incentive to promote this technology	#27
-0,36		1,43	

#27: electrical storage with abundant and environmentally friendly materials is essential for the transition of the energy supply system

Are you aware of any ethical dilemmas or social problems associated with silicon nanowire lithium ion-battery?	
	Comment
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
There are some minor ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
-0,36	

4.3.3 Technical questions (performance attributes)

4.3.3.1 Selection of attributes (1st round)

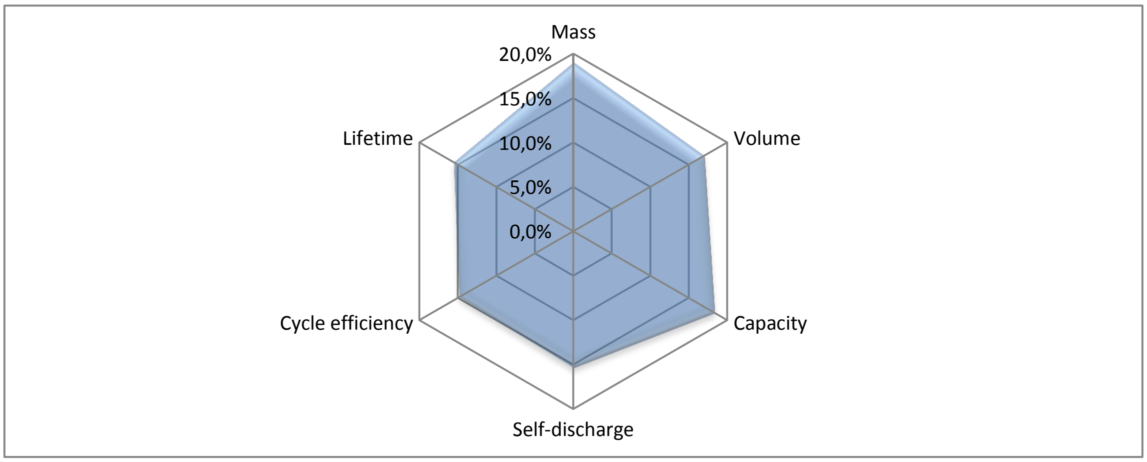
Select or name the 5 most important performance attributes of energy storage devices.								
Mass	Volume	Capacity	Self-discharge	Impedance	Cycle efficiency	Lifetime	Toxicity	Other
Yes	Yes	Yes	Yes	No	No	No	Yes	
Yes	No	Yes	Yes	No	Yes	Yes	No	
Yes	No	Yes	Yes	No	Yes	Yes	No	
Yes	No	Yes	Yes	No	Yes	Yes	No	
Yes	Yes	Yes	No	No	No	Yes	No	
Yes	Yes	Yes	No	Yes	No	No	Yes	
Yes	Yes	Yes	Yes	No	No	Yes	No	
7	4	7	5	1	3	5	2	

4.3.3.2 Rating (2nd & 3rd round)

Compare the technology to the state of the art on each attribute on a scale from -5 to +5.						
Mass	Volume	Capacity	Self-discharge	Cycle efficiency	Lifetime	Comment
2	1	1	1	1	1	
2	4	4	3	2	3	
3	2	4	-1	2	0	
2	2	2	1	1	2	
0	-1	-1	1	2	2	
3	1	1	1	2	1	
5	5	5	-1	4	-1	
2,43	2,00	2,29	0,71	2,00	1,14	

4.3.3.3 Weighting (2nd & 3rd round)

Rate the importance of the attributes on a scale of 1 to 5. Rate each attribute independently.					
Mass	Volume	Capacity	Self-discharge	Cycle efficiency	Lifetime
5	5	5	2	3	4
3	3	4	4	3	3
4	4	4	3	3	2
3	3	3	3	2	3
4	3	4	4	4	4
5	3	3	3	3	3
5	5	5	4	5	5
19,0%	17,0%	18,3%	15,3%	14,8%	15,6%



4.4 *Super/ultra capacitors*

4.4.1 Technology description

A supercapacitor, also known as ultracapacitor or electric double-layer capacitor (EDLC), is an electrochemical capacitor with relatively high energy density.

In conventional capacitors, energy is stored by the removal of charge carriers, typically electrons, from one metal plate and depositing them on another. This charge separation creates a potential between the two plates, which can be harnessed in an external circuit. The total energy stored in this fashion increases with both the amount of charge stored and the potential between the plates. The amount of charge stored per unit voltage is essentially a function of the size, the distance, and the material properties of the plates and the material in between the plates, while the potential between the plates is limited by the breakdown field strength of the dielectric. The dielectric controls the capacitor's voltage. Optimizing the material leads to higher energy density for a given size of capacitor.

Supercapacitors do not have a conventional dielectric. Rather than two separate plates separated by an intervening insulator, these capacitors use virtual plates that are in fact two layers of the same substrate. Their electrochemical properties result in the effective separation of charge despite the vanishingly thin physical separation of the layers. The lack of need for a bulky layer of dielectric, and the porosity of the material used, permits the packing of plates with much larger surface area into a given volume, resulting in high capacitances in practical-sized packages. Each layer of supercapacitors by itself is quite conductive, but the physics at the interface where the layers are effectively in contact means that no significant current can flow between the layers. However, the double layer can withstand only a low voltage, which means that supercapacitors rated for higher voltages must be made of matched series-connected individual supercapacitors, much like series-connected cells in higher-voltage batteries.

Supercapacitors have much higher power density (10 to 100 times) than conventional batteries. Power density combines the energy density with the speed that the energy can be delivered to the load. Batteries, which are based on the movement of charge carriers in a liquid electrolyte, have relatively slow charge and discharge times. Supercapacitors can be charged or discharged at a rate that is typically limited by current heating of the electrodes.

Main advantages include: Virtually unlimited life cycles (cycles millions of times - 10 to 12 years of life), low impedance, charges in seconds, no danger of overcharge, very high rates of charge and discharge, high cycle efficiency (95% or more).

4.4.2 Social, Economic and Political (SEP) questions

Compare the new technology (super/ultra capacitors) to the existing dominant technology (state of the art) in respect to:				
Environmental benefits	Potential for spin-off	Production complexity and material cost	Operation complexity and maintenance cost	Comments
New technology is better	New technology is better	New technology is better	New technology is better	
New technology is better	New technology is better	Both are the same	New technology is better	
Both are the same	New technology is better	Old technology is better	Both are the same	
New technology is better	New technology is far	Both are the same	Both are the same	
New technology is better	New technology is far	Old technology is better	Both are the same	
New technology is better	New technology is better	Both are the same	Both are the same	
New technology is better	New technology is better	Both are the same	New technology is better	#28
2,14	3,21	-0,36	1,07	

#28: comparison with batteries is difficult because special properties (self-discharge, volume etc.) are different and have to be evaluated with special applications

Will the market (area of application) of energy storage devices increase or decrease in the coming years?	
	Comment
The market will stay the same	
The market will increase substantially	
The market will increase substantially	
The market will increase substantially	
The market will increase substantially	
The market will increase substantially	
The market will increase substantially	
4,29	

Do you know or can you think of any restrictions or regulations that can hinder the entry of super/ultra capacitors into the space sector?	
	Comment
I am not aware of any restrictions/regulations concerning this technology	
I am not aware of any restrictions/regulations concerning this technology	
I am not aware of any restrictions/regulations concerning this technology	
There are some minor regulations/restrictions concerning this technology	#29
I am not aware of any restrictions/regulations concerning this technology	
There are some minor regulations/restrictions concerning this technology	
I am not aware of any restrictions/regulations concerning this technology	
-0,71	

#29: Handling of large amounts of energy in a small device is always critical.

In what timeframe do you anticipate this technology to be ready to be used in a space environment?		Are you aware of any political incentive to promote or prevent the development of super/ultra capacitors (or their field of application)?	
	Comment		Comment
In the next 10 years		I am not aware of any political incentive concerning this technology	
In the next 10 years		I am not aware of any political incentive concerning this technology	
In the next 10 years		I am not aware of any political incentive concerning this technology	
In the next 10 years		I am not aware of any political incentive concerning this technology	
Longer than 20		There is political incentive to promote this technology	
In 10 to 20 years		I am not aware of any political incentive concerning this technology	
In the next 10 years		There is political incentive to promote this technology	#30
-0,36		1,43	

#30: for electromobiltiy super caps could be an important component

Are you aware of any ethical dilemmas or social problems associated with super/ultra capacitors?	
	Comment
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
0,00	

4.4.3 Technical questions (performance attributes)

4.4.3.1 Selection of attributes (1st round)

Select or name the 5 most important performance attributes of energy storage devices.								
Mass	Volume	Capacity	Self-discharge	Impedance	Cycle efficiency	Lifetime	Toxicity	Other
Yes	Yes	Yes	Yes	No	No	No	Yes	
Yes	No	Yes	Yes	No	Yes	Yes	No	
Yes	No	Yes	Yes	No	Yes	Yes	No	
Yes	No	Yes	Yes	No	Yes	Yes	No	
Yes	Yes	Yes	No	No	No	Yes	No	
Yes	Yes	Yes	No	Yes	No	No	Yes	
Yes	Yes	Yes	Yes	No	No	Yes	No	
7	4	7	5	1	3	5	2	

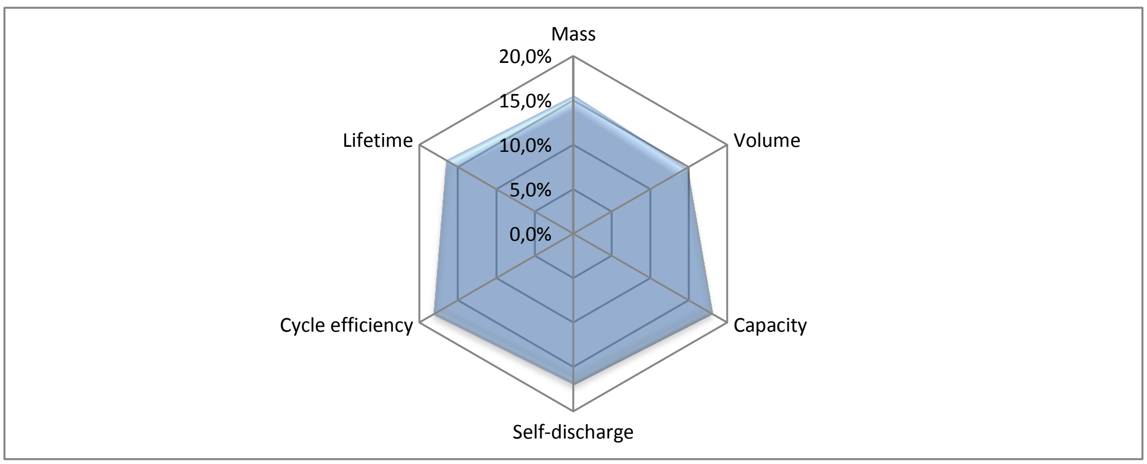
4.4.3.2 Rating (2nd & 3rd round)

Compare the technology to the state of the art on each attribute on a scale from -5 to +5.						
Mass	Volume	Capacity	Self-discharge	Cycle efficiency	Lifetime	Comment
2	3	4	3	4	5	
4	3	5	5	5	5	
1	1	3	1	5	3	
3	2	3	0	3	3	
1	1	0	0	0	0	
2	-1	2	2	5	5	*15
1	1	3	3	3	3	
2,00	1,43	2,86	2,00	3,57	3,43	

*15: Lifetime of a battery limits lifetime of satellites. If the lifetime is unlimited, we can use the satellite for a long time.

4.4.3.3 Weighting (2nd & 3rd round)

Rate the importance of the attributes on a scale of 1 to 5. Rate each attribute independently.					
Mass	Volume	Capacity	Self-discharge	Cycle efficiency	Lifetime
5	5	5	4	4	4
4	4	5	5	5	4
4	4	5	4	5	3
3	2	3	3	3	3
3	3	4	3	4	4
2	2	3	5	5	5
5	5	5	4	4	4
15,6%	14,7%	18,0%	17,0%	18,2%	16,6%



4.5 Quantum-dot solar cells

4.5.1 Technology description

As opposed to conventional photovoltaic solar cells based on bulk semiconductors, such as silicon, copper indium gallium selenide or cadmium telluride, quantum dot solar cells use quantum dots as photovoltaic material. Quantum dots are nano-scale particle of semiconductor materials whose excitons are confined in all three spatial dimensions. Semiconductor quantum dots typically have diameters from about 2 to 10 nanometers and contain only hundreds to thousands of atoms. In contrast to bulk materials, which have larger crystals and more atoms than nanomaterials and where the bandgap is fixed by the choice of material composition, quantum dots have bandgaps that are tunable across a wide range of energy levels by changing the quantum dot size. The ability to tune the bandgap makes quantum dots desirable for solar cell use, where a variety of different energy levels are used to extract more power from the solar spectrum. The conversion process works by multiple exciton generation (MEG) while a single photon of light of sufficient energy is absorbed by the quantum dot; it produces more than one bound electron-hole pair per absorbed photon. The extra efficiency comes from harvesting energy that would otherwise be lost as heat. Quantum dots used in third-generation solar cells have the potential to increase the efficiency of converting sunlight to electricity up to 66%, exceeding the limits of about 31% of first-generation (silicon) and second-generation (thin-film silicon, cadmium telluride, and copper indium gallium diselenide) solar cells. QD solar cells can reduce wasteful heat and maximize the amount of the sun's energy that is converted to electricity..

4.5.2 Social, Economic and Political (SEP) questions

Compare the new technology (quantum-dot solar cells) to the existing dominant technology (state of the art) in respect to:				
Environmental benefits	Potential for spin-off	Production complexity and material cost	Operation complexity and maintenance cost	Comments
New technology is better	New technology is better	Both are the same	Both are the same	
Both are the same	New technology is better	Both are the same	Both are the same	#31
Both are the same	New technology is better	Old technology is better	Both are the same	
New technology is better	New technology is better	Old technology is better	Both are the same	
New technology is better	New technology is far	New technology is far better	New technology is better	
Both are the same	Old technology is better	Old technology is far better	Old technology is far	
Old technology is better	Both are the same	New technology is better	Both are the same	#32
0,71	1,79	-0,36	-0,36	

#31: The standard technology in space solar cells are triple junction solar cells of III-V compounds (e.g. GaAs). Within these cells quantum dots may be included to increase the efficiency of this technology.

#32: Quantum dot solar cells did not yet prove better performance compared to existing PV cells. There might be an advantage for production but not yet evident

Will the market (area of application) of solar cells increase or decrease in the coming years?		**Do you know or can you think of any restrictions or regulations that can hinder the entry of quantum-dot solar cells into the space sector?**	
	Comment		Comment
The market will increase marginally		I am not aware of any restrictions/regulations concerning this technology	
The market will increase substantially		There are some minor regulations/restrictions concerning this technology	
The market will increase substantially		I am not aware of any restrictions/regulations concerning this technology	
The market will increase substantially		I am not aware of any restrictions/regulations concerning this technology	
The market will increase substantially		I am not aware of any restrictions/regulations concerning this technology	
The market will stay the same		There are some minor regulations/restrictions concerning this technology	
The market will increase substantially		I am not aware of any restrictions/regulations concerning this technology	
3,93		-0,71	

In what timeframe do you anticipate this technology to be ready to be used in a space environment?		Are you aware of any political incentive to promote or prevent the development of quantum-dot solar cells (or their field of application)?	
	Comment		Comment
In the next 10 years		I am not aware of any political incentive concerning this technology	
In 10 to 20 years		I am not aware of any political incentive concerning this technology	
In the next 10 years		I am not aware of any political incentive concerning this technology	
In the next 10 years		There is political incentive to promote this technology	#33
In 10 to 20 years		There is political incentive to promote this technology	
In 10 to 20 years		There is political incentive to promote this technology	
Longer than 20		There is political incentive to promote this technology	
-0,36		2,86	

#33: There are still incentives for solar electricity generation, but they are more and more reduced.

Are you aware of any ethical dilemmas or social problems associated with quantum-dot solar cells?	
	Comment
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
There are major ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
-0,71	

4.5.3 Technical questions (performance attributes)

4.5.3.1 Selection of attributes (1st round)

Select or name the 5 most important performance attributes of solar cells.						
Efficiency	Lifetime	Radiation resistance	Power density	Material density	Temperature sensitivity	Other
Yes	Yes	Yes	Yes	No	Yes	
Yes	Yes	Yes	Yes	No	Yes	
Yes	Yes	Yes	Yes	No	No	mechanical flexibility
Yes	Yes	Yes	Yes	No	Yes	
Yes	Yes	Yes	Yes	Yes	No	
Yes	Yes	Yes	Yes	No	No	Weight
Yes	Yes	Yes	No	No	Yes	weight
7	7	7	6	1	4	

4.5.3.2 Rating (2nd & 3rd round)

Compare the technology to the state of the art on each attribute on a scale from -5 to +5.						
Efficiency	Lifetime	Radiation resistance	Power density	Temperature sensitivity	Weight	Comment
2	1	0	0	0	0	
3	3	3	4	3	4	
2	-1	-1	2	0	1	
2	2	2	2	1	0	*16
-4	-4	-2	-4	0	1	*17
-3	-3	-4	-3	-2	-2	*18
2	-2	-1	2	0	1	
0,57	-0,57	-0,43	0,43	0,29	0,71	

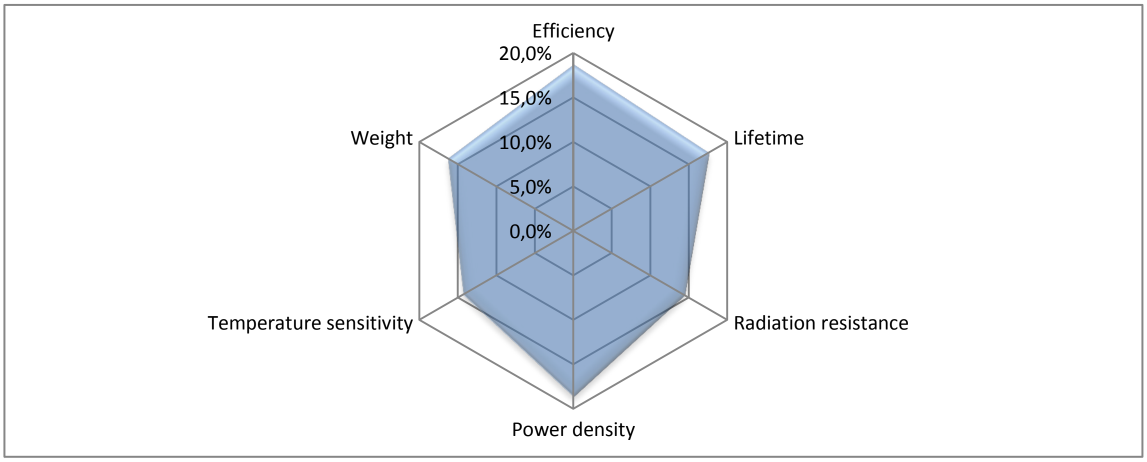
*16: Quantum dot solar cells are a technology for improvement of multijunction solar cells, such as the state-of-the-art triple junction solar cells - it is not an independent technology.

*17: There is no evident advantage of state of the art quantum dot solar cells.

*18: Although QD-cell can extend the efficiency of the solar cell, the amount of efficiency is very low. I think that this technology is not important to apply for satellites.

4.5.3.3 Weighting (2nd & 3rd round)

Rate the importance of the attributes on a scale of 1 to 5. Rate each attribute independently.					
Efficiency	Lifetime	Radiation resistance	Power density	Temperature sensitivity	Weight
5	4	4	4	5	5
4	4	4	4	4	4
4	4	2	4	2	3
3	3	2	2	2	2
5	4	3	4	2	4
1	1	1	2	1	1
5	5	5	5	5	5
18,8%	17,6%	14,4%	18,6%	14,3%	16,3%



4.6 UltraFlex solar panels

4.6.1 Technology description

The UltraFlex Solar Panel is a lightweight, low volume, triple junction solar array which provides 5% higher efficiency and increased foldability compared with traditional triple junction Gallium Arsenide cells. UltraFlex solar cells have 25% less mass than conventional solar panels, which allow reduced launch costs. In addition, UltraFlex solar panels have a compact and extremely low stowage volume (25% less volume of standard solar arrays) that enables spacecraft and launch vehicle flexibility.

The UltraFlex solar array is an accordion fanfold flexible-blanket solar array comprised of interconnected triangular shaped lightweight substrates/gores. During deployment, each interconnected triangular substrate/gore unfolds in a rotational fan fashion. Upon full deployment, the structure becomes tensioned into a rigid shallow umbrella-shaped structure. Lightweight composite radial spar elements attached to each substrate/gore provide structural support for the gores during deployment and in the deployed state. When fully deployed, the UltraFlex gores are maintained in a preloaded and tensioned state via the elastic deflection of in-plane spring flexures, forming a high-stiffness structural platform for the solar cells.

The UltraFlex solar panel provides less mass, higher efficiency, compact stowage volume, exceptional deployed structural performance, high reliability, scalability, and operational capability.

4.6.2 Social, Economic and Political (SEP) questions

Compare the new technology (UltraFlex solar panels) to the existing dominant technology (state of the art) in respect to:				
Environmental benefits	Potential for spin-off	Production complexity and material cost	Operation complexity and maintenance cost	Comments
New technology is better	Both are the same	Both are the same	Both are the same	
Both are the same	Both are the same	Old technology is better	Both are the same	
New technology is better	Both are the same	Old technology is better	Both are the same	
Both are the same	New technology is far	Both are the same	Both are the same	
Both are the same	New technology is better	Old technology is better	New technology is better	
New technology is better	New technology is better	Old technology is better	Both are the same	
Both are the same	New technology is better	New technology is better	Both are the same	
1,07	1,79	-1,07	0,36	

Will the market (area of application) of solar arrays increase or decrease in the coming years?		Do you know or can you think of any restrictions or regulations that can hinder the entry of UltraFlex solar panels into the space sector?	
	Comment		Comment
The market will stay the same		I am not aware of any restrictions/regulations concerning this technology	
The market will increase marginally		I am not aware of any restrictions/regulations concerning this technology	
The market will increase marginally		I am not aware of any restrictions/regulations concerning this technology	
The market will increase substantially		I am not aware of any restrictions/regulations concerning this technology	
The market will increase substantially		I am not aware of any restrictions/regulations concerning this technology	
The market will increase substantially		I am not aware of any restrictions/regulations concerning this technology	
The market will increase substantially		I am not aware of any restrictions/regulations concerning this technology	
3,57		0,00	

In what timeframe do you anticipate this technology to be ready to be used in a space environment?		Are you aware of any political incentive to promote or prevent the development of UltraFlex solar panels (or their field of application)?	
	Comment		Comment
In the next 10 years		I am not aware of any political incentive concerning this technology	
In 10 to 20 years		I am not aware of any political incentive concerning this technology	
In the next 10 years		I am not aware of any political incentive concerning this technology	
In the next 10 years		There is political incentive to promote this technology	#34
In 10 to 20 years		There is political incentive to promote this technology	
In 10 to 20 years		I am not aware of any political incentive concerning this technology	
In 10 to 20 years		I am not aware of any political incentive concerning this technology	
0,00		1,43	

#34: There are incentives but they will be reduced in the future.

Are you aware of any ethical dilemmas or social problems associated with UltraFlex solar panels?	
	Comment
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
0,00	

4.6.3 Technical questions (performance attributes)

4.6.3.1 Selection of attributes (1st round)

Select or name the 5 most important performance attributes of solar arrays.									
Mass specific panel area	Thickness (Volume)	Complexity	Total efficiency	Reliability	Lifetime	Cell packing	Foldability / compactnes	Scalability	Other
Yes	Yes	No	Yes	Yes	Yes	No	No	No	
Yes	Yes	No	Yes	Yes	Yes	No	No	No	
Yes	No	No	Yes	Yes	Yes	No	Yes	No	
Yes	Yes	No	Yes	No	No	Yes	Yes	No	
Yes	Yes	Yes	Yes	No	Yes	No	No	No	
Yes	No	No	Yes	Yes	No	No	Yes	Yes	
Yes	Yes	No	Yes	Yes	No	No	Yes	No	
7	5	1	7	5	4	1	4	1	

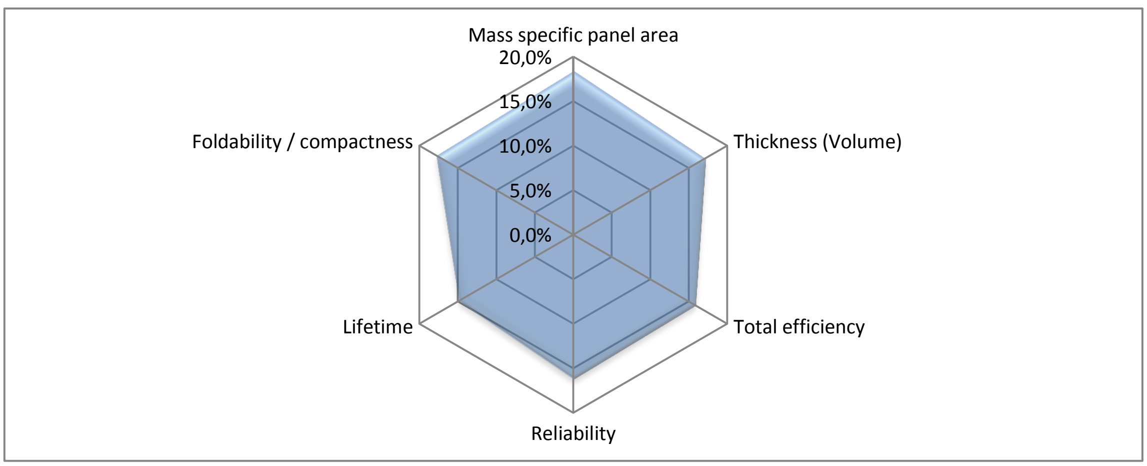
4.6.3.2 Rating (2nd & 3rd round)

Compare the technology to the state of the art on each attribute on a scale from -5 to +5.						
Mass specific panel area	Thickness (Volume)	Total efficiency	Reliability	Lifetime	Foldability / compactness	Comment
4	3	3	0	0	3	
3	3	3	3	4	4	
4	3	2	0	0	2	
1	1	0	1	1	1	
1	2	-2	-2	-2	3	
3	3	4	0	0	2	*19
3	3	2	0	0	4	
2,71	2,57	1,71	0,29	0,43	2,71	

*19: Thin film solar cells on flexible substrate are a great candidate for future space solar cell. For example, IMM solar cells are very famous and popular. Ultra flex solar panel is necessary to apply the cells for satellites.

4.6.3.3 Weighting (2nd & 3rd round)

Rate the importance of the attributes on a scale of 1 to 5. Rate each attribute independently.					
Mass specific panel area	Thickness (Volume)	Total efficiency	Reliability	Lifetime	Foldability / compactness
5	4	4	4	4	4
3	4	4	4	4	4
4	3	3	3	3	4
2	2	1	1	1	2
4	3	4	4	3	4
4	4	5	4	3	3
5	5	3	5	5	5
18,4%	17,1%	15,7%	16,1%	14,9%	17,8%



5 Propulsion

5.1 Magnetoplasmadynamic thruster

5.1.1 Technology description

The magnetoplasmadynamic thruster (MPDT) is a form of electromagnetic spacecraft propulsion that uses the Lorentz force to generate thrust.

The Magnetoplasmadynamic thruster has two metal electrodes: a central rod-shaped cathode, and a cylindrical anode that surrounds the cathode. A high-current electric arc is struck between the anode and cathode. As the cathode heats up, it emits electrons that collide with and ionize a propellant gas to create plasma. A magnetic field is created by the electric current returning to the power supply through the cathode, just like the magnetic field that is created when electrical current travels through a wire. This self-induced magnetic field interacts with the electric current flowing from the anode to the cathode (through the plasma) to produce an electromagnetic (Lorentz) force that pushes the plasma out of the engine, creating thrust. An external magnet coil may also be used to provide additional magnetic fields to help stabilize and accelerate the plasma discharge. Unlike chemical propulsion, there is no combustion of fuel. There are two main types of Magnetoplasmadynamic thrusters: the applied-field and the self-field. The applied-field thrusters have magnetic rings surrounding the exhaust chamber to produce the magnetic field, while the self-field thrusters have a cathode extending through the middle of the chamber. Applied fields are necessary at lower power levels, where self-field configurations are too weak. Various propellants such as xenon, neon, argon, hydrazine, and lithium have been used, with lithium generally achieved the best results. The MPDT is a very powerful electric propulsion system which could make interplanetary manned flights possible. With a huge amount of electric energy, the MPDT can provide an efficient, megawatt-class electromagnetic thruster capable of several thousand hours of continuous operation. With its high exhaust velocities, MPDTs offer advantages over conventional types of propulsion for each of these mission applications. MPDTs expel plasma to create propulsion. MPDTs can process more power and create more thrust than any other type of electric propulsion currently available, while maintaining the high exhaust velocities associated with ion propulsion.

Performance data: Exhaust velocity: 80.000 m/s; Specific impulse: 2.500-8.000s; Thrust: several hundred Newton are possible.

5.1.2 Social, Economic and Political (SEP) questions

Compare the new technology (magnetoplasmadynamic thruster) to the existing dominant technology (state of the art) in respect to:				
Environmental benefits	Potential for spin-off	Production complexity and material cost	Operation complexity and maintenance cost	Comment
New technology is better	New technology is better	Old technology is better	Old technology is better	
Old technology is better	Both are the same	Old technology is better	Old technology is better	#35
New technology is better	New technology is far better	Both are the same	Old technology is better	
Old technology is better	New technology is far better	New technology is better	New technology is better	
New technology is better	New technology is far better	Both are the same	Both are the same	
New technology is better	Both are the same	Old technology is better	Old technology is better	
New technology is better	Both are the same	New technology is better	Old technology is far better	
New technology is far better	Both are the same	Old technology is better	New technology is better	
Both are the same	Old technology is far better	Old technology is far better	Old technology is better	#36
Both are the same	Both are the same	Both are the same	New technology is better	
Both are the same	Both are the same	New technology is better	New technology is better	#37
Both are the same	New technology is better	Old technology is better	Old technology is better	#38
1,04	1,25	-0,83	-0,83	

#35: Answers assume the comparison is made with a lithium MPD, which (as claimed in the description of the technology), gives the best performance. On Environmental benefits, Production and Operation complexity: the answer can be "Both are the same" if a different propellant is used (e.g. hydrogen)

#36: The attributes listed for comparison may be of importance for some technologies, but for high-power advanced space propulsion they are not particularly relevant. e.g. - if MPD's could provide 10-100X scalability in power and thrust over state-of-the-art then spin-off applications or production complexity vs. state-of-the-art aren't compelling comparison criteria.

#37: In case of use of lithium as propellant, the environmental impact on ground might be disadvantageous for the MPDT as lithium is very rare and expensive to be produced. Otherwise no advantage of MPDT on this attribute. MPDT could be used for material deposition (nitrogen impingement in metals for hardening) alike ion sources (RIT/Kaufmann) are used in Semiconductor industry. Self-Field MPDTs propose to be simple, this less complex in electronics and operations

#38: environmental impact may depend on source of energy, existing technology is simpler resulting in reduced production costs and operation complexity

Will the market (area of application) of conductors for batteries increase or decrease in the coming years?		**Do you know or can you think of any restrictions or regulations that can hinder the entry of aluminium-celmet for li-ion batteries into the space sector?**	
	Comment		Comment
The market will stay the same		I am not aware of any restrictions/regulations concerning this technology	
The market will decrease marginally	#39	There are some minor regulations/restrictions concerning this technology	#43
The market will increase marginally		I am not aware of any restrictions/regulations concerning this technology	
The market will stay the same		I am not aware of any restrictions/regulations concerning this technology	
The market will decrease marginally		I am not aware of any restrictions/regulations concerning this technology	
The market will increase substantially		I am not aware of any restrictions/regulations concerning this technology	
The market will increase marginally		I am not aware of any restrictions/regulations concerning this technology	
The market will increase marginally		I am not aware of any restrictions/regulations concerning this technology	
The market will increase substantially	#40	There are major regulations/restrictions concerning this technology	#44
The market will increase substantially		I am not aware of any restrictions/regulations concerning this technology	
The market will increase marginally	#41	I am not aware of any restrictions/regulations concerning this technology	#45
The market will increase marginally	#42	I am not aware of any restrictions/regulations concerning this technology	#46
1,88		-0,63	

#39: The missions that would benefit mostly by this technology are those associated with the human exploration of the solar system. This program is undergoing funding cuts, a trend that is likely to continue for at least the next few years. However, historically, significant funding fluctuations have not been uncommon so it is possible that the market could "increase marginally" or even "substantially" in the next decade.

#40: With the advent of higher power levels in space for space platforms (> 30 kWe), and the requirements for moving heavy payloads in space efficiently - and other developing requirements such as orbital debris mitigation - the market for advanced in-space propulsion capabilities should dramatically increase.

#41: although everybody is dreaming of, the system aspects (power, system mass) are hindering the extensive use of MPDT; if power shortage can be overcome, MPDT market can increase significantly

#42: LEO, MEO and GEO applications will be main driver, other mission will play minor role in market only.

#43: Again, assuming Li-MPD, some restrictions may be associated with the use of liquid metals on-ground and in-space. For the other propellants I am not aware of any restrictions/regulations concerning this technology.

#44: MPD technology improves (performance) with input power. Generally this requires >> 100 kWe power levels per device - which represents a level of in-space power greatly exceeding available systems. Additionally for MPD's and other high power electric propulsion SYSTEMS, the mass (specific mass) of the power system must be very low. Hence - to hasten the application of this and other high power electric propulsion technology application requires a concurrent and substantial investment in the development of space power systems technology.

#45: What is the EMC characteristic of such a thruster? Is it possibly interfering with satellite communications?

#46: Source of energy might be the problem.

In what timeframe do you anticipate this technology to be ready to be used in a space		**Are you aware of any political incentive to promote or prevent the development of aluminium-celmet for li-ion batteries (or their field of application)?**	
	Comment		Comment
In 10 to 20 years		I am not aware of any political incentive concerning this technology	
In the next 10 years		I am not aware of any political incentive concerning this technology	
In the next 10 years		I am not aware of any political incentive concerning this technology	
In 10 to 20 years	#47	There is political incentive to promote this technology	#53
In the next 10 years		I am not aware of any political incentive concerning this technology	
Longer than 20 years	#48	I am not aware of any political incentive concerning this technology	
In 10 to 20 years		I am not aware of any political incentive concerning this technology	
Longer than 20 years	#49	I am not aware of any political incentive concerning this technology	
In 10 to 20 years	#50	There is political incentive to prevent this technology	#54
In the next 10 years		There is political incentive to promote this technology	
In the next 10 years	#51	I am not aware of any political incentive concerning this technology	#55
In 10 to 20 years	#52	I am not aware of any political incentive concerning this technology	
-0,42		0,42	

#47: MPD thrusters are mainly developed for a manned mission to Mars - this is a political decision and will not occur before 2030

#48: Power demand

#49: The key issue is thermal load on the electrodes. As long as there is no technical solution, these loads will prohibit reaching the requested reliability and lifetime.

#50: I anticipate an evolutionary progression of advanced electric propulsion and power systems for in-space operations, beginning with the advent of 30 kWe propulsion stages over the next 10 years. Then evolving to 100 kWe+ class systems, and finally Mega-Watt class systems; the final being appropriate for MPDs. If MPD technology is tied only to Nuclear power in space, then the event-horizon for its application gets pushed out by decades. If it can be married to ~0.5 MWe-solar power systems, then it is possible that this and other technologies will be developed and fielded within a couple decades.

#51: The technology can well be mastered but power supply and conditioning is key!

#52: First pilot project within 5 to 10 years.

#53: Again - Mars mission/MPD thruster technology is a political decision. Most probably there will be a space race between China/India and the West.

#54: I wouldn't characterize it as political - but the advent of high-power electric in-space propulsion systems reduces the heavy-lift requirements. As such investments in this technology compete directly with resources presently applied to launch vehicles. So future investments in this technology 'threaten' so-to-speak the status quo with respect to space propulsion investment portfolios.

#55: there exist already a large number of electric propulsion technologies; most of them are not used for current missions --> the return of investment is quite low --> decision takers typically look at past performance and could see that this might just be another area to lose money...

Are you aware of any ethical dilemmas or social problems associated with aluminium-celmet for li-ion batteries?	
	Comment
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
There are some minor ethical or social problems concerning this technology	#56
There are some minor ethical or social problems concerning this technology	#57
-0,42	

#56: to use rare metals and/or gases and to expel them to space could bring up the question whether this is the right way to go. This is however also true for the current state of the art technologies

#57: For a significant advantage of MPD compared to existing technologies the source of energy must be nuclear fission or nuclear fusion with all its implications.

5.1.3 Technical questions (performance attributes)

5.1.3.1 Selection of attributes (1st round)

Select or name the 5 most important performance attributes of course orbit control systems.										
Initial specific impulse	Lifetime	Mass (of the system)	Efficiency	Reliability	Scalability	Power drain	Dimension (Volume)	Thrust precision	Throttle ability	Other
Yes	No	Yes	No	No	Yes	No	Yes	No	No	Specific Mass
Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	
Yes	Yes	Yes	Yes	No	Yes	No	No	No	No	
Yes	No	No	Yes	No	Yes	Yes	No	No	Yes	
Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	
Yes	Yes	Yes	Yes	No	No	Yes	No	No	No	
No	Yes	Yes	No	Yes	No	Yes	Yes	No	No	
No	Yes	Yes	Yes	Yes	No	No	No	Yes	No	
No	No	Yes	Yes	No	Yes	Yes	No	No	Yes	
Yes	Yes	Yes	No	Yes	No	Yes	No	No	No	
No	Yes	Yes	Yes	Yes	No	Yes	No	No	No	
No	Yes	Yes	Yes	Yes	No	No	No	Yes	No	
7	9	11	9	7	4	6	2	2	2	

5.1.3.2 Rating (2nd & 3rd round)

Compare the technology to the state of the art on each attribute on a scale from -5 to +5.						
Initial specific impulse	Lifetime	Mass (of the system)	Efficiency	Reliability	Power drain	Comment
3	1	0	-1	1	2	
3	-1	2	1	-1	-1	
4	4	4	4	0	-5	*20
2	0	2	-1	1	-3	*21
3	-2	2	3	-2	-3	
0	2	-1	1	2	0	
3	1	-1	2	-1	-4	*22
2	1	-2	-1	0	-2	
5	-2	4	-1	-1	0	*23
2,78	0,44	1,11	0,78	-0,11	-1,78	

*20: MPD thrusters make sense in the MW range - therefore large power drain and reliability (cathode erosion) problems. But of course the performance it outstanding.

*21: compared to RIT, the specific impulse is comparable but overall thrust levels are much higher for MPD - with the high power output and fast ions inside the thruster erosion effects will be dominating lifetime - high thermal losses indicate reduced electrical efficiency - simple design -->

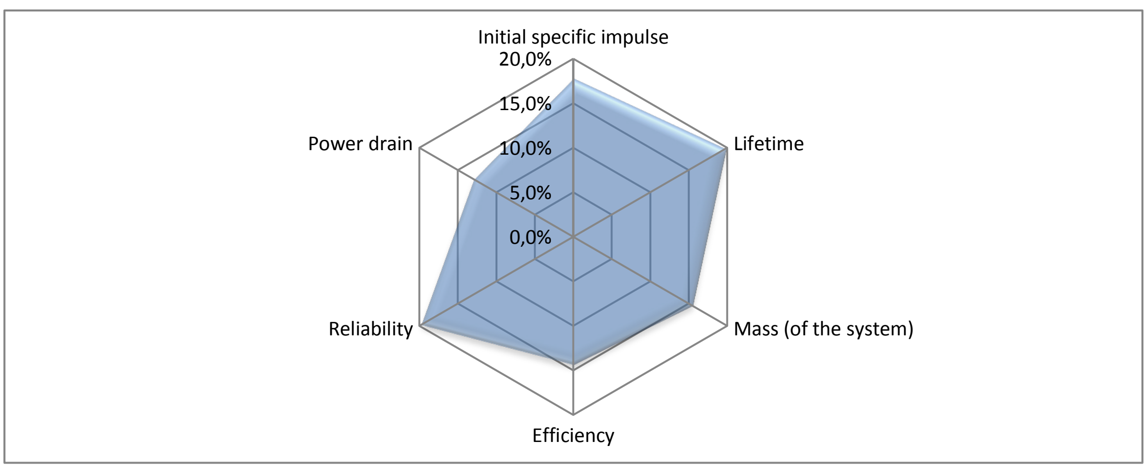
higher reliability - high power thruster will consume significantly more power than state of the art ones

*22: Improved impulse and overall mission efficiency, but power consumption thus mass of total system might be an obstacle.

*23: Results based on the published study: "Evaluation of High-Power Solar Electric Propulsion Using Advanced Ion, Hall, MPD, and PIT Thrusters for Lunar and Mars Cargo Missions," by R. H. Frisbee, Paper No. AIAA-2006-4465. Comparison is made to a SOA chemical rocket for conceptual Lunar and Mars Cargo missions.

5.1.3.3 Weighting (2nd & 3rd round)

Rate the importance of the attributes on a scale of 1 to 5. Rate each attribute independently.					
Initial specific impulse	Lifetime	Mass (of the system)	Efficiency	Reliability	Power drain
3	4	4	2	4	1
2	4	2	2	3	3
5	5	4	3	4	2
4	3	2	4	4	4
4	5	4	4	5	4
5	5	4	3	3	3
4	3	4	2	5	3
3	4	2	4	5	2
5	5	4	4	5	3
17,8%	19,7%	15,4%	14,3%	19,7%	12,9%



5.2 *Alternative solid propellant CL-20*

5.2.1 Technology description

One of the most active areas of solid propellant research is the development of high-energy, minimum-signature propellant using CL-20 (China Lake compound #20), C6H6N6(NO2)6, which has 14% higher energy per mass and 20% higher energy density than HMX. It has higher energy content, higher heat of formation and better oxidizer-to-fuel ratio and detonation properties, but lower impact and friction sensitivity than the conventionally used high-energy propellants and explosives such as HMX or RMX. As an explosive, CL-20 is about 14% stronger than HMX. Its detonation velocity is maximum 10.3 km s-1, so that the substance of the most explosive mixtures of tetranitromethane and toluene is not superior to smaller densities, and lead block compression tests significantly more energy than HMX. CL-20's explosive force is 1.9 and TNT equivalent. The thermal stability as well as the vapor pressure of CL-20 is significantly lower than that of octogen.

The new propellant has been successfully developed and tested in tactical rocket motors. The propellant is non-polluting: acid free, solid particulates free, and lead free. It is also smoke free and has only a faint shock diamond pattern that is visible in the otherwise transparent exhaust. Without the bright flame and dense smoke trail produced by the burning of aluminized propellants, these smokeless propellants all but eliminate the risk of giving away the positions from which the missiles are fired. The new CL-20 propellant is shock-insensitive (hazard class 1.3) as opposed to current HMX smokeless propellants which are highly detonable (hazard class 1.1). CL-20 has numerous military and commercial applications. The trend today is to explore the possibilities that Cl-20 can provide to munitions, propellants, etc. The only limitation of Cl-20 is the cost of its production. CL-20 is also considered a major breakthrough in solid rocket propellant technology but has yet to see widespread use because costs remain high.

5.2.2 Social, Economic and Political (SEP) questions

Compare the new technology (alternative solid propellant CL-20) to the existing dominant technology (state of the art) in respect to:				
Environmental benefits	Potential for spin-off	Production complexity and material cost	Operation complexity and maintenance cost	Comment
New technology is far better	Both are the same	Both are the same	New technology is better	
New technology is better	Both are the same	Old technology is better	Old technology is better	
Both are the same	Both are the same	Both are the same	Both are the same	
New technology is far better	New technology is better	Old technology is far better	New technology is better	
New technology is far better	Both are the same	Old technology is far better	Both are the same	
New technology is far better	New technology is better	Old technology is better	Both are the same	
New technology is better	New technology is better	Both are the same	Old technology is better	
New technology is better	New technology is better	Both are the same	Old technology is better	
New technology is far better	New technology is better	Old technology is better	Old technology is better	
New technology is better	New technology is better	Old technology is better	Both are the same	
New technology is better	New technology is better	Old technology is better	Both are the same	
New technology is better	Both are the same	Old technology is better	Both are the same	
3,33	1,46	-2,08	-0,42	

Will the market (area of application) of solid rocket propellants increase or decrease in the coming years?		Do you know or can you think of any restrictions or regulations that can hinder the entry of alternative solid propellant CL-20 into the space sector?	
	Comment		Comment
The market will stay the same		I am not aware of any restrictions/regulations concerning this technology	
The market will stay the same		I am not aware of any restrictions/regulations concerning this technology	
The market will increase marginally		I am not aware of any restrictions/regulations concerning this technology	
The market will decrease marginally	#58	I am not aware of any restrictions/regulations concerning this technology	
The market will stay the same		There are some minor regulations/restrictions concerning this technology	#59
The market will increase substantially		I am not aware of any restrictions/regulations concerning this technology	
The market will increase marginally		I am not aware of any restrictions/regulations concerning this technology	
The market will stay the same		There are major regulations/restrictions concerning this technology	#60
The market will increase marginally		I am not aware of any restrictions/regulations concerning this technology	
The market will decrease marginally		I am not aware of any restrictions/regulations concerning this technology	
The market will increase marginally		I am not aware of any restrictions/regulations concerning this technology	
The market will stay the same		I am not aware of any restrictions/regulations concerning this technology	
0,83		-0,63	

#58: Military spending as well as space spending is decreasing over the next years.

#59: No toxic exhaust, NOx restriction will be applied.

#60: as it is of military use I expect restrictions, although I have no definite information on the subject

In what timeframe do you anticipate this technology to be ready to be used in a space		Are you aware of any political incentive to promote or prevent the development of alternative solid propellant CL-20 (or their field of application)?	
	Comment		Comment
In the next 10 years		I am not aware of any political incentive concerning this technology	
In the next 10 years		I am not aware of any political incentive concerning this technology	
In the next 10 years		There is political incentive to promote this technology	
In the next 10 years	#61	I am not aware of any political incentive concerning this technology	
In 10 to 20 years		I am not aware of any political incentive concerning this technology	
In the next 10 years		I am not aware of any political incentive concerning this technology	
In the next 10 years		There is political incentive to promote this technology	
In 10 to 20 years		There is political incentive to promote this technology	
In the next 10 years		I am not aware of any political incentive concerning this technology	
In the next 10 years		I am not aware of any political incentive concerning this technology	
In the next 10 years		I am not aware of any political incentive concerning this technology	
In the next 10 years		I am not aware of any political incentive concerning this technology	
0,00		1,25	

#61: It appears already mature enough if used in tactical missiles.

Are you aware of any ethical dilemmas or social problems associated with alternative solid propellant CL-20?	
	Comment
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
There are some minor ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
-0,21	

5.2.3 Technical questions (performance attributes)

5.2.3.1 Selection of attributes (1st round)

Select or name the 5 most important performance attributes of solid rocket propellants.								
Initial specific impulse	Density per mass	Toxicity	Chemical stability / radiation resistance	Burn rate	Exhausts	Temperature sensitivity	Storage stability / Lifetime	Other
No	No	Yes	Yes	No	Yes	Yes	Yes	
Yes	Yes	Yes	Yes	Yes	No	No	No	
Yes	Yes	Yes	No	No	Yes	No	Yes	
Yes	Yes	Yes	No	No	No	Yes	Yes	
Yes	No	Yes	Yes	No	Yes	Yes	No	
Yes	Yes	Yes	No	Yes	No	Yes	No	
Yes	No	Yes	Yes	No	No	Yes	Yes	
No	No	No	Yes	Yes	Yes	No	Yes	
Yes	Yes	Yes	Yes	No	No	No	Yes	
Yes	Yes	No	No	Yes	Yes	No	Yes	
Yes	Yes	No	Yes	Yes	No	No	Yes	
No	Yes	Yes	No	Yes	No	Yes	Yes	
9	8	9	7	6	5	6	9	

5.2.3.2 Rating (2nd & 3rd round)

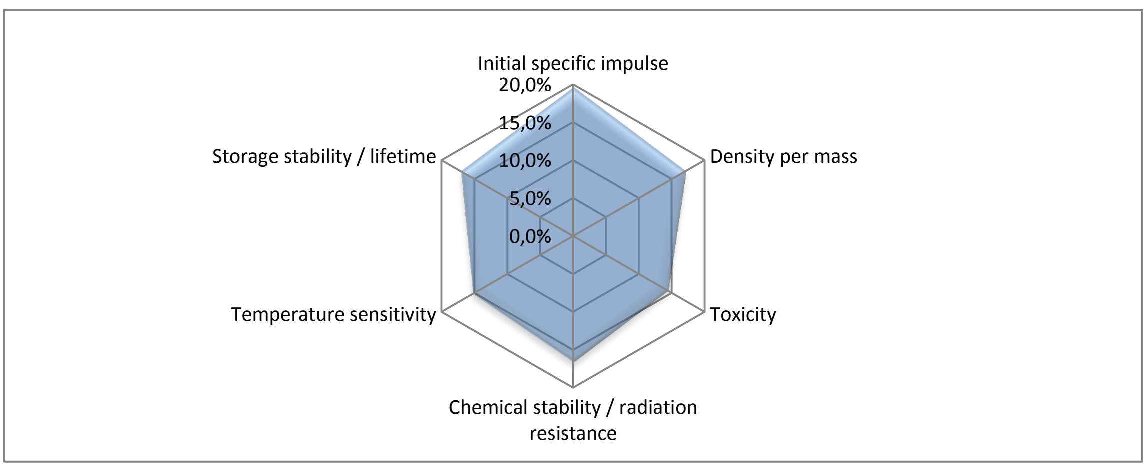
Compare the technology to the state of the art on each attribute on a scale from -5 to +5.						
Initial specific impulse	Density per mass	Toxicity	Chemical stability / radiation resistance	Temperature sensitivity	Storage stability / lifetime	Comment
2	0	0	1	0	0	
2	2	-1	0	0	0	
5	5	4	3	0	0	
1	3	2	3	3	0	
0	0	3	2	2	2	*24
2	2	3	0	2	0	
3	1	2	-2	-1	-1	*25
3	3	2	1	1	0	
1	3	-1	0	-1	0	
2,11	2,11	1,56	0,89	0,67	0,11	

*24: density per mass is specific volume??

*25: Thermal stability could be a problem...

5.2.3.3 **Weighting (2nd & 3rd round)**

Rate the importance of the attributes on a scale of 1 to 5. Rate each attribute independently.					
Initial specific impulse	Density per mass	Toxicity	Chemical stability / radiation resistance	Temperature sensitivity	Storage stability / lifetime
4	3	3	4	4	5
2	2	3	3	2	4
5	5	3	3	3	4
4	3	4	3	2	2
3	1	3	3	3	3
5	4	1	3	3	3
4	5	2	3	4	3
4	4	2	4	3	3
5	5	5	4	4	4
19,6%	17,1%	14,3%	16,6%	15,3%	17,1%



5.3 Micro-electric space propulsion MEP/NanoFET

5.3.1 Technology description

The micro electric space propulsion (MEP) or most commonly called nanoparticle field extraction thruster (NanoFET) is a high-speed electrostatic thruster technology that uses nanoparticles as propellant and utilizes micro- and nano-electromechanical system technologies, known as MEMS and NEMS, to transport, charge, extract, and accelerate the nanoparticles. NanoFET technology provides conductive nanoparticles to be transported to a small liquid-filled reservoir by a micro-fluidic flow transport system. Nanoparticles that come into contact with the bottom conducting plate would become charged and pulled to the liquid surface by the imposed electric field. If the electrostatic force near the surface can cause charged nanoparticles to break through the surface tension, field focusing would quickly accelerate the particles through the surface. Once extracted, the charged nanoparticles would be accelerated by the vacuum electric field and ejected, thus generating thrust. MEMS/NEMS technology is used in nanoparticle field extraction thruster concept where a multi-layer grid establishes the critical electric fields to charge, extract, accelerate, and eject conducting nanoparticles from the surface of an insulating liquid used to transport these particles. These nanoparticles will likely have diameters ranging from 1 nm to over 10 nm.

NanoFET concepts potentially have the performance and integration flexibility to be employed on a diverse set of missions. NanoFETs have a high thrust-to-power ratio for electric propulsion systems. They can adjust specific impulse over a large range from 100s to 10.000s. Today used chemical propulsion systems have a maximum specific impulse of around 500 s. In addition, nanoFETs would be able achieve nearly constant acceleration and show a high efficiency range of over 90% over the entire specific impulse range.

5.3.2 Social, Economic and Political (SEP) questions

Compare the new technology (micro-electric space propulsion MEP/NanoFET) to the existing dominant technology (state of the art) in respect to:				
Environmental benefits	Potential for spin-off	Production complexity and material cost	Operation complexity and maintenance cost	Comment
Both are the same	New technology is better	Old technology is better	Old technology is better	
Both are the same	Both are the same	New technology is better	New technology is better	#62
New technology is better	Both are the same	Old technology is better	Old technology is better	
New technology is better	New technology is better	New technology is better	Old technology is better	
Both are the same	New technology is far better	Old technology is far better	Both are the same	
Both are the same	Both are the same	Old technology is better	Old technology is better	
New technology is far better	Both are the same	Old technology is far better	Old technology is better	
Both are the same	Both are the same	Both are the same	Both are the same	
Both are the same	Both are the same	Both are the same	Both are the same	
Both are the same	Both are the same	Old technology is better	Old technology is better	
Both are the same	Both are the same	Old technology is better	Both are the same	#63
Both are the same	New technology is better	Old technology is better	Old technology is far better	
0,83	1,04	-1,67	-1,46	

#62: Last two answers assume propellant in dry powder form.

#63: compare to FEEPs, µRITs and Colloids new technology could be used as spray deposit technology. The compound of different layers of MEMS elements seem to be complicated in production and maintenance - verification of production process and process control will have to be mastered

Will the market (area of application) of precision orbit control systems increase or decrease in the coming years?		Do you know or can you think of any restrictions or regulations that can hinder the entry of micro-electric space propulsion MEP/NanoFET into the space sector?	
	Comment		Comment
The market will increase marginally		I am not aware of any restrictions/regulations concerning this technology	
The market will increase marginally	#64	I am not aware of any restrictions/regulations concerning this technology	
The market will stay the same		I am not aware of any restrictions/regulations concerning this technology	
The market will increase substantially	#65	I am not aware of any restrictions/regulations concerning this technology	
The market will increase marginally		I am not aware of any restrictions/regulations concerning this technology	
The market will increase marginally		I am not aware of any restrictions/regulations concerning this technology	
The market will increase marginally		I am not aware of any restrictions/regulations concerning this technology	
The market will stay the same		I am not aware of any restrictions/regulations concerning this technology	
The market will stay the same	#66	I am not aware of any restrictions/regulations concerning this technology	
The market will increase marginally		I am not aware of any restrictions/regulations concerning this technology	
The market will increase substantially	#67	I am not aware of any restrictions/regulations concerning this technology	
The market will increase marginally	#68	I am not aware of any restrictions/regulations concerning this technology	
2,29		0,00	

#64: Micro- nano-satellite military and science missions will likely increase in the future based on recent trends.

#65: New missions that require ultraprecise attitude control are coming up in the next years (NGO, etc.)

#66: I find suspect the market for micro-propulsion. I don't see the opportunities for large increases in small satellite applications and associated propulsion systems. Additionally it is extremely challenging to scale these systems down and yield specific masses and system efficiencies that provide large benefits over state-of-art.

#67: precise attitude control is the key for high precise earth observation and fundamental science programs

#68: Interesting for the use in mini and nano satellites.

In what timeframe do you anticipate this technology to be ready to be used in a space		Are you aware of any political incentive to promote or prevent the development of micro-electric space propulsion MEP/NanoFET (or their field of application)?	
	Comment		Comment
In 10 to 20 years		I am not aware of any political incentive concerning this technology	
In 10 to 20 years		I am not aware of any political incentive concerning this technology	
In 10 to 20 years		I am not aware of any political incentive concerning this technology	
In the next 10 years	#69	There is political incentive to promote this technology	#72
In 10 to 20 years		I am not aware of any political incentive concerning this technology	
Longer than 20 years	#70	I am not aware of any political incentive concerning this technology	
In 10 to 20 years		I am not aware of any political incentive concerning this technology	
In the next 10 years		I am not aware of any political incentive concerning this technology	
In the next 10 years		I am not aware of any political incentive concerning this technology	
In 10 to 20 years		I am not aware of any political incentive concerning this technology	
In the next 10 years		I am not aware of any political incentive concerning this technology	
Longer than 20 years	#71	There is political incentive to promote this technology	U.S. military
-0,42		0,83	

#69: Required by a number of missions - but competing with FEEP, micro-RIT, etc.

#70: Very early phase of technology development

#71: As far as I know, only the basic concept is elaborated (TRL 1-2).

#72: New technologies are always good for political promotion

Are you aware of any ethical dilemmas or social problems associated with micro-electric space propulsion MEP/NanoFET?	
	Comment
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
0,00	

5.3.3 Technical questions (performance attributes)

5.3.3.1 Selection of attributes (1st round)

Select or name the 5 most important performance attributes of precision orbit control systems.										
Initial specific impulse	Lifetime	Mass (of the system)	Efficiency	Reliability	Scalability	Power drain	Dimension (Volume)	Thrust precision	Throttle ability	Other
Yes	No	No	No	No	Yes	No	No	Yes	Yes	
Yes	Yes	Yes	No	Yes	No	No	No	Yes	No	
No	Yes	Yes	No	Yes	Yes	No	No	Yes	No	
No	Yes	No	No	No	Yes	Yes	No	Yes	Yes	
Yes	Yes	Yes	Yes	No	No	No	Yes	No	No	
Yes	Yes	Yes	No	Yes	No	Yes	No	No	No	
No	Yes	Yes	Yes	Yes	No	No	Yes	No	No	
No	Yes	Yes	No	Yes	No	No	No	Yes	No	
Yes	Yes	Yes	Yes	No	No	No	No	Yes	No	
Yes	Yes	Yes	Yes	No	No	Yes	No	No	No	
No	No	No	No	Yes	Yes	No	No	Yes	Yes	thrust noise
No	Yes	Yes	Yes	Yes	No	No	No	Yes	No	
6	10	9	5	7	4	3	2	8	3	

5.3.3.2 Rating (2nd & 3rd round)

Compare the technology to the state of the art on each attribute on a scale from -5 to +5.						
Initial specific impulse	Lifetime	Mass (of the system)	Efficiency	Reliability	Thrust precision	Comment
0	0	3	2	1	4	
1	0	2	-1	-1	1	
4	3	1	1	0	5	
-1	2	0	2	3	2	*26
3	0	3	0	0	3	*27
0	1	0	0	0	3	
2	-1	0	2	-1	2	*28
4	2	0	1	2	5	
-1	0	1	2	2	1	*29
1,33	0,78	1,11	1,00	0,67	2,89	

*26: - it is hard to imagine that for typical operation scenarios, the Isp will be higher than for FEEPs - reliability of thruster could be higher than state of the art FEEPs if technology is robust to manufacturing tolerances - no wear out due to impinging ions --y lifetime could be better; lifetime is key as these thruster must operate nearly continuously - due to modularity, thus scalability of thruster, also thrust precision could be well controlled - but is matter of system complexity

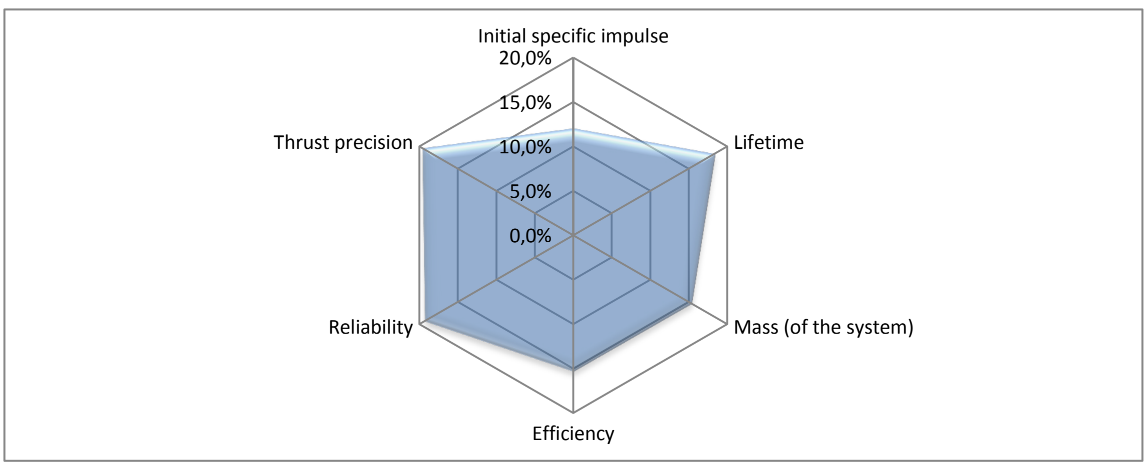
*27: no information on lifetime and reliability available, thus rated neutral.

*28: Good performance and thrust precision, but complexity might have negative impact on reliability and lifetime.

*29: Comparison is made with SOA colloid thrusters and FEEPs.

5.3.3.3 Weighting (2nd & 3rd round)

Rate the importance of the attributes on a scale of 1 to 5. Rate each attribute independently.					
Initial specific impulse	Lifetime	Mass (of the system)	Efficiency	Reliability	Thrust precision
1	4	4	3	4	5
1	3	2	3	4	2
3	5	4	3	5	4
2	5	3	4	4	5
4	5	4	4	5	5
5	5	4	3	3	4
3	4	4	3	5	4
2	2	2	3	3	5
4	4	4	4	5	5
12,1%	18,4%	15,3%	15,3%	19,3%	19,6%



5.4 Aerospike engine

5.4.1 Technology description

The aerospike engine is a type of rocket engine that maintains its aerodynamic efficiency across a wide range of altitudes through the use of an aerospike nozzle.

The aerospike engine is a member of the class of altitude compensating nozzle engines. A vehicle with an aerospike engine uses 25 to 30% less fuel at low altitudes, where most missions have the greatest need for thrust. Aerospike engines have been studied for a number of years and are the baseline engines for many single-stage-to-orbit (SSTO) designs and were also a strong contender for the Space Shuttle Main Engine. No aerospike engine is in commercial production. The best large-scale aerospikes are still only in testing phases.

The basic concept of any engine bell is to efficiently expand 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. Instead of firing the exhaust out of a small hole in the middle of a bell, an aerospike engine avoids this random distribution by firing along the outside edge of a wedge-shaped protrusion, the "spike". The spike forms one side of a virtual bell, with the other side being formed by the outside air - thus the "aerospike". The idea behind the aerospike design is that at low altitude the ambient pressure compresses the wake against the nozzle. The recirculation in the base zone of the wedge can then raise the pressure there to near ambient. Since the pressure on top of the engine is ambient, this means that base gives no overall thrust. It also means that this part of the nozzle doesn't lose thrust by forming a partial vacuum, thus the base part of the nozzle can be ignored at low altitude. As the spacecraft climbs to higher altitudes, the air pressure holding the exhaust against the spike decreases, but the pressure on top of the engine decreases at the same time, so this is not detrimental. Further, although the base pressure drops, the recirculation zone keeps the pressure on the base up to a fraction of 1 bar, a pressure that is not balanced by the near vacuum on top of the engine; this difference in pressure gives extra thrust at altitude, contributing to the altitude compensating effect. This produces an effect like that of a bell that grows larger as air pressure falls, providing altitude compensation.

The disadvantages of aerospikes seem to be extra weight for the spike, and increased cooling requirements due to the extra heated area. Further, the larger cooled area can reduce performance below theoretical levels by reducing the pressure against the nozzle. Also, aerospikes work relatively poorly between Mach 1-3, where the airflow around the vehicle has reduced pressure, and this reduces the thrust.

5.4.2 Social, Economic and Political (SEP) questions

Compare the new technology (aerospike engine) to the existing dominant technology (state of the art) in respect to:				
Environmental benefits	Potential for spin-off	Production complexity and material cost	Operation complexity and maintenance cost	Comment
New technology is better	Both are the same	Both are the same	Both are the same	
Both are the same	Both are the same	Both are the same	Both are the same	
New technology is better	Both are the same	Both are the same	New technology is better	
Both are the same	Both are the same	Old technology is better	Old technology is better	
Both are the same	Both are the same	Old technology is better	New technology is better	
Both are the same	Both are the same	Both are the same	Old technology is better	
Old technology is better	Old technology is better	Old technology is better	Old technology is better	
Both are the same	Both are the same	New technology is better	Both are the same	
Both are the same	Both are the same	Old technology is better	Old technology is better	
Both are the same	Old technology is better	Old technology is better	Old technology is better	
Both are the same	Both are the same	Both are the same	Both are the same	
Both are the same	Both are the same	Both are the same	Old technology is better	#73
0,21	-0,42	-0,83	-0,83	

#73: Robust and reliable design is crucial for operability.

Will the market (area of application) of rocket engines increase or decrease in the coming years?		**Do you know or can you think of any restrictions or regulations that can hinder the entry of aerospike engine into the space sector?**	
	Comment		Comment
The market will increase marginally		I am not aware of any restrictions/regulations concerning this technology	
The market will increase marginally		I am not aware of any restrictions/regulations concerning this technology	
The market will stay the same		I am not aware of any restrictions/regulations concerning this technology	
The market will decrease marginally	#74	I am not aware of any restrictions/regulations concerning this technology	
The market will stay the same		I am not aware of any restrictions/regulations concerning this technology	
The market will increase marginally		I am not aware of any restrictions/regulations concerning this technology	
The market will stay the same		I am not aware of any restrictions/regulations concerning this technology	
The market will stay the same		I am not aware of any restrictions/regulations concerning this technology	
The market will stay the same	#75	I am not aware of any restrictions/regulations concerning this technology	
The market will decrease marginally		I am not aware of any restrictions/regulations concerning this technology	
The market will stay the same		I am not aware of any restrictions/regulations concerning this technology	
The market will increase marginally	#76	I am not aware of any restrictions/regulations concerning this technology	#77
0,42		0,00	

#74: Military and space spendings are going to decrease in the near future.

#75: Great concept in theory; marginal benefits at a systems-level in practice. This is an area of marginal-benefits.

#76: I would expect a market grow of approx. 1.5 to 2% per year.

#77: Technology is comparable to state-of-art technology with respect to restrictions/regulations.

In what timeframe do you anticipate this technology to be ready to be used in a space		Are you aware of any political incentive to promote or prevent the development of aerospike engine (or their field of application)?	
	Comment		Comment
In 10 to 20 years		I am not aware of any political incentive concerning this technology	
In the next 10 years		I am not aware of any political incentive concerning this technology	
In 10 to 20 years		I am not aware of any political incentive concerning this technology	
In 10 to 20 years	#78	There is political incentive to promote this technology	#82
In 10 to 20 years		I am not aware of any political incentive concerning this technology	
In 10 to 20 years		I am not aware of any political incentive concerning this technology	
Longer than 20 years	#79	I am not aware of any political incentive concerning this technology	
In the next 10 years		I am not aware of any political incentive concerning this technology	
In 10 to 20 years		I am not aware of any political incentive concerning this technology	
In 10 to 20 years		I am not aware of any political incentive concerning this technology	
In 10 to 20 years	#80	I am not aware of any political incentive concerning this technology	
In the next 10 years	#81	I am not aware of any political incentive concerning this technology	#83
-0,21		0,42	

#78: To be implemented in a next generation launcher.

#79: There seem to be many technical difficulties.

#80: the business case of re-usable, single vehicles to orbit is no longer existing (tbc); unless this changes, there is no real need for Aerospike Engines???

#81: The technology is mostly understood, but there is no strong will or market need to introduce this technology.

#82: Good to show to other people.

#83: Technology seems to play no important role in political decisions.

Are you aware of any ethical dilemmas or social problems associated with aerospike engine?	
	Comment
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
0,00	

5.4.3 Technical questions (performance attributes)

5.4.3.1 Selection of attributes (1st round)

Select or name the 5 most important performance attributes of rocket engines.													
ISP vacuum	ISP sea level	Mass (of the system)	Throttle ability	Engine cycle	Combustion chamber pressure	Exit pressure	Mass (of the engine)	Nozzle length	Re-ignitability	Ignitability in vacuum	Lifetime	Reusability	Other
No	No	No	No	No	No	Yes	No	No	No	Yes	No	Yes	
No	Yes	No	No	No	Yes	Yes	Yes	Yes	No	No	No	No	
Yes	Yes	Yes	No	No	No	No	No	No	Yes	No	No	Yes	
Yes	Yes	Yes	No	No	Yes	No	Yes	No	No	No	No	No	
No	Yes	Yes	Yes	No	Yes	No	No	Yes	No	No	No	No	
Yes	Yes	Yes	No	No	No	No	Yes	No	Yes	No	No	No	
Yes	Yes	Yes	No	No	No	No	No	No	No	No	Yes	No	Reliability
Yes	No	Yes	Yes	No	No	No	Yes	No	No	No	Yes	No	
Yes	Yes	Yes	Yes	No	No	No	No	No	No	No	No	Yes	
Yes	Yes	Yes	No	No	No	No	No	No	No	No	Yes	Yes	
Yes	No	Yes	No	Yes	No	No	No	No	Yes	No	Yes	No	
Yes	Yes	Yes	No	Yes	Yes	No	No	No	No	No	No	No	
9	9	10	3	2	4	2	4	2	3	1	4	4	

5.4.3.2 Rating (2nd & 3rd round)

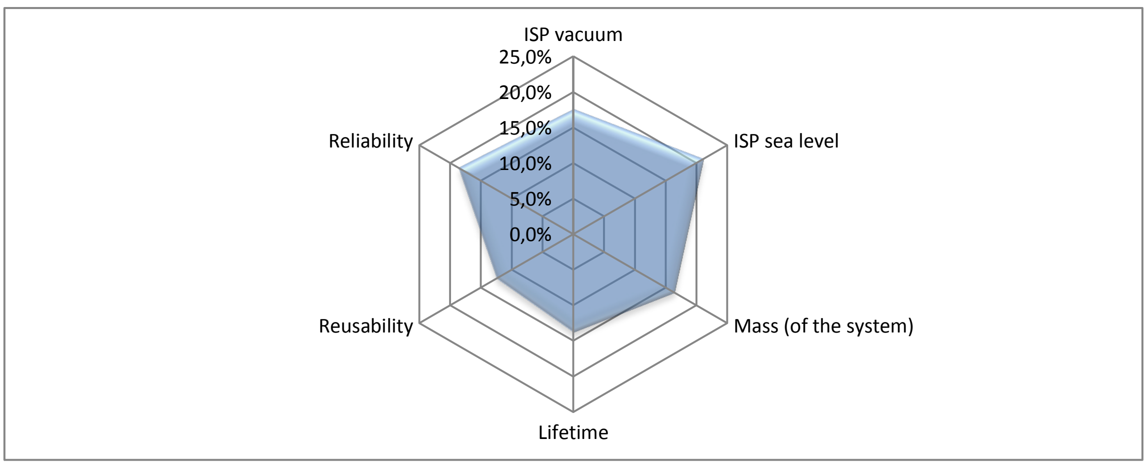
Compare the technology to the state of the art on each attribute on a scale from -5 to +5.						
ISP vacuum	ISP sea level	Mass (of the system)	Lifetime	Reusability	Reliability	Comment
1	4	3	2	0	0	
1	1	-3	-1	0	1	
0	5	5	-1	-1	0	
0	2	-2	0	2	-1	*30
-3	-3	-3	0	0	0	
0	-2	-2	0	0	1	
-1	4	2	0	1	2	*31
0	3	-2	0	-1	0	
2	0	-1	-1	0	0	
0,00	1,56	-0,33	-0,11	0,11	0,33	

*30: - reliability might be reduced due to more complex cooling system

*31: Significantly better Isp@SL, but Isp@vac slightly worse esp. for 2D aerospike. Overall shorter and more compact engine reduces mass and improves reusability due to easier handling and integration. Better reliability due to less critical transient behavior and much smaller side loads.

5.4.3.3 Weighting (2nd & 3rd round)

Rate the importance of the attributes on a scale of 1 to 5. Rate each attribute independently.					
ISP vacuum	ISP sea level	Mass (of the system)	Lifetime	Reusability	Reliability
2	5	4	2	4	4
2	2	3	2	2	3
5	5	3	3	3	3
4	4	2	3	2	4
4	4	4	4	1	4
5	5	4	3	3	3
4	5	4	1	2	5
2	4	2	3	2	3
5	5	4	4	4	5
17,6%	21,1%	16,4%	13,7%	12,5%	18,7%



5.5 *Transpiration cooling*

5.5.1 Technology description

Compared with metals, ceramic shows properties like low specific mass, high temperature stability, damage tolerance, among others. These properties make ceramic highly attractive for use in a thrust chamber environment.

The transpiration/effusion cooling is well known over decades. However, if a porous and permeable metallic wall material based on platelet technology created by sintering processes is used, a critical situation may occur during operation when local overheating melts the porous surface resulting in rapid further damage due to the interrupted local cooling. Today, ceramics with either no melting phase or very high operational temperature limits offer the potential to establish transpiration/effusion cooled concepts that avoid such disadvantages and associated operational risks inherent to metals. Furthermore, the significant pressure loss occurring in the regenerative cooling channels can be avoided or reduced when using a transpiration/effusion cooled system.

The principle of effusion or transpiration cooling consists of two mechanisms. First, coolant comes from the reservoir flows through the porous wall towards the hot gas side wall surface. Passing through the porous structure the coolant absorbs the heat flux conducted into the solid material of the wall. Since the absorbed heat flux is transported backwards into the hot gas with the coolant flow, the porous wall becomes a counter flow heat exchanger. At steady state a thermal equilibrium between the coolant and the solid wall is reached. Second, having passed through the porous wall the coolant forms a film on the hot gas side surface. The coolant film partially absorbs the convective wall heat flux and thus reduces the heat flux conducted into the wall to a certain amount, just like actual film cooling. The heated coolant at the film surface is transported downstream by the momentum of the hot gas flow, continuously replaced with fresh coolant flowing out of the wall.

The need of continued fundamental research in the fields of ceramic materials, cooling strategy, injectors, etc. is required for applying the new ceramic combustion chamber technology in vehicles. Cooling options such as transpiration or effusion cooling have the potential to reduce heat loads on hypersonic vehicles, allowing thinner leading edges and sharper noses. Moreover, the aerodynamic performance of such vehicles can thus be greatly improved.

5.5.2 Social, Economic and Political (SEP) questions

Compare the new technology (transpiration cooling) to the existing dominant technology (state of the art) in respect to:				
Environmental benefits	Potential for spin-off	Production complexity and material cost	Operation complexity and maintenance cost	Comment
New technology is better	New technology is better	Old technology is better	Old technology is better	
Both are the same	Both are the same	Both are the same	Old technology is better	
Both are the same	New technology is better	Both are the same	Both are the same	
Both are the same	New technology is better	Old technology is far better	Old technology is better	
Both are the same	Both are the same	New technology is better	New technology is better	
Both are the same	Both are the same	New technology is better	Both are the same	
New technology is better	New technology is better	Old technology is better	Old technology is far better	
Both are the same	Both are the same	New technology is better	Old technology is better	#84
Both are the same	New technology is far better	Old technology is better	Old technology is far better	#85
Both are the same	New technology is better	Old technology is better	Both are the same	
Both are the same	New technology is better	Both are the same	New technology is better	
Both are the same	New technology is far better	Old technology is better	Both are the same	
0,42	2,08	-0,83	-1,25	

#84: combustion efficiency is be expected to be less as compared to conventional cooling techniques

#85: Complexity and maintenance costs are TBD but a wild-card here.

Will the market (area of application) of cooling systems increase or decrease in the coming years?		Do you know or can you think of any restrictions or regulations that can hinder the entry of transpiration cooling into the space sector?	
	Comment		Comment
The market will increase marginally		I am not aware of any restrictions/regulations concerning this technology	
The market will increase marginally		I am not aware of any restrictions/regulations concerning this technology	
The market will increase marginally		I am not aware of any restrictions/regulations concerning this technology	
The market will decrease marginally	#86	I am not aware of any restrictions/regulations concerning this technology	
The market will increase marginally		I am not aware of any restrictions/regulations concerning this technology	
The market will increase marginally		I am not aware of any restrictions/regulations concerning this technology	
The market will increase marginally		I am not aware of any restrictions/regulations concerning this technology	
The market will stay the same		I am not aware of any restrictions/regulations concerning this technology	
The market will increase marginally		I am not aware of any restrictions/regulations concerning this technology	
The market will decrease marginally		I am not aware of any restrictions/regulations concerning this technology	
The market will increase substantially	#87	I am not aware of any restrictions/regulations concerning this technology	
The market will increase substantially	#88	I am not aware of any restrictions/regulations concerning this technology	
1,88		0,00	

#86: Military and space spendings are going to decrease in the near future.

#87: higher temperatures are needed to increase performance of thermal engines at the same time system complexity must be kept low and less system losses are expected --> better performance with simpler system

#88: High pressure and high temperature applications for increased performance.

In what timeframe do you anticipate this technology to be ready to be used in a space		Are you aware of any political incentive to promote or prevent the development of transpiration cooling (or their field of application)?	
	Comment		Comment
In the next 10 years		I am not aware of any political incentive concerning this technology	
In the next 10 years		I am not aware of any political incentive concerning this technology	
In the next 10 years		I am not aware of any political incentive concerning this technology	
In the next 10 years	#89	There is political incentive to promote this technology	
In the next 10 years		I am not aware of any political incentive concerning this technology	
In 10 to 20 years		I am not aware of any political incentive concerning this technology	
In the next 10 years		I am not aware of any political incentive concerning this technology	
Longer than 20 years	#90	I am not aware of any political incentive concerning this technology	
In 10 to 20 years		I am not aware of any political incentive concerning this technology	
In the next 10 years		I am not aware of any political incentive concerning this technology	
In the next 10 years		There is political incentive to promote this technology	#92
In 10 to 20 years	#91	There is political incentive to promote this technology	#93
-0,21		1,25	

#89: Technology is already advanced and it could be slowly implemented.

#90: regen cooling superior, no replacement be effusion cooling expected

#91: The way I see it, transpiration cooling has currently a TRL of 4-6 depending on CMC used. I do not expect transpiration cooling being applied in the next generation rocket engines, but the generation thereafter.

#92: this technology is good to open a field for development for a lot of space/rocket engineers

#93: Related EU and DFG funding is known to me...

Are you aware of any ethical dilemmas or social problems associated with transpiration cooling?	
	Comment
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
I am not aware of any ethical or social problems concerning this technology	
0,00	

5.5.3 Technical questions (performance attributes)

5.5.3.1 Selection of attributes (1st round)

Select or name the 5 most important performance attributes of cooling systems.						
Mass	Performance loss (of engine)	System limitations	Range of applicability (e.g. to small engines)	Max cooling capability (depending on mass flow)	Efficiency	Other
Yes	No	Yes	Yes	Yes	Yes	
Yes	Yes	Yes	No	Yes	Yes	
Yes	Yes	Yes	No	Yes	Yes	
Yes	Yes	No	Yes	Yes	Yes	
Yes	No	Yes	No	Yes	Yes	material strength
Yes	Yes	No	No	Yes	Yes	Reliability
Yes	Yes	Yes	No	Yes	Yes	
Yes	Yes	Yes	Yes	Yes	No	
Yes	Yes	Yes	No	Yes	Yes	
Yes	Yes	No	Yes	Yes	Yes	
Yes	Yes	Yes	Yes	Yes	No	
Yes	Yes	Yes	No	Yes	Yes	
12	10	9	5	12	10	

5.5.3.2 Rating (2nd & 3rd round)

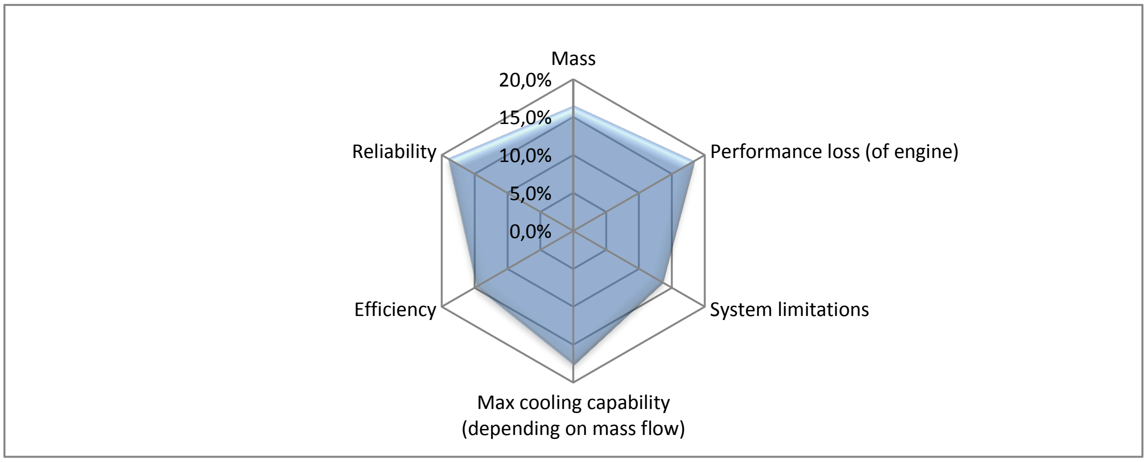
Compare the technology to the state of the art on each attribute on a scale from -5 to +5.						
Mass	Performance loss (of engine)	System limitations	Max cooling capability (depending on mass flow)	Efficiency	Reliability	Comment
2	2	1	1	0	0	
1	1	0	2	1	0	
3	3	1	4	2	0	
-1	0	2	3	2	2	
2	-2	0	-2	-2	-2	*32
1	1	1	2	1	0	
3	1	-1	2	2	-2	*33
2	2	2	2	2	1	
1	1	0	-1	1	0	
1,56	1,00	0,67	1,44	1,00	-0,11	

*32: Comparison is rather not possible, as there is no validated performance behavior on the state of the art of the technology. Potential characteristics depend strongly on assumptions. Critical items are not addressed in the list above, e.g. combustion behavior at low temperature fuel injection.

*33: Lightweight solution with good cooling capability but reduced performance penalties. Limitations (e.g. delta p, impact of water vapor and free oxygen) has to be reduced. Reliability esp. in series manufacturing to be proven.

5.5.3.3 Weighting (2nd & 3rd round)

Rate the importance of the attributes on a scale of 1 to 5. Rate each attribute independently.					
Mass	Performance loss (of engine)	System limitations	Max cooling capability (depending on mass flow)	Efficiency	Reliability
5	3	2	4	2	4
2	3	3	3	2	3
5	5	3	4	3	3
2	4	3	5	4	4
2	4	1	1	4	5
4	4	4	5	3	3
5	4	2	4	3	5
3	3	4	4	3	4
4	5	4	4	4	5
16,5%	18,4%	13,5%	17,6%	14,8%	19,2%


Mass
20,0%
15,0%
10,0%
5,0%
0,0%
Performance loss (of engine)
System limitations
Max cooling capability
(depending on mass flow)
Efficiency
Reliability

Annex 3: AHP results

Overall factors

Social	1	Technical	9	Technical factors are much more important than social factors because they determine if a DST is better than the state of the art. Weight: 7
Social	1	Economic	5	Economic factors are more important than Social factors because a decrease in any form of costs makes the technology more interesting for development. Weight: 5
Social	1	Political	4	Since political factors are highly important within the space sector, it has a moderate increased performance over social factors. Weight: 4
Technical	4	Economic	1	Technical factors are more important than economic factors because a DST might also be a high-end encroachment. Weight: 5
Technical	6	Political	1	Technical factors are strongly more important than political factors because they determine the value of a technology. Weight: 6
Economic	3	Political	1	Economic factors are slightly more important than Political factors because an important factor for political decisions are economic factors Weight: 3

	Comparison Matrix									Weighting
	Social	Technical	Economic	Political	Normalization				Σ Row	w
Social	1	0,111	0,200	0,250	0,053	0,073	0,036	0,024	0,186	**0,046**
Technical	9,000	1	4,000	6,000	0,474	0,655	0,723	0,585	2,436	**0,609**
Economic	5,000	0,250	1	3,000	0,263	0,164	0,181	0,293	0,900	**0,225**
Political	4,000	0,167	0,333	1	0,211	0,109	0,060	0,098	0,477	**0,119**
Σ Column	19,000	1,528	5,533	10,250	1,000	1,000	1,000	1,000	4,000	**1,000**

	Mean Matrix				Σ Row	λ		
	0,046	0,068	0,045	0,030	0,189	4,067	n =	4
	0,418	0,609	0,900	0,716	2,644	4,340	λ_max =	4,186
	0,232	0,152	0,225	0,358	0,968	4,300		
	0,186	0,102	0,075	0,119	0,482	4,037	CI =	6,20E-02

n	1	2	3	4	5	6	7	8	9	10
R	0,00	0,00	0,52	0,89	1,11	1,23	1,35	1,40	1,45	1,49

CR =	0,070	**Boundary Value =**	0,1
Evaluation consistent?	Yes		

Social

SQ1	1	SQ2	2	Usually people rate the environment as less imporant then ethical dilemmas. Weight: 2

	Comparison Matrix					Weighting
	SQ1	SQ2	Normalization		Σ Row	w
SQ1	1	0,500	0,333	0,333	0,667	**0,333**
SQ2	2,000	1	0,667	0,667	1,333	**0,667**
Σ Column	3,000	1,500	1,000	1,000	2,000	**1,000**

	Mean Matrix		Σ Row	λ
	0,333	0,333	0,667	2,000
	0,667	0,667	1,333	2,000

n =	2
λ_max =	2,000
CI =	0,00E+00

n	1	2	3	4	5	6	7	8	9	10
R	0,00	0,00	0,52	0,89	1,11	1,23	1,35	1,40	1,45	1,49

CR =	0,000	**Boundary Value =**	0,1

Evaluation consistent?	Yes

Economic

EQ1	1	EQ2	3	Spin-off potential is very helpfull but production complexity and material cost have a high impact on the performance of a technology. Weight: 3
EQ1	1	EQ3	3	Spin-off potential is very important but operation complexity and maintenance cost have a high impact on the performance of a technology. Weight: 3
EQ1	1	EQ4	7	An increase in market size will mean a higher potential of a concept to become disruptive as the development cost can be shared. Weight: 7
EQ2	1	EQ3	1	Both questions are cost factors and have an equal importance Weight: 1
EQ2	1	EQ4	4	Cost factors factors are not as important as market size factors Weight: 4
EQ3	1	EQ4	4	Cost factors factors are not as important as market size factors Weight: 4

	Comparison Matrix									Weighting
	EQ1	EQ2	EQ3	EQ4	Normalization				Σ Row	w
EQ1	1	0,333	0,333	0,143	0,071	0,053	0,053	0,087	0,264	**0,066**
EQ2	3,000	1	1,000	0,250	0,214	0,158	0,158	0,152	0,682	**0,171**
EQ3	3,000	1,000	1	0,250	0,214	0,158	0,158	0,152	0,682	**0,171**
EQ4	7,000	4,000	4,000	1	0,500	0,632	0,632	0,609	2,372	**0,593**
Σ Column	14,000	6,333	6,333	1,643	1,000	1,000	1,000	1,000	4,000	**1,000**

	Mean Matrix				Σ Row	λ		
	0,066	0,057	0,057	0,085	0,264	4,010	n =	4
	0,198	0,171	0,171	0,148	0,687	4,028	λ_max =	4,037
	0,198	0,171	0,171	0,148	0,687	4,028		
	0,461	0,682	0,682	0,593	2,419	4,079	CI =	1,22E-02

n	1	2	3	4	5	6	7	8	9	10
R	0,00	0,00	0,52	0,89	1,11	1,23	1,35	1,40	1,45	1,49

CR =	0,014	**Boundary Value =**	0,1
Evaluation consistent?	Yes		

Political

PQ1	5	PQ2	1	Restriction and regulations are a lot stronger indicator than a possible timeframe Weight: 5
PQ1	1	PQ3	1	Restriction and regulation are of an equal importance then a political incentive Weight: 1
PQ2	1	PQ3	5	A political incentive is a lot stronger indicator than a possible timeframe Weight: 5

	Comparison Matrix			Normalization			Σ Row	Weighting
	PQ1	PQ2	PQ3					w
PQ1	1	5,000	1,000	0,455	0,455	0,455	1,364	**0,455**
PQ2	0,200	1	0,200	0,091	0,091	0,091	0,273	**0,091**
PQ3	1,000	5,000	1	0,455	0,455	0,455	1,364	**0,455**
Σ Column	2,200	11,000	2,200	1,000	1,000	1,000	3,000	**1,000**

	Mean Matrix			Σ Row	λ
	0,455	0,455	0,455	1,364	3,000
	0,091	0,091	0,091	0,273	3,000
	0,455	0,455	0,455	1,364	3,000

n =	3
λ_max =	3,000
CI =	0,00E+00

n	1	2	3	4	5	6	7	8	9	10
R	0,00	0,00	0,52	0,89	1,11	1,23	1,35	1,40	1,45	1,49

CR =	0,000	**Boundary Value =**	0,1

Evaluation consistent?	Yes

Annex 4: Concept Scoring

Materials

	Cathodic arc application of amorp. boron coatings			Ceramic composite structures			Highly Conductive Graphite epoxy			Nanocrystaline diamond aerogel			Metallic microlattice		
Criteria	Average weight	Average Score	Weighted Score	Average weight	Average Score	Weighted Score	Average weight	Average Score	Weighted Score	Average weight	Average Score	Weighted Score	Average weight	Average Score	Weighted Score
SOCIAL	**4,5%**			**4,5%**			**4,5%**			**4,5%**			**4,5%**		
SQ1	33,3%	0,8	0,01	33,3%	1,3	0,02	33,3%	-0,4	-0,01	33,3%	0,4	0,01	33,3%	2,9	0,04
SQ2	66,7%	0,0	0,00	66,7%	0,0	0,00	66,7%	-0,4	-0,01	66,7%	-0,4	-0,01	66,7%	0,0	0,00
TECHNICAL	**61,9%**			**61,9%**			**61,9%**			**61,9%**			**61,9%**		
A1	15,7%	1,0	0,10	17,3%	2,8	0,30	16,8%	2,6	0,27	13,1%	0,4	0,03	13,2%	1,2	0,10
A2	15,0%	0,8	0,07	15,3%	1,0	0,09	18,9%	2,4	0,28	22,4%	2,6	0,36	17,4%	2,4	0,26
A3	15,1%	2,0	0,19	21,5%	3,4	0,45	12,3%	-0,4	-0,03	14,5%	0,0	0,00	18,9%	2,6	0,30
A4	21,8%	1,6	0,22	14,3%	1,0	0,09	15,2%	0,6	0,06	23,3%	3,0	0,43	9,9%	0,4	0,02
A5	17,5%	1,0	0,11	14,4%	0,4	0,04	15,4%	-0,2	-0,02	14,6%	-0,2	-0,02	20,6%	2,8	0,36
A6	14,9%	2,2	0,20	17,0%	0,6	0,06	21,3%	2,4	0,32	12,0%	0,8	0,06	20,1%	3,0	0,37
ECONOMIC	**22,4%**			**22,4%**			**22,4%**			**22,4%**			**22,4%**		
EQ1	6,6%	2,1	0,03	6,6%	2,5	0,04	6,6%	3,8	0,06	6,6%	2,9	0,04	6,6%	3,8	0,06
EQ2	17,1%	0,0	0,00	17,1%	-0,4	-0,02	17,1%	0,4	0,02	17,1%	0,0	0,00	17,1%	-0,4	-0,02
EQ3	17,1%	-1,3	-0,05	17,1%	0,8	0,03	17,1%	-0,8	-0,03	17,1%	0,0	0,00	17,1%	1,3	0,05
EQ4	59,3%	4,6	0,61	59,3%	2,9	0,39	59,3%	3,8	0,50	59,3%	3,8	0,50	59,3%	3,3	0,44
POLITICAL	**11,2%**			**11,2%**			**11,2%**			**11,2%**			**11,2%**		
PQ1	45,5%	0,0	0,00	45,5%	-0,4	-0,02	45,5%	-1,3	-0,06	45,5%	-0,4	-0,02	45,5%	0,0	0,00
PQ2	9,1%	0,0	0,00	9,1%	0,0	0,00	9,1%	0,0	0,00	9,1%	0,0	0,00	9,1%	0,0	0,00
PQ3	45,5%	0,0	0,00	45,5%	0,8	0,04	45,5%	1,7	0,08	45,5%	0,0	0,00	45,5%	0,8	0,04
Total Score			1,49			1,52			1,42			1,38			2,03
Rank		3			2			4			5			1	

Data Handling

Criteria	Chalcogenide-based reconfigurable memory			Holographic data storage			Multicarrier signals		
	Average weight	Average Score	Weighted Score	Average weight	Average Score	Weighted Score	Average weight	Average Score	Weighted Score
SOCIAL	**4,5%**			**4,5%**			**4,5%**		
SQ1	33,3%	0,5	0,01	33,3%	0,0	0,00	33,3%	1,0	0,01
SQ2	66,7%	0,0	0,00	66,7%	0,0	0,00	66,7%	0,0	0,00
TECHNICAL	**61,9%**			**61,9%**			**61,9%**		
A1	19,3%	0,3	0,04	14,3%	3,0	0,26	20,1%	0,0	0,00
A2	21,2%	2,0	0,26	19,6%	1,0	0,12	16,4%	1,7	0,17
A3	16,9%	1,3	0,14	16,1%	1,3	0,13	19,7%	1,0	0,12
A4	18,9%	2,7	0,31	15,9%	2,0	0,20	12,7%	-0,3	-0,03
A5	10,9%	0,3	0,02	14,4%	-2,7	-0,24	16,4%	0,3	0,03
A6	12,9%	2,0	0,16	19,6%	0,7	0,08	14,7%	-0,3	-0,03
ECONOMIC	**22,4%**			**22,4%**			**22,4%**		
EQ1	6,6%	2,0	0,03	6,6%	3,0	0,04	6,6%	2,0	0,03
EQ2	17,1%	-1,5	-0,06	17,1%	-1,0	-0,04	17,1%	-0,5	-0,02
EQ3	17,1%	0,0	0,00	17,1%	-0,5	-0,02	17,1%	2,0	0,08
EQ4	59,3%	3,0	0,40	59,3%	3,0	0,40	59,3%	4,5	0,60
POLITICAL	**11,2%**			**11,2%**			**11,2%**		
PQ1	45,5%	-0,5	-0,03	45,5%	-1,0	-0,05	45,5%	-1,5	-0,08
PQ2	9,1%	0,0	0,00	9,1%	0,0	0,00	9,1%	0,0	0,00
PQ3	45,5%	0,0	0,00	45,5%	0,0	0,00	45,5%	0,0	0,00
Total Score			1,29			0,89			0,89
Rank		1			2			3	

Power

Criteria	Aluminium-celmet for li-ion batteries			Bacterial nanowire			Silicon nanowire lithium ion-battery			Super/ultra capacitors			Quantum-dot solar cells			UltraFlex solar panels		
	Average weight	Average Score	Weighted Score	Average weight	Average Score	Weighted Score	Average weight	Average Score	Weighted Score	Average weight	Average Score	Weighted Score	Average weight	Average Score	Weighted Score	Average weight	Average Score	Weighted Score
SOCIAL	**4,5%**			**4,5%**			**4,5%**			**4,5%**			**4,5%**			**4,5%**		
SQ1	33,3%	2,1	0,03	33,3%	0,7	0,01	33,3%	1,8	0,03	33,3%	2,1	0,03	33,3%	0,7	0,01	33,3%	1,1	0,02
SQ2	66,7%	0,0	0,00	66,7%	-0,4	-0,01	66,7%	-0,4	-0,01	66,7%	0,0	0,00	66,7%	-0,7	-0,02	66,7%	0,0	0,00
TECHNICAL	**61,9%**			**61,9%**			**61,9%**			**61,9%**			**61,9%**			**61,9%**		
A1	20,6%	3,0	0,38	21,3%	1,9	0,25	19,0%	2,4	0,29	15,6%	2,0	0,19	18,8%	0,6	0,07	18,4%	2,7	0,31
A2	20,4%	1,4	0,18	18,2%	-0,1	-0,02	17,0%	2,0	0,21	14,7%	1,4	0,13	17,6%	-0,6	-0,06	17,1%	2,6	0,27
A3	16,2%	1,4	0,14	16,5%	1,3	0,13	18,3%	2,3	0,26	18,0%	2,9	0,32	14,4%	-0,4	-0,04	15,7%	1,7	0,17
A4	15,4%	0,7	0,07	15,7%	-0,3	-0,03	15,3%	0,7	0,07	17,0%	2,0	0,21	18,6%	0,4	0,05	16,1%	0,3	0,03
A5	13,5%	-0,1	-0,01	13,7%	-1,3	-0,11	14,8%	2,0	0,18	18,2%	3,6	0,40	14,3%	0,3	0,03	14,9%	0,4	0,04
A6	13,9%	-0,1	-0,01	14,4%	-1,1	-0,10	15,6%	1,1	0,11	16,6%	3,4	0,35	16,3%	0,7	0,07	17,8%	2,7	0,30
ECONOMIC	**22,4%**			**22,4%**			**22,4%**			**22,4%**			**22,4%**			**22,4%**		
EQ1	6,6%	2,9	0,04	6,6%	2,5	0,04	6,6%	3,6	0,05	6,6%	3,2	0,05	6,6%	1,8	0,03	6,6%	1,8	0,03
EQ2	17,1%	-0,7	-0,03	17,1%	-0,4	-0,01	17,1%	0,0	0,00	17,1%	-0,4	-0,01	17,1%	-0,4	-0,01	17,1%	-1,1	-0,04
EQ3	17,1%	0,7	0,03	17,1%	0,0	0,00	17,1%	0,0	0,00	17,1%	1,1	0,04	17,1%	-0,4	-0,01	17,1%	0,4	0,01
EQ4	59,3%	2,5	0,33	59,3%	2,5	0,33	59,3%	4,3	0,57	59,3%	4,3	0,57	59,3%	3,9	0,52	59,3%	3,6	0,47
POLITICAL	**11,2%**			**11,2%**			**11,2%**			**11,2%**			**11,2%**			**11,2%**		
PQ1	45,5%	-0,4	-0,02	45,5%	-0,4	-0,02	45,5%	-0,4	-0,02	45,5%	-0,7	-0,04	45,5%	-0,7	-0,04	45,5%	0,0	0,00
PQ2	9,1%	0,0	0,00	9,1%	-1,1	-0,01	9,1%	-0,4	0,00	9,1%	-0,4	0,00	9,1%	-0,4	0,00	9,1%	0,0	0,00
PQ3	45,5%	2,1	0,11	45,5%	-0,7	-0,04	45,5%	1,4	0,07	45,5%	1,4	0,07	45,5%	2,9	0,15	45,5%	1,4	0,07
Total Score			1,25			0,41			1,81			2,31			0,73			1,68
Rank	4			6			2			1			5			3		

Propulsion

Criteria	Magnetoplasmadynamic thruster			Alternative solid propellant CL-20			Micro-electric space propulsion MEP/NanoFET			Aerospike engine			Transpiration cooling		
	Average weight	Average Score	Weighted Score	Average weight	Average Score	Weighted Score	Average weight	Average Score	Weighted Score	Average weight	Average Score	Weighted Score	Average weight	Average Score	Weighted Score
SOCIAL	**4,5%**			**4,5%**			**4,5%**			**4,5%**			**4,5%**		
SQ1	33,3%	1,0	0,02	33,3%	3,3	0,05	33,3%	0,8	0,01	33,3%	0,2	0,00	33,3%	0,4	0,01
SQ2	66,7%	-0,4	-0,01	66,7%	-0,2	-0,01	66,7%	0,0	0,00	66,7%	0,0	0,00	66,7%	0,0	0,00
TECHNICAL	**61,9%**			**61,9%**			**61,9%**			**61,9%**			**61,9%**		
A1	17,8%	2,8	0,31	19,6%	2,1	0,26	12,1%	1,3	0,10	17,6%	0,0	0,00	16,5%	1,6	0,16
A2	19,7%	0,4	0,05	17,1%	2,1	0,22	18,4%	0,8	0,09	21,1%	1,6	0,20	18,4%	1,0	0,11
A3	15,4%	1,1	0,11	14,3%	1,6	0,14	15,3%	1,1	0,11	16,4%	-0,3	-0,03	13,5%	0,7	0,06
A4	14,3%	0,8	0,07	16,6%	0,9	0,09	15,3%	1,0	0,09	13,7%	-0,1	-0,01	17,6%	1,4	0,16
A5	19,7%	-0,1	-0,01	15,3%	0,7	0,06	19,3%	0,7	0,08	12,5%	0,1	0,01	14,8%	1,0	0,09
A6	12,9%	-1,8	-0,14	17,1%	0,1	0,01	19,6%	2,9	0,35	18,7%	0,3	0,04	19,2%	-0,1	-0,01
ECONOMIC	**22,4%**			**22,4%**			**22,4%**			**22,4%**			**22,4%**		
EQ1	6,6%	1,3	0,02	6,6%	1,5	0,02	6,6%	1,0	0,02	6,6%	-0,4	-0,01	6,6%	2,1	0,03
EQ2	17,1%	-0,8	-0,03	17,1%	-2,1	-0,08	17,1%	-1,7	-0,06	17,1%	-0,8	-0,03	17,1%	-0,8	-0,03
EQ3	17,1%	-0,8	-0,03	17,1%	-0,4	-0,02	17,1%	-1,5	-0,06	17,1%	-0,8	-0,03	17,1%	-1,3	-0,05
EQ4	59,3%	1,9	0,25	59,3%	0,8	0,11	59,3%	2,3	0,30	59,3%	0,4	0,06	59,3%	1,9	0,25
POLITICAL	**11,2%**			**11,2%**			**11,2%**			**11,2%**			**11,2%**		
PQ1	45,5%	-0,6	-0,03	45,5%	-0,6	-0,03	45,5%	0,0	0,00	45,5%	0,0	0,00	45,5%	0,0	0,00
PQ2	9,1%	-0,4	0,00	9,1%	0,0	0,00	9,1%	-0,4	0,00	9,1%	-0,2	0,00	9,1%	-0,2	0,00
PQ3	45,5%	0,4	0,02	45,5%	1,3	0,06	45,5%	0,8	0,04	45,5%	0,4	0,02	45,5%	1,3	0,06
Total Score			0,57			0,90			1,07			0,21			0,83
Rank		4			2			1			5			3	