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Future power supply in mobile radar systems

Master of Science Thesis in the Master Degree Program, Management and Economics of Innovation

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Executive Summary

The present technique used to supply power to Saab EDS' mobile radar systems in the Giraffe AMB and Arthur are diesel driven Piston Engine generators. It is a proven power supplying system characterized by mainly minor incremental improvements in the last 30 years. This indicates that the present system has reached its peaking point of performance, while still many issues regarding the present system remain for Saab EDS' customers. Furthermore, the increasing environmental awareness among society may require more environmentally friendly technologies in the defense industry in the coming future. Therefore, the purpose of this thesis is to investigate the industry of power supply and the linking industries in order to understand what developments are under way, what future technologies one can expect and their future potential to replace the present system.

In order to evaluate the explored energy technologies a set of criterions have been developed. These criterions are based on the data collected from the initial interviews done with respondents from Saab EDS together with the framework Techno-Economic Analysis developed by Lindmark (2006). Adding to this, interviews have been done with respondents both from the business world and academia in order to gather as much information and insight as possible regarding available energy technologies. Thereafter, the most interesting energy technologies with regards to Saab EDS' and their customers' demand were selected. Finally, these energy technologies were subjected for a Scenario Analysis where four possible future scenarios were developed.

The case study of Saab EDS has shown that the current power supply is difficult to replace. There are, however, four prominent energy technologies that could serve as possible replacement in the coming future, more precisely; Fuel Cell, Gas Turbine, Lithium-Ion Battery and Super Capacitor. Moreover, the future development based on the two identified critical uncertainties, oil price and investments in new energy technologies, will certainly be important to follow. Depending on the future unfolding, the selected energy technologies will have different development. Consequently, it will be important for Saab EDS to follow these critical uncertainties by following the identified signals. It will also be of interest for Saab EDS to engage in in-depth projects for the four prominent energy technologies as further studies.

Preface

This project has been an inspiring master thesis with the possibility to apply the knowledge, such as many interesting models and frameworks, learnt at Chalmers University of Technology to a real company assignment. This would not have been possible without the help received. We would like to address the importance of all the support we have received throughout our work with this project. We are very grateful for all the people that have been involved in the process of writing our master thesis. All opinions have been appreciated and taken into consideration.

First and foremost, we would like to thank our supervisors; Sven Olsson at Saab Group in Gothenburg for his support and guidance within the Saab EDS network, and Christian Sandström at Chalmers University of Technology for all his invaluable feedback and help in order to set us in the right direction. Furthermore, we would like to thank everyone from OEGPE at Saab EDS in Gothenburg who have been very helpful and contributed to the final result. We would also like to thank everyone at Chalmers University of Technology who has helped us with interviews and information regarding people and firms to interview throughout the thesis.

We are very grateful that we have been given this chance to work with Saab Group and we sincerely hope our results will be as valuable to them as this experience have been to us.

Gothenburg, June 2011

Alexander Johansson

Ken Leong

List of Abbreviation

APU	Auxiliary Power Unit
Arthur	Artillery Hunting Radar
BRICS	Brazil, Russia, India, China and South Africa
CEP	Clean Energy Partnership
DME	Dimethyl Ether
EDLC	Electrochemical Double-Layer Capacitors
FCEV	Fuel Cell Electrical Vehicle
FMV	Försvarets Materialverk (Swedish Defence Material Administration)
Giraffe AMB	Giraffe Agile Multi Beam
IEA	International Energy Agency
IPHE	International Partnership for Hydrogen and Fuel Cell in the Economy
IR	Infrared
Li-ion	Lithium-Ion
MoU	Memorandum of Understanding
MTBF	Mean Time Between Failure
OPEC	Organization of the Petroleum Exporting Countries
PE	Piston Engine
PEM	Proton Exchange Membrane
Saab EDS	Saab Electronic Defence Systems. The investigated business segment of Saab Group.
SECA	Solid State Energy Conversion Alliance
SOFC	Solid Oxide Fuel Cell
TEA	Techno-Economic Analysis
UAV	Unmanned Aerial Vechicle

Table of Contents

1 Introduction

This chapter will present the background to the research. It consist of a short presentation of Saab Electronic Defence Systems, followed by the current circumstances leading up to the purpose of the research. In addition, this chapter will include the research questions, delimitations and the outline of the report.

1.1 Background

Saab Electronic Defence Systems (Saab EDS) is a merger between the former Saab Avitronics and Saab Microwave Systems, and it is a department within Saab Group. They supply solutions for surveillance, threat detection and location, platform and force protection, as well as avionics. In the product portfolio there are airborne, ground-based and naval mobile radar systems with different microwave and antenna technology. Within avionics Saab EDS offer systems of Control & Monitoring, Recording, Mission computing etc. Moreover, sales in 2009 were 4.6 BSEK and in 2009 they had 2601 employees. (Saab Group, 2010)

The current product portfolio, concerning ground-based radar system, in Saab EDS includes Arthur (Figure 1) and Giraffe AMB (Figure 2). The Arthur is a weapon locator system that detects and locates enemy fire of rockets, artillery and mortars (RAM). It can warn for incoming RAM and calculate its point of origin and point of impact and the time of impact. It has a capacity of localizing up to 100 targets per minute. The Arthur system can be placed on a truck or a tracked vehicle. It has a range of 20, 30, 40 and 60 km. The Arthur system is widely used by customers around the world. Examples of customers are Czech Republic, Denmark, Greece, Norway, Spain, Sweden and UK. (Saab Group, 2010)

Figure 1 Arthur (Saab Group)

The Giraffe AMB is used for rapid air surveillance and air defense. A 3D surveillance radar system intended for short and medium-range air defense systems. With its 12 meter antenna mast and software, it can target search and track 200 air targets simultaneously. Also, its software system can carefully calculate what kind of air target it is tracking. The tracking ranges are 40, 120 and 180 km depending on the model of the Giraffe AMB. It is equipped with a similar 360 degree weapon locator of RAM as Arthur. The customers of Giraffe AMB are for example the Swedish army, the British army and the France Air Force among others. (Saab Group, 2010)

Figure 2 Giraffe AMB (Saab Group)

The present technique used to supply power to the mobile radar systems in the Giraffe AMB and Arthur are either diesel driven synchronous or asynchronous generators which are integrated in to the current platform[1]. Using diesel in a combustion engine is a well established method to convert chemical energy to (via kinetic energy) electricity for these kinds of systems. It is a system which has not had any radical improvements the last 30 years. There have only been minor incremental improvements, e.g. engine efficiencies which rendered in more power and less fuel consumption, and mainly been pushed by the vehicle industry[2]. Other things that have changed during this period have been initialized after complaints from the customers. Complaints regarding for example the reliability of the product, the continuous need for supply of oil and fuel, the sound level and the heat emitted from the engine etc[3]. However, these changes have also been small, e.g. moving oil containers or cables etc. One can then start to assume that the technology in the present system has reached its peaking point of performance. Thus Saab EDS and the customers will still be struggling with the limits of today's system with years to come unless something radical is changed.

Furthermore, Saab EDS does not need to follow all the environmental directives (i.e. they have certain exceptions) set up by the government due to its type of market. Nevertheless, the increasing environmental awareness among the society suggests that Saab EDS cannot neglect the possibility of changes in these exceptions[4]. Thus, they must look into other more environmental friendly technologies. This together with the saturated performance improvements of the present technique mentioned above leads to the purpose of this Master Thesis.

[1] Sven Olsson, System Designer Electrical Installations, Saab Group, Interview 2011-01-24

[2] Jan-Olov Winnberg, Senior Product Manager, Saab Group, Interview 2011-01-27

[3] Lennart Steen, Senior Product Manager, Saab Group, Interview 2011-01-31

[4] Jan, Rydén, Senior Specialist System Mechanics, Saab Group, Interview 2011-01-18

1.2 Purpose

The purpose is to investigate the industry of power supply and the linking industries in order to understand what developments are under way, what future technologies one can expect and their future potential to replace the present system. Rendering from this the following research questions has been developed:

- What energy technologies will be of most interest for Saab EDS?
- Which of the identified energy technologies will prevail in the coming 15-20 years?
- How should Saab EDS cope with the possible changes in energy technologies in the coming 15-20 years?

1.3 Delimitations

This report will address each identified technology separately. Therefore discussions on how a replacing complete system (with more than one identified technology) will only be held in a broad perspective in the different future scenarios. In other words, there will not be a deeper analysis of the technical possibilities (e.g. the fit with the complete radar system) or the total cost of such a system.

Since the power supply system is not something developed by Saab EDS, but bought from a supplier, the report will focus on describing the power supply system in order to understand what type of future technologies Saab EDS are interested in. Therefore the competitive technological positions for different competitors do not need to be addressed. Also Saab EDS's in-house knowledge about the future technologies will not need to be evaluated or taken into consideration during the investigation.

Given that the power supply is a part of the complete mobile radar system, the analysis on possible future scenarios will only concern how the power supply could develop. In other words, nothing will be discussed regarding the possibility of a changing use or need of the complete mobile radar system. This means that for example if another product (such as satellites) develops to such an extent that it will replace the application of the mobile radar system today and with it change the use of the mobile radar system.

1.4 Outline/Structure

The outline of the report is basically based on three major parts, chapter 3, 4 and 5. It was decided to use the research questions to steer the report, and thus theoretical frameworks, empirical data and analyses is divided among each chapter accordingly.

Chapter 3 is about developing a set of criterions which are necessary in order to answer research question one. The structure of this chapter is first a theoretical framework used to analyze the technical system of today, its performance and utility parameters. It continues with an empirical part of the requirements of Saab EDS and their customers. Lastly, there is the analysis which renders in the final development of the criterions. With the criterions the right type of technology could be investigated and evaluated which chapter 4 will address.

In chapter 4, research question one is answered. That chapter's structure starts with the empirical data gathered and an evaluation of each technology. Thereafter, there is selection phase of the most interesting energy technology. Chapter 5 answers research question two and three. The chapter is about looking into the future of these selected technologies. The Scenario Planning framework is used where each energy technology's future is analyzed and investigated (with a set of theoretical frameworks on the dynamics of technological transformation).

The structure in chapter 5 starts with the theoretical frameworks used. It continues with empirical macro data on trends and driving factors within the power supply industry. Then the larger section of the chapter, the Analysis, is about choosing the critical uncertainties (from the driving factors, used for building the scenarios), developing the scenarios and investigating how each technology will evolve in each scenario. Furthermore, there is a part where implications for Saab EDS are discussed. Finally chapter 6 will describe the conclusions and recommendations of the master thesis.

2 Methodology

This chapter will present the methodology that was employed in the study. It includes research design, research method and data analysis. Thereafter, the validity and reliability of the study is assessed.

2.1 Research Design

Before conducting a research it is important to choose a research design. According to Bryman and Bell (2007), a research design enables the study to employ a framework on how to collect and analys data. It also reflects what the research prioritizes in terms of a range of dimensions of the research process. As the main focus in this research was to investigate the trends and future technologies in power supplies for Saab EDS' mobile radar system, the case study design was chosen. Bryman and Bell (2007) describes the case study as a detailed and intensive analysis of a single case and that the design is concerned with the complexity of the particular nature of the case in question. By choosing the case study design specific and in-depth description of Saab EDS and their customers, the identified energy technologies and the anticipated problems were able to be presented. Moreover, the subject for the study was Saab EDS, more specifically their products Arthur and Giraffe AMB.

Throughout the study theory has been matched with empirical data and the case in an iterative process. In other words, systematic combining has been done. This suggests, in accordance to Dubois and Gadde (2002), that an abductive approach has been adopted which can be seen as a mixture of deductive and inductive approaches.

2.2 Research Methods

The collection of data in this study consists of both primary and secondary data. The collection of primary data has been done in an iterative process and was the main source of data. In the early stages it was done to grasp the situation of Saab EDS and to understand the customers as well as served as a first indication of what energy technologies were available. In the later phases in the study primary data has been collected to complement the initial findings as well as to provide thicker descriptions. In order to collect this primary data, qualitative interviews have been done with employees from different levels from the areas that are relevant for the study. These areas include the ones that are connected to the mobile radar systems' Arthur and Giraffe AMB. Interviews have also been done with relevant persons outside Saab EDS in order to collect data regarding interesting energy technologies that could possibly replace the current one as well as future development in the 50kW power supply industry. The main reason for choosing interviews has been due to the nature of the study. As many of the information regarding Saab EDS and their customers as well as the energy technologies and their future development are complex and subjective the interviews enabled more elaboration during the answers. In contrast, if questionnaires had been used it would have been much more difficult to capture the vital information, since it do not enable the respondents to give a thorough explanation. Some questions were also difficult for the respondents to grasp immediately and needed further explanation which would have been difficult to do with other research methods. Moreover, the secondary data consisted of internal documents from Saab EDS and other publications. These data were complements to the gathered primary data and enabled thicker descriptions. In addition, multiple sources of evidence provide better triangulation (Yin, 1994).

The interviews conducted throughout the study were of semi-structured and structured nature. The early phase interviews with personal from Saab EDS where semi-structured in order to get an overview and understanding of Saab EDS and their power supplying system. The interview template can be found in *Appendix B.* Interviews were also done with personal from Saab EDS that had closed contact with their customers in order to get further input and understanding. The reason for not interviewing the customers directly was because of confidential basis. These interviews resulted in a overview of how the power supplies in Saab EDS ' radar system worked and what its advantages as well as disadvantages were. Also, the customers' preferences were understood from these interviews. Furthermore, these initial studies were then used to form relevant question for the next semi-structured interviews.

After the first initial semi-structured interviews information regarding what the vital information regarding power supplies where understood. From this information a new semi-structured interview was constructed (See *Appendix C*). These interviews were done in order to probe relevant person from different companies, organizations and academia for interesting energy technologies. This resulted in information regarding how the energy technologies worked, what it is used for today and how its future development will look like. The selection of the sample was done by snowball sampling. In accordance with Bryman and Bell (2007), snowball sampling is useful when conducting a qualitative research such as case studies. This was helpful since relevant persons were more easily approached with referral from colleagues and/or friends.

The structured interviews were intended to get complementary information regarding the identified technologies. In other words, the structured interviews consisted of questions regarding the values in different comparable measures between the energy technologies such as size, weight, efficiency, etc. The main reason for not constructing a survey for this phase was that a structured interview enabled additional underlying information to be explored. The structured interview guide can be found in *Appendix D.* In addition, these interviews were conducted with the same respondents in the earlier phases as well as some additional sources that were recommended from the earlier respondents.

In the semi-structured interviews, both researchers were present and took notes. The interviews were also digitally recorded if allowed from the respondents. As mentioned, respondents were mainly chosen based on recommendation from the previous respondents. Though, the initial respondents were recommended from the supervisor at Saab EDS and professors at Chalmers University of Technology. The structured interviews were conducted to get further information regarding specific values in each energy technologies. These interviews were conducted mainly via telephone, which were most convenient. This was suitable since the main reason with the structured interviews was to get the hard fact and not the respondents' expressions or such. The interviewing process was stopped when enough information was gathered in the sense that further interviews did not result in much additional value. A more detailed list of the profiles of the interviewed persons can be found in *Appendix A.*

In combination with interviews, relevant documents have been used as a secondary source of data. Public documents from government research and other organization, such as Vätgas Sverige, have been used. Different relevant trade and business magazines have been explored as well in order to gain a better understanding of the trends and future technologies. These secondary sources functioned as complementarities to the interviews and provided further triangulation, i.e. using more sources of data. In addition, the quality of the documents is important to assess and Scott (1990) suggest four criterions; Authenticity, Credibility, Representativeness. Basically, these criterions refer to the quality of the data, such as its genuineness and clearness, which were considered during the collection.

2.3 Data Analysis

The main source of data in the research has been the interviews. The data gathered from the interviews were mainly based on words. This needs processing which in itself is a form of analysis according to Miles and Huberman (1994). Adding to this, within-case analysis has been employed in order to further analyze the data. Miles and Huberman (1994) describe within-case analysis as when data is compared with theory. Since theory has been used to compare with the collected data and the fact that the thesis is a single case study, the techniques from the within-case analysis were suitable.

There are three main steps in qualitative data analysis, more precisely data reduction, data display and conclusion/verification (Miles and Huberman, 1994). Before final analysis can be drawn the data collected regarding the identified energy technologies as well as future developments in the 50kW power supply industry were organized and sharpen which was achieved through data reduction analysis. By comparing the gathered data from both the interviews and documents, data have been reduced and sorted out based on its importance. The data have been further reduced by comparison with the theoretical frameworks employed in this thesis. Thereafter, the reduced data have been displayed in an organized and compressed way in order for it to be more easily analyzed. Finally, the identified energy technologies and its future development have been compared to the theoretical framework in order to draw conclusions and give recommendations to Saab EDS.

2.4 Validity and Reliability

In order to conduct a convincing and credible case study certain criterions must be fulfilled. According to Yin (2003) and Siggelkow (2007) there are four requirements, construct validity, internal validity, external validity and reliability. Moreover, Bryman and Bell (2007) describe validity as the integrity of the conclusions generated in the research and reliability is concerned with the consistency of the measures.

2.4.1 Construct Validity

Construct validity is sometime referred as measurement validity and assess how well the ideas or theories are translated into measures (Scandura and Williams, 2000; Bryman and Bell, 2007). In order to explore which energy technology that will be of most interest for Saab EDS as well as to understand how the future development will plan out for these energy technologies different theories have been used in the thesis. However, it is difficult to include every possible theory and ensure the best measure is used, but a set of precautions have been employed to increase the construct validity of the thesis.

First, a literature review has been conducted to understand how different dimensions can be used to evaluate technologies. In addition, the early phase semi-structured interviews aimed to identify the important aspect for Saab EDS and their customers in terms of the power supply in the mobile radar systems. These steps have resulted in a clear definition of the important aspects as well as how to evaluate the energy technologies. Close collaboration has also been kept with Saab EDS throughout the project, including interim presentations of the thesis, in order to avoid misunderstanding.

In accordance with Cepeda and Martin (2005), the thesis' general methods have been presented and described in detail in this chapter to increase the construct validity. Also, several data sources have been used to ensure triangulation. Interviews have been conducted with different personal from Saab EDS to compare the data. Same idea was employed when interviews were done to collect information regarding different energy technologies, in order to ensure triangulation. Adding to this, secondary data have been used to further ensure triangulation. Consequently, the construct validity of the study is believed to be high.

2.4.2 Internal Validity

There are two main parts in this study. One that investigates energy technologies and another that explore the future for the identified energy technologies. In terms of the first part internal validity, which concerns the causality, has been important to consider when exploring how the different technologies' performance parameters connects to Saab EDS' and their customers' demands. The main way to make sure that this has been done has been to interview and gather data from as many respondents as possible. However, the problem with getting interviews with Saab EDS' customers may be an issue in terms of finding out what they prefer. Personal from Saab EDS that have close contact with customers have been interviewed instead to gather this data.

In terms of the second part of the study, internal validity has been important in how the future will plan put. Again, many sources have been used in order to provide a substantial description in order to ensure internal validity. Naturally, more sources could have been used to increase the sample size, but due to the time frame as well as lack of available sources, especially for certain energy technologies, the amount of possible interviews have been limited. On the other hand, many of the interviewees' answers given about the future development became similar, thus indicating that a larger sample size may not provide much additional information. Consequently, the internal validity of the study is believed to be medium.

2.4.3 External Validity

According to Cepede and Martin (2005) external validity is concerned with the generalization of a study. As this study mainly concerned Saab EDS, especially in the first part, it is difficult to confirm. The evaluation of the energy technologies where based on Saab EDS' and their customers specific demands. However, in the second part of the study external validity may be more applicable. Bryman and Bell (2007) explains that external validity can be ensured through a thorough description of the object and concept of study. This has been done by providing a comprehensive literature review as well as interviews with relevant subjects.

2.4.4 Reliability

The aspect of reliability refers to the consistency of the measures, i.e. to what extent the research of a study are repeatable (Bryman and Bell, 2007; Cepede and Marin, 2005). In order to make sure that a systematic investigation has been conducted a thorough description of the overall study has been showed in this chapter and more specific steps are explained in each chapter. Also, the research question developed in this study has been constructed as clear as possible to further increase the reliability. Consequently, this study can certainly be replicable by others. However, in chapter 5 when the critical uncertainties were identified the prioritization of the influencing factors was based on interpretation from various interviews and documentations. The scenarios would certainly been different if different critical uncertainties were chosen. In other words, the prioritization of the influencing factors was in a sense subjective which could be difficult to replicate in this study.

3 Developing Criterions in order to Screen the Technologies

In order to answer research questions one a set of criterions were developed. This chapter will be divided into theoretical framework, empirical findings and lastly an analysis which renders in the criterions.

The analysis starts with describing the application of the technology today and what its function is in order to understand what type of technologies to investigate. Then it continues with a discussion regarding the performance parameters of the current system, and link a set of developed utility parameters in order to understand the relation with the customers. Finally, the criterions is developed and presented. The criterions are then used in later chapters to prioritize and screen the identified energy technologies.

3.1 Theoretical Framework

An important thing when analyzing a new technology or innovation for economic growth and industrial competitiveness is to find the relations and interaction between technical and economic variables. A good way to map this is to use an approach of a Techno-Economic Analysis (TEA) (Lindmark, 2006). According to Lindmark (2006) TEA can be conducted at several levels of analysis; industry level, company level, technological level and product level. However it should be emphasized that there is no unique way of conducting a TEA, several analytical approaches and intermediate variables should therefore be used (Granstrand, O. 2000). Since the variables and their interactions also vary through time, using several analytical approaches becomes even more important.

The concept of innovation might need a clarification. Innovation is a concept that does not have one sole definition. Rogers (1998) defines innovation as a new or substantially improved; good or service that has been commercialized or process used for commercial production of good or service.

Figure 3 describes a set of variables and concepts that should be included in the analysis according to Lindmark (2006). This describes the technological variables on the one hand and the economic variables on the other. The utilities (for a present or future customer) in the middle link the two together. The analysis in the TEA does not need to be followed in a sequential order from left to right in the Figure. For example, the underlying technologies of a product or service might first be understood after the desired function of a certain need is discovered for a customer.

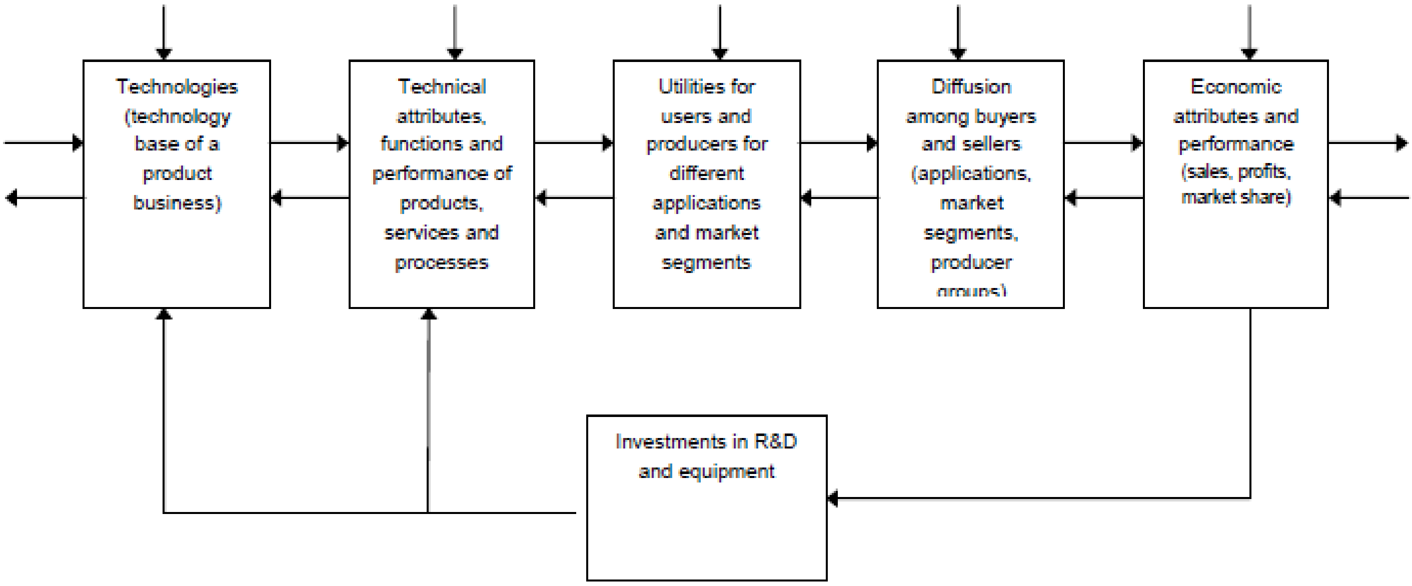

Figure 3: Framework TEA on product level, source: based on Grandstrand (1994) and Granstrand (1999)

3.1.1 Technical System Analysis

A product, service or production process can be viewed as a technical system, a set of interconnected components and their relations which each has its own functions and properties. The function is of particular importance to define since it defines what purpose the product, service or production process fulfills (Lindmark, 2006). Functions should be broad enough so the notion of substitutes can be incorporated in the analysis and narrow enough so the function does not involve too many product categories. A battery for example has the function to store energy, while a generator has the function to convert mechanical energy to electrical energy. A TEA should always at some point breakdown the list of functions performed by the technical system according to Lindmark (2006).

In order to fulfill any utility for the user or consumer the products and services most often need interaction with other products and services in a user system. For instance, a computer without any software does not have much value. Thus most technical systems are applied in a larger context where they interact with other technical systems or users. These can be referred to as complementary sub-systems. These systems of use are referred to as applications. If there are functions in the application that can come from other sources that fulfill the same function, i.e. other technical systems, they are referred to as substitutes. Although it is important that the referred substitute indeed covers the same function otherwise it is not a substitute. For example, artificial sweetener cannot explicitly be referred to as a substitute for sugar since sugar both gives a sweet taste and provides energy. The artificial sweetener only gives a sweet taste. (Lindmark, 2006)

To extend the concept of complementary sub-systems, concepts like complementary assets, complementary products and complementary technologies can be added. Depending on the form of a product or service these concepts might need to be addressed. Complementary assets according to Teece (2003) are essential for a commercialization of an innovation. It requires know-how in a combination with other capabilities or assets. These are for example marketing, after sales support etc. Complementary products are those that increase, or even enable in some cases, the sale of a source product (Gorchels, 2003), for example what would a bluray player be without any bluray films or a razor without razor blades? When there is a co-evolution of multiple technologies it has historically been shown that for some technologies the break through is depended on the development of other complementary technologies (Geels, 2005). The evolution of the steamship in 1860 was according to Geels (2005) depended on three radically improved technical trajectories of the screw propulsion, iron hulls and compound engine. Another more modern example is the Internet. The diffusion and development of the Internet would probably not have been possible without the major development of the computer.

3.1.2 Technical Performance and Cost Analysis

It is of great importance in a TEA to identify the technical properties, or the technical performance parameters. Most often they are related to a how well a function in a technical system of a product or service is performed, for instance how fast, what quality i.e. how often does it need service etc. They can also be related to the attributes of the product, like size, weight, form etc. in other words measure of the delimitations of the functions. (Lindmark, 2006)

It is essential that the performance parameters are chosen with an economical relevance to the customer. A parameter can change over time since it is often compared with the other parameters. They might have different importance within different values i.e. the marginal utility of the technical improvements decreases. For example the resolution improvements of a camera might reach its utility peak for many customers within certain values, maybe 5-8 pixels, anything more than that is just a waste of R&D. Instead new dimensions can be added to the functionality of the technical systems when this happens. Following the example above, after reaching 8 pixels the next thing could be to add a functionality of zoom, both an optic and digital, to add further value for the customer. It can also be that when a technology makes a radical switch of context, new technical parameters can evolve or become more important than others. This was evident when the mobile telephone became portable and was taken from its context of a vehicle and into the hand of the customer. (Lindmark, 2006)

Also, the technical performance parameters might have a relation between them that might involve an engineering trade-off. For instance, size and weight be negatively correlated to operating time if we use the camera example above. This trade-off is also connected to the cost parameters of each. Each function within the product or the products service/process is related to some sort of cost. These are as dynamic as the other technical performance parameters due to economies of scale (unit cost reduction as volume increases) and changes in complementary systems and substitutes. Lindmark (2006) gives an example of some generic parameters that can be found in many technical systems: size, complexity, efficiency, capacity, density, noise, weight, accuracy etc.

3.1.3 Utility Analysis

Utility is, as mentioned before, the linkage between technology and economics. Lindmark (2006) defines utility as the pleasure or satisfaction derived from an individual from consuming a good or a service. The economic theory tells us that the consumers' goal, when they perform any economic activity, is utility. It is when the consumer chooses between available goods or services when they reveal what their utility are (Lindmark, 2006). When it comes to translating consumer insight into concrete products and services, managers using traditional market research techniques can unintentionally make tremendous interpretative leaps that do not always work in their favor (Wunker, 2005). A consumer is looking for a job to get done and it is the functional, emotional and social dimensions of the consumers that constitute the circumstances on what they need to get done and what good or service there is that can be hired to do that job. In other words if the consumers' circumstance is understood the maximum utility can be achieved. This jobs-to-be-done perspective is the only way to accurately see what products and services the customers will value in the future, and why (Christensen & Raynor, 2003).

According to Bannock et al. (1991) and the neo-classical economic theory the consumer are utility-maximizers, and that the marginal utility of a good or service decreases with each added similar good or service. For example the fifth banana you eat does not give the same utility as the first one. Thus the specific commodity with the highest marginal utility for a consumer is the one he or she will buy.

There are many ways to break down the utilities into different dimensions, Kim and Mauborgne (2000) give one example. They discuss six utility levers as well as six stages of the buyer experience cycle. The six utility levers are customer productivity, simplicity, convenience, risk, fun and image. The stages are divided in purchase, delivery, use, supplements, maintenance and the disposal of the product. Now, in each of the stages or levers an innovation or new technology can improve the utility of the product or service (Lindmark, 2006).

Kim and Mauborgne (2000) might be more designed with an emphasis on the consumer market but according to Shilling (2010) it can be adapted to industrial products or different aspects of buyer utility. The levers can for example be broken down in another matter. Customer productivity can instead be broken down to sub-levers such as speed, efficiency etc.

Utility is according to Schilling (2010) also depended on complementary goods availability and installed base value. Complementary goods have already been defined above and its importance has been stressed. Installed base value refers to the number of users with which the user can interact, for example when an individual buys a telephone, the value or its utility is depended on how many that already has a telephone i.e. the installed base. These concepts have a major effect on the difficulties for new innovations to displace the incumbent ones Schilling (2010).

3.1.4 Synthesizing Utility with Technical Parameters

In TEA there is a need to link the utility with the technical parameters and this is a difficult task since the buyers do not know their own utility (Lindmark 2006). Whatever the method used it is important to grasp the relations where the marginal utility increases to improvements in the technical performance. Sometimes the attribute of a product, service or technology can be hard for the customer to assess. Thus the technical performance parameters may need to be translated into utility dimensions i.e. a reduction in weight might imply an increase in portability for the customer, thus portability as a performance parameter might be easier to be assessed by the customer. This can be connected to what Ulwick (2002) discusses. He raises the issue with listening solely to the customers. Since the customers have a limited frame of reference, they only know what they have experienced and may not be familiar with emergent technologies. Thus, the customers should not be asked for solutions but rather what they want in terms of outcome.

Moreover, the performance parameters can then be categorized as either order winners or order qualifiers. Those are the criteria required in the marketplace. Order qualifiers need to be in place in order for the customer to even consider the product/service. Order winners, become the things that differentiate the product and make the customer want to buy that particular product instead of something else, i.e. win the bid or purchase of the customer. Thus they need to be better than the competitors' order winners in terms of the customers' utility. Qualifiers need to be as good as the competitors'. The order winners and qualifiers are market- and time specific, which means that they differ across markets and changes through time. When a firm's perception of order winners and qualifiers matches the customer's perception of the same, there exists a "fit" between the two perspectives which will cause a positive sales performance. (Hill, 2000)

Conjoint analysis is one of many techniques that are used when a decision maker is facing multiple options that simultaneously vary across two or more attributes (Lindmark, 2006). Conjoint analysis is a trade-off measurement technique for analyzing customer preferences. It is also a method for simulating how consumers might respond to changes in existing products/services or the introduction of a new product into the competitive array (Thurnston, 1991).

When designing a conjoint analysis, one of the first steps is to find the set of attributes and levels that sufficiently characterizes one competitive domain. Thus the conjoint analysis tries to make use of orthogonal arrays to reduce the number of attributes and with it reduce the stimulus for different things with the consumer (Lindmark 2006). Lindmark (2006) suggests that good sources to find these attributes are in-depth interviews with consumers and internal corporate expertise. Consumers can then be asked to rank the attributes with its levels.

3.1.5 Technological System

Technology serves as the base of a product business according to Figure 3. It can be defined as a body of knowledge that combined with appropriate means has the objective to transform material, carriers of energy information from less desirable form to more desirable forms (Ayres, 1994). This body of knowledge deals with engineering and applied science. Improvements of technology are linked to improvements of the technical systems. Technology is often linked to natural sciences and their methodologies and has a rather high codifiability through use of formulas in a formal language (mathematics, chemistry etc.), models, patent, document, text books (Granstrand, 1999).

The identification of technologies must be accepted to be imprecise and changing over time. Useful input for the identification is its relation to functions, sub-functions and the specific processes for the production and development of technical systems. Relations to various other systems like, the educational system (i.e. different department, research area etc) and the patent classification system are also useful input. Note that technologies include not only knowledge on how products function and how to design them but also the process of producing them, thus both product technologies and process technologies might be important to consider. (Lindmark, 2006)

3.1.6 Economic Value of Technologies

The economic value of the technology is an assessment of the economic potential or properties of the technologies. Lindmark (2006) refers it as the "importance" of the technologies and discuss several key factors that affect this. They have impact on both the producers' side and adopters' side; the producer cost and performance characteristics (through these on customer utility or customer costs) respectively.

One key factor is *applicability*, i.e. the range of applications. If the technology is generic there is a greater possibility for it to reap economies of scale and scope due to a larger range of applications. For example, advances in battery technology used in mobile phones may be speeded up due to the use of similar battery technology in laptops and electric vehicles. *Substitutability* refers to the degree to which other competing technologies could realize the same function. One of the most important determinants when facing multiple competing technologies is the performance/cost ratio and these might differ depending on the demands on the performance and the customer's willingness to pay. Cost is not only the purchasing cost for the customer but also the cost of usage and learning etc (Arthur, 1988). Another key factor is the *Potential for improvements*. This is closely related to the effort and the S-curves (will be explained in chapter 5) and the R&D investments needed to achieve a certain performance. *Diffusion* on the market describes the market growth potential for the products based on the technology thus affecting both the producer side (scale opportunities etc) and adopter side (increasing returns to adoption Arthur, 1998). The cost of *Imitability* should be rather high so frog-leaping (their knowledge base) competitors can be more easily avoided. The last key factor is *tradability*, meaning that if trade of the technology is easy then there is less value for leveraging competitive advantage.

In many types of analysis there is also a need to assess and monitor the technological activity. In general these activities are important events, trends, threats and opportunities. One useful way to systemize this is to use an approach of input and output activity. Input indicators can be R&D investments in different companies, educational statistics etc. and output indicators which can be found in four different carriers of technology, namely products, people, publications and patents. (Granstrand, 1999)

3.2 Empirical Findings

In this section the description of Saab EDS' requirements and their customers' requirements will be presented. These data were gathered from various interviews within Saab EDS.

3.2.1 Description of Saab EDS' requirements

The present power supplying system, a Piston Engine generator, (read more about it in chapter 4) used in the mobile radar system is not something Saab EDS develops. It is bought from one supplier, Harrington Generators International Ltd, which Saab EDS later builds into the complete product (Arthur or Giraffe AMB, the radar system with the mobility in forms of a truck or other). The radar system and the customers of Saab EDS have several demands on the engine generator. The system demands that the generator can supply it with a power output of 30 kW. In a future of 10 years, the system is expected to demand a power output of around 40-50 kW. Besides this, the system requires a constant frequency of 50 Hz[5].

The dimension of the engine generator is important for Saab EDS. It has to fit in the mobile radar system. It used to be customized to fit each customer's need but it is now a standardized product which means that Saab EDS has had to make adjustment on the rest of the product in order to make it fit. Today the generator has dimensions of around 1,5 *1*0,5 m^3. The weight is also an issue. It cannot weigh more than around 900 kg. If the weight becomes more than that, it will cause problems with logistics from the supplier to Saab EDS, which in turn would bring further costs to Saab EDS. Costs are of course always an issue for every product in every industry, nevertheless for Saab EDS[6].

The last demand of Saab EDS is that the product they use for the power supply needs to be ubiquitous. It should especially been tried in extreme conditions, i.e. high and low environmental temperatures, high and low loads etc. since customers are situated all over the world[7].

3.2.2 Description of Saab EDS Customers' requirements

According to Steen[6] (2011) the customers do not care, specifically, much about the power generation in the mobile radar systems. Instead, they want a radar system that is working with as few problems as possible. This means that there are some criteria, for the power generation, which is more important than other in order for the radar system to work as satisfactory as possible in terms of the customers' perspective. Those parameters are the following:

The radar system must be operational for as long time as possible. Thus, the *reliability* of the system is an essential factor. One way to measure this is the mean time between failures, where higher value means better reliability. In addition, the radar system is usually on-

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[5] Sven Olsson System Designer Electrical Installation, Saab Group, Interview 2011-01-25

[6] Lennart Steen, Senior Product Manager, Saab Group, Interview 2011-01-27

[7] Mattias Skogsberg, Manager Power and Cabling, Saab Group, Interview 2011-01-27

stream 23 hours in a day which put even more strain on the reliability of the power generator[8].

Another factor that the customer value is how much service the power generation needs. The power generator is only a small part of a larger system and not the primary concern for the customers. Consequently, the aspect of *maintenance* of the power generator in the radar system must be kept as minimal as possible since the customer focus is on the entire radar system. For instance, the frequent need of oil changes is a huge obstacle for the customers since they must shut down the system and thus incur more down time[6].

The customer wants the entire radar system to be as light and compact as possible. This means that the *weight* and *size* of the power generation are important factor. By being lighter and smaller the radar system can more easily be transported as well as fitted in to the radar system especially when more functions are implemented into the radar system. Also, the fuel consumption may be reduced as well if weight can be reduced[9].

It is vital that the radar system is as concealed as possible, i.e. more stealth, because the customers use it to track enemies' airborne or non-airborne vehicles and missiles. Therefore, the *noise* and *IR-heat signal* of the power generator should be as quiet and low as possible. If the power generator creates much excess heat, there must be shielding around it in order to prevent detection. Same idea goes for loud noises. This means that loud noise and high IR-heat signal will lead to larger and heavier mobile radar systems which are not ideal[10].

Since the mobile radar systems are deployed in order to track enemy's movement and at the same time need to be stealth, the conditions that the radar system must function in are quite extreme. For this reason, an important criterion for the power generator is that it must be operational and able to start in both *cold and warm conditions*[11].

Furthermore, the *fuel* used in the power generation is an important parameter as well. The perfect scenario would be if the customers do not need to use any external fuel and the radar system will still function. However, since most of the power generators need some sort of fuel in order to work it will be more preferable with a standardized fuel that is used for other systems as well. For instance, if the customers' vehicles uses diesel it will be more favorable if the radar system's power generator used diesel as well in order to make the logistical aspect more trouble-free[11].

From the customers' perspective, the *cost* will certainly be a vital aspect. A cheaper system with the same functionality and quality will be more lucrative. Sometimes the cost will even be the main criteria in a purchase decision. However, the cost of a power generator in terms of the total cost of the radar system is quite small. More specifically, it is around 5-10 percent of the total radar system[10].

[8] Jan-Olov Winnberg, Senior Product Manager, Saab Group, Interview 2011-01-27
[9] Rolf Andersson, Programme Manager, Saab Group, Interview 2011-03-15
[10] Jan-Olov Winnberg, Senior Product Manager, Saab Group, Interview 2011-01-27
[11] Lennart Steen, Senior Product Manager, Saab Group, Interview 2011-01-27

3.4 Analysis

In order to reach the criterions of which to perform a comparison on the future technologies, the theoretical framework TEA will be applied to the empirical data regarding Saab EDS, the present power supplying system and Saab EDS's customers' need.

3.4.1 Technical System, Function and Application

The technical system of the present power supplying system is edified by an internal combustion engine (a Piston Engine and will henceforth be addressed as such) and a generator. Together with the sub-systems of a capacitor and a battery they form the application of generating power to the radar system. More specifically the Piston Engine has the function of converting the chemical energy (in the diesel) into kinetic energy. The generator then uses the kinetic energy with the function of producing electricity to the radar applications in the bigger system. The sub-systems' components battery and capacitor, have the function to stabilize the system in order for it to produce a constant frequency of 50 Hz when the needed power varies (see Figure 4 below).

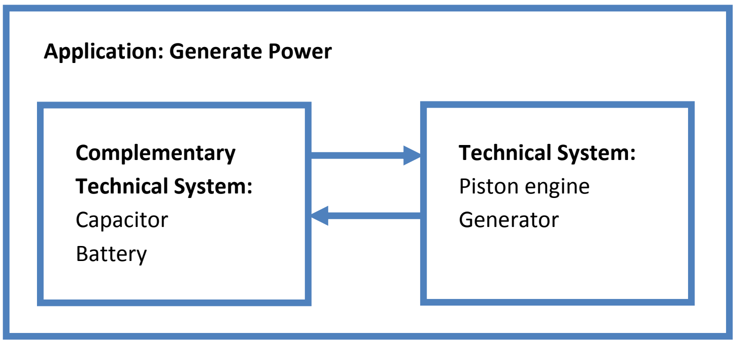

Figure 4 Connections between the systems in order to understand the type of future technology

3.4.2 Performance Parameters

Besides the self-evident need to generate power to the system there are some other internal demands of Saab EDS and their customers' need that will constitute a list of performance parameters. They can be based on how well a function is performed or on an attribute of the technical system. The essential attributes of the performance parameters found are size, weight, fuel flexibility (type of fuel), frequency, power, operating temperature, robustness and life span. Other parameters which are more measures of how well the function is performed by the technical systems are efficiency (of the system), MTBF (mean time between failures), service intervals, fuel consumption, sound level, upstart temperature, cost and load variation.

The importance of these performance parameters is based on the empirics. Saab EDS wants flexibility in the product since it is used in very different environments when their customers are situated all over the world. Thus there is a need for fuel flexibility, robustness and a wide span in the upstart temperature, which might be considered as order qualifiers since Saab EDS has to abide with the customers' need. The fuel is an essential complementary good to the engine generator. It is very important that the fuel is easy accessible or ubiquitous so it fits Saab EDS's customers' need.

The radar system demands a certain power, a certain frequency and the ability to withstand load variation, thus the three are naturally performance parameters. They are explicitly order qualifiers; it must be at least 30 kW with 50 Hz for the radar system of the larger product to work. Size and weight are more considered as order winners. They are of equal importance to the customer and Saab EDS. They affect how easy it is transported and indirectly other performance parameters such as costs and fuel consumption. The smaller and lighter it gets the better it is for Saab EDS and for the customers. However, there might be an issue of economic relevance for the customer. They might not care if the final product weighs 300 kg or 500 kg, though the analysis cannot address this issue due to unavailable data.

The operating temperature affects how easy the product is to use and the life span is a measure of the quality of the product, thus both are important performance parameters for the customers, as order winners. The reason for this is because the customers sort of take the power generating application for granted and thus wants to minimize the needed maintenance time. Furthermore, MTBF, service intervals and fuel consumption also affect the needed maintenance level, thus these are also considered as order winners. This means the higher the MTBF, the larger the service intervals and the lower the fuel consumption the better it is for the customers.

Efficiency is of great interest for Saab EDS as an order winner. It is of course preferable to have a system with a high efficiency since you want electricity and nothing else (not waste energy in form of heat). Thus you want the conversion from chemical to electricity to be as efficient as it can get. The wasted energy in form of heat must be cooled in order to avoid over heating the radar system. A higher efficiency leads to lesser waste heat which means lesser power to cool the system. This affects the IR emitted which with the sound level affects the final stealth ability of the big product. Stealthability is an order qualifier of the product the IR, and also sound to some extent, is usually minimized with protective materials which indirectly affects the final weight and size of the product (see Table 1 for a summary).

Performance Parameter	Attribute (A)/How Well (W)	Order Winner/Qualifier
Size	A	Order Winner
Weight	A	Order Winner
Efficiency	W	Order Winner
Mean Time Between Failure	W	Order Winner
Service Intervals	W	Order Winner
Fuel Consumption	W	Order Winner
Fuel Flexibility	A	Order Qualifier
Frequency (50Hz)	A	Order Qualifier
Power (30kW)	A	Order Qualifier
Sound	W	Order Qualifier
Upstart Temperature	W	Order Qualifier
Operating Temperature	A	Order Winner
Cost	W	Order Winner
Robustness	A	Order Qualifier
Life Span	A	Order Winner
Load Variation	W	Order Winner

Table 1 Summary of Performance Parameters

3.4.3 Utility Parameters

Theory says that utility is the linkage between technology and economics and its relation is hard to grasp since the customers do not know their own utility. Besides the example by Shilling (2010) where the utility sub-levers are the same as the performance parameters (speed, efficiency), the utility parameters have had to be developed depending on how they affect the customer. Thus, they are derived and developed (or translated) into key indicators regarding the customers' preference by mapping the performance parameters and the empirical data regarding the customers and understanding their links. The utility parameters developed are transportability, reliability, maintenance, quality, stealthability, price and usability. Figure 5 summarizes the parameters and how they are linked to one another. The link describes the relation, which of the performance parameters affect which of the utility parameters.

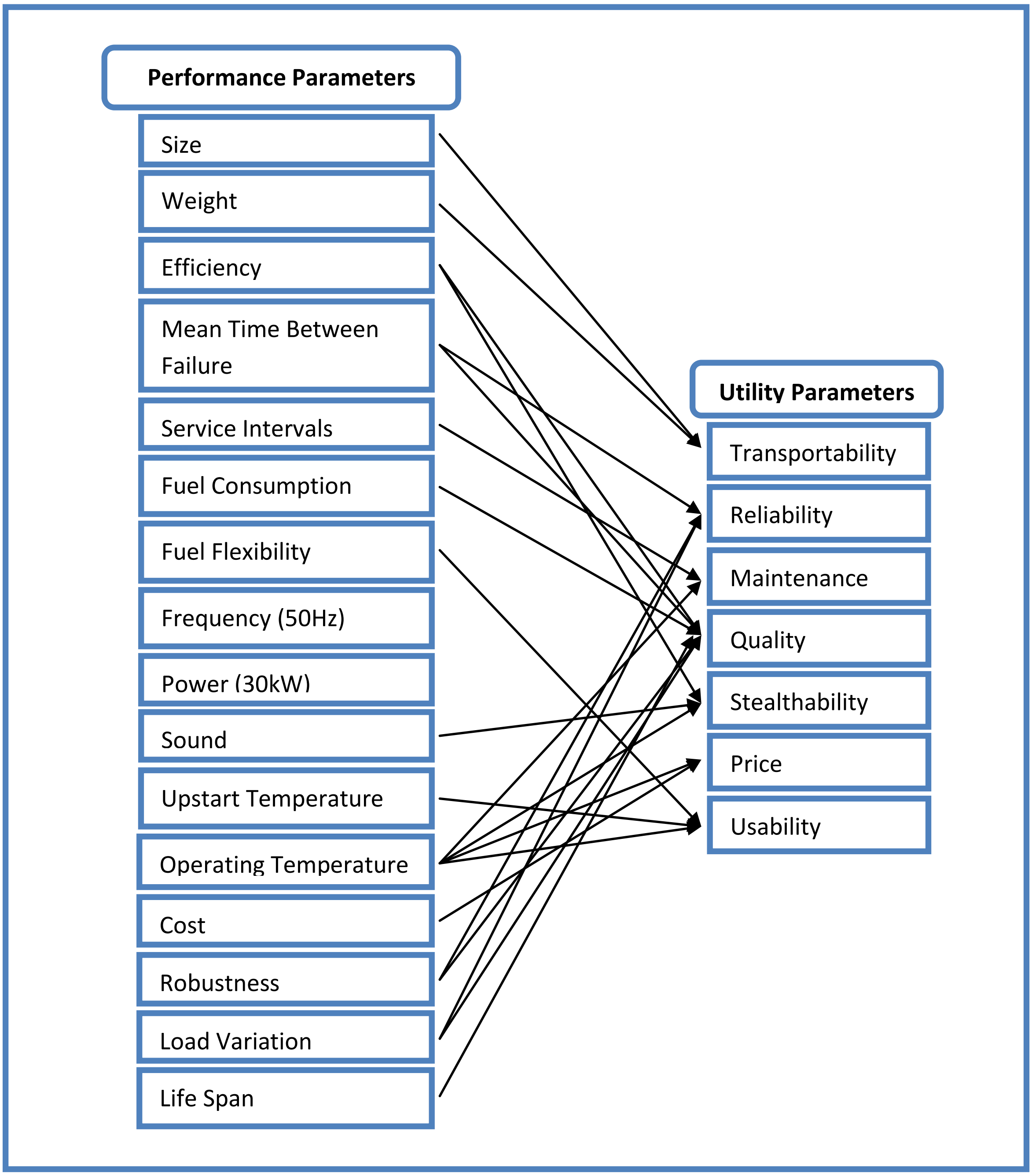

Figure 5 Connections between the Performance Parameters and the Utility Parameters

3.5 The Developed Evaluation Criterions

From the performance parameters and utility parameters in Figure 5 a set of criterions can be developed. These criterions will later be used to evaluate the investigated power generating and energy storage technologies. The criterions are not presented with the specific range (f.eg. size must be within x m^3 to y m^3) in this report since the values that were gathered from Saab EDS and their customers were sensitive information. However, when the identified technologies were evaluated the values of each criterion were taken into consideration. Some of the performance and utility parameters can be grouped together. This means that instead of for example using load variation and Mean Time Between Failure as separate criterion these can be grouped as the utility parameter *Reliability.* The main rational for doing this is that it will be easier to evaluate the technologies since some performance parameters are tightly connected and difficult to compare separately. Also, if a technology is better suited for load variation it is certainly more reliable and is in a sense better in terms of Mean Time Between Failure*.* On the other hand, the performance parameters that is for example linked to stealthability, which is sound, operating temperature and efficiency, cannot be grouped together with the same rational. This is because low sound level does not automatically mean low operating temperature. Consequently, these parameters need to be evaluated separately.

Some of the parameters identified in the previous section will not be used in the evaluation process. This is because when the technologies where chosen these parameters had to be satisfied which are generation of 30kW and with the frequency of 50 Hz. Another parameter that is not going to be considered further is fuel consumption. The main reason for this is that many of the investigated technologies is under development and going to be improved constantly which makes the fuel consumption value difficult to identify. In addition, since the parameter service interval is difficult to put a number on the parameter will be included in the *maintenance* criterion instead and thus only be given a relative value compared between the investigated technologies. Moreover, from the analysis about economic value, two additional criterions can be developed. Technical maturity is the first criterion which covers the economic value of applications (economy of scale) and substitutability (performance/cost ratio). Thus if the technical maturity is high it means that the technology can reap large economics of scale since it has a lot of applications in many different industries. It is also means that the performance/cost ratio is high. Diffusion potential covers the rest i.e. potential for improvements, growth potential, cost of imitability, and ease of tradability. The highest diffusion potential will be if the potential for improvements is deemed to be high, if there is a high growth potential, if the cost is high to imitate and finally if it is easy to trade.

The final criterions are divided into quantitative and qualitative, which can be seen in Table 2. This is because the qualitative criterions have to be weighed in a relative manner and given a ranking number on a scale from 1 to 10 which will be done in an analytical subjective approach. The quantitative can be given an actual number.

The quantitative criterions:	The qualitative criterions:
Size	Reliability
Weight	Technical maturity
Operating temperature	Diffusion potential
Upstart temperature	Maintenance
Life span	
Sound	
Efficiency	
Fuel flexibility (type of fuel)	
Robustness	
Costs	

Table 2 The Developed Quantitative and Qualitative Criterions

4 Evaluation and Selection of the Energy Technologies

In this chapter the identified technologies will be presented. Thereafter the identified technologies will be evaluated and screened in order to determine the most interesting ones for Saab EDS. *In the evaluation a shorter analysis is presented in order to determine the value on each of the qualitative criterions from the previous chapter. This is required since they incorporate many aspects and do not have specific numbers. Those values are determined by comparing the technologies relative each other. The selection is based on both the quantitative criterions and the qualitative criterions (values from Tables 13-14).*

4.1 Power Generating Technologies

The identification of technologies is imprecise and changing over time according to Lindmark (2006). Therefore some identified power generating technologies that only had few articles written about them, i.e. technologies that either were too improbable or unproven (such as cold fusion) or too "new" (such as Carbon Nanotubes) had to be neglected since their future is too hard to predict. These technologies may, however, still need to be followed up in the coming years (Lewan, 2011; Alternative Energy, 2010).

The identified power generating technologies were; Fuel Cell, Gas Turbine, Thermoelectric generator, Solar Cell, Stirling Engine, Wankel Engine, Piston Engine generator and Free Piston Engine.

4.1.1 Fuel Cell

In Table 3 the compiled figures regarding the Fuel Cell Technologies are presented. These data are collected from Ekdunge[12], Ljungberg[13] and US Department of Energy (2011) and are complements to the following text.

For a ~30kW-system	PEM	SOFC
Size	100W/dm^3	100W/dm^3
Weight	2kW/kg	0,5kW/kg
Operating Temperature (°C)	60-80 or 300-400 (HTPEM)	800 – 1000
Upstart Temperature (°C)	-25 - 60	-25 – 800
Life Span (hours)	5000 – 40 000	N/A
Sound Level	<60 db at 3m	Very low
Efficiency	40 – 60%	50 -65%
Fuel Flexibility	Hydrogen or Reformate	Everything
Cost	>> 1000 SEK/kW[14]	40 000 SEK/kW[15]
Robustness	High	High

Table 3 Compilation of the figures for Fuel Cell Technologies

[12] Per Ekdunge, Vice President, PowerCell AB, Interview 2011-01-25

[13] Rickard Ljungberg, CEO, GETT Fuel Cells AB, Interview 2011-02-15

[14] Manufacturing cost for PowerCell AB of a prototype.

[15]Data from Gett Fuel Cell for a protype. However, found other sources where the cost is substantially lower. In addition, the cost goal from various national energy organizations in 2012 is around 700 USD (US Department of Energy, 2011).

A Fuel Cell is an electrochemical cell, which is a device capable of either deriving electrical energy from chemical reactions or facilitating chemical reactions through the introduction of electrical energy. The electrical energy is generated from the reaction from a fuel supply and an oxidizing agent. Fuel Cells can operate as long as these are maintained. (Dicks & Laminie, 2003)

There are many combinations of reactants and oxidizing agents, one form that is commonly associated with Fuel Cells is where hydrogen acts as the reactant and oxygen as the oxidizing agent (see Figure 6). The results of the two reactions below are water and electrons which are allowed to flow through an external device as a current. The typical design is the three layer sandwich, which contains an anode, a cathode and an electrolyte. The electrolyte substance determines the type of Fuel Cell.

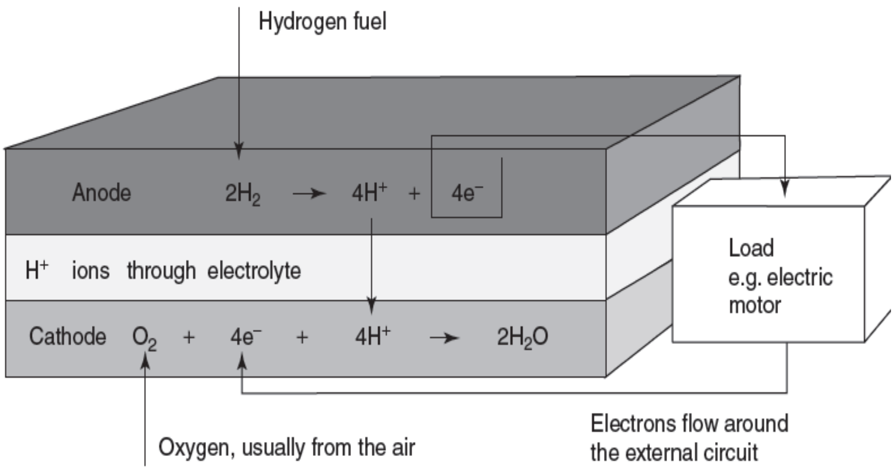

Figure 6 Basic concept of the Fuel Cell (Dicks and Laminie, 2003)

4.1.1.1 Technology Today

The reactions in the Fuel Cell require an activation energy which can be dealt with in three ways, increasing temperature, use of catalysts and increasing the electrode area (important for Fuel Cells) (Dicks and Laminie, 2003). Catalysts used are depended on the type of Fuel Cell, though the most common catalyst used for the anode is a powder of platinum and nickel for the cathode. Platinum is quite an expensive metal. It constitutes around USD 1700 of the total cost of USD 5000 per stack of Fuel Cell[16]

Two interesting types of Fuel Cells for the purpose of this thesis are Proton Exchange Membrane (PEM) and Solid Oxide Fuel Cell (SOFC), since the power area of interests (given by Saab EDS) is around 30kW (see Figure 7). In general, the great advantages with Fuel Cell compared to the conventional combustion engine is its reliability (no moving parts), low need for service, higher efficiency, environmental friendliness and it is also very silent (<60 db at a distance of 3 meters)[17]

[16]Rickard Ljungberg, CEO, GETT Fuel Cells AB, Interview 2011-02-15

[17] Per Ekdunge, Vice President, PowerCell AB, Interview 2011-01-25

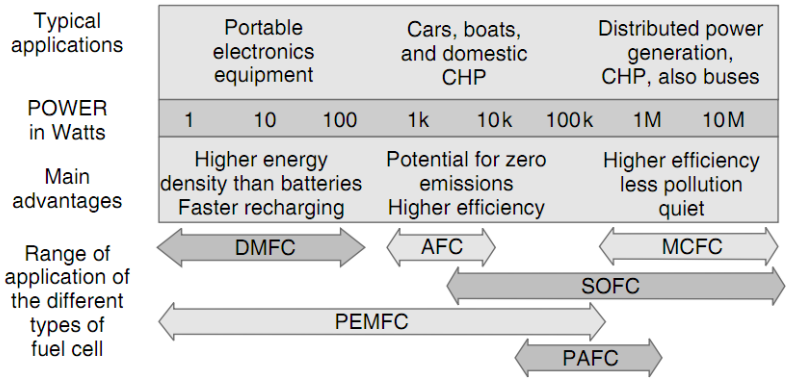

Figure 7 Range of application for each type of Fuel Cell Source: Dicks & Laminie (2003)

PEM uses a poly membrane as the electrolyte and therefore has the advantage of easy construction, high power density, short start up time and a high work capability under dynamic load compared to other Fuel Cells. PEM is one of the Fuel Cells that use platinum as the catalyst. A drawback with platinum, besides the cost, is its sensitiveness to carbon monoxide and sulfur, thus pure hydrogen as the fuel supply is preferable (FMV, 2004). There are two specific sub types of the PEM, High temperature PEM (operating temp 300-400˚C) and Low temperature PEM (50-100˚C). Efficiency is increased with the temperature but the drawback is the higher demand on and cost of material[18]. The PEM Fuel Cells are very expensive at the moment since there are no sales in enough volume to push the prices down. Often they are sold as prototypes at a price >>1000 SEK/kW. They weigh around 2kW/kg, thus Saab EDS would need Fuel Cells of about 15 kg to have enough power. PEM Fuel Cells can start at temperature as low as -25˚C. The only thing limiting it is the water that is emitted from the reaction. If there is water left in the system it is hard to start it at a too low temperature for the water to freeze[19].

Besides testing PEM in cars, PEM has been used in buses in Britain, Stockholm and other major European cities with success[20]. The airplane industry is also trying out PEM, for example Boeing has done some test flights in 2008 with a manned airplane using PEM and Lithium-Ion battery as the power supply (Koehler, 2008).

SOFC are working in a higher temperature environment, typically around 800-1000˚C. Thus catalysts of platinum are not required for the activation energy. The drawback with the high temperature is creeping of the material used. Another drawback is the possibility for other reactions to occur inside the Fuel Cell, for example graphite is common to get built up at the anode preventing fuel to reach it. Thus there are higher demands for the materials which add an extra cost. One of the great advantages with SOFC is that it can use a wide variety of fuel types. Unlike most other Fuel Cells, which usually run on hydrogen, SOFC can run on petrol, methanol, butane and other petroleum products. It is also highly tolerant to impurities in the fuel. (Sahibzada et al, 2000)

[18] Niklas Janehag, Electrical Design Engineer, Saab Group, Interview 2011-02-08

[19] Per Ekdunge, Vice President, PowerCell AB, Interview 2011-03-16

[20] Rickard Ljungberg, CEO, GETT Fuel Cells AB, Interview 2011-02-15

SOFC has been tried in different mini-APUs, battery chargers, handheld electronics and UAVs (Unmanned Aerial Vehicle) by FMV (Försvarets MaterialVerk)[21]. SOFC is relatively new compared to PEM, therefore there are few sources which mentions the typical application with SOFC. However Figure 7 above shows the wide power area span which SOFC is likely to compete in[22].

4.1.1.2 Future Development

According to a joint learning agreement in September 2009 with most of the major car manufacturers (GM, Ford, Daimler, Toyota, Volkswagen, Hyundai etc) there will be a serial produced FCEV (Fuel Cell Electrical Vehicle) by 2015. According to IPHE (2011) about the distribution of car types from now up to 2050, the FCEV (in the best case scenario) could constitute of more than 50 percent (or 137 million) of the total cars in Europe by 2050. The major driving factor to this is the EU goal to reduce CO_2 emission by 80 percent by 2050, which would mean a need to reduce of 95 percent in the road transport sector. The scenarios are based on assumptions from the report "A portfolio for power-trains for Europe: a fact based analysis" (IPHE, 2011).

A report from U.S Department of Energy shows an estimation of what a Fuel Cell can cost in 2015. An 80 kW PEM Fuel Cell in a FCEV would cost USD 21/kW, and the total system USD 39/kW with an annual production rate of 500 000 FCEV (see Figure 8). With an annual sale of around 60 million cars, FCEV would have to obtain less than 1 percent of the total market in order to reach this cost (Scotiabank Group, 2010).

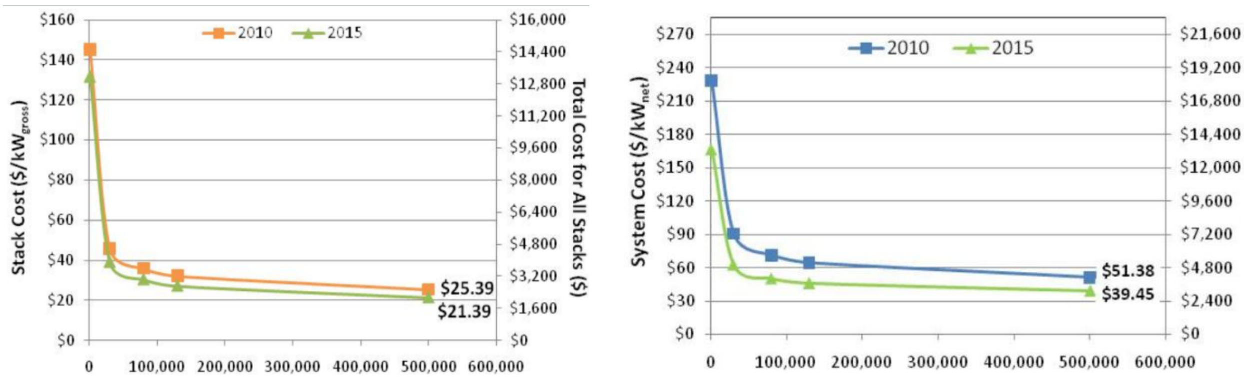

Figure 8 Cost for PEMFC with different annual production rate, Source: U.S Department of Energy (right "y-value" total cost for 80kW)

Since it is so costly with the precious metal platinum, other materials acting as catalysts are being investigated. For example, Chalmers University of Technology has developed one that is carbon based and John Innes Centre in the UK is investigating one that is iron sulphur based. This would cut the price of the PEM Fuel Cells by a third of its price today[23].

In the end of January, Vätgas Sverige (English: Hydrogen Sweden) signed a Memorandum of Understanding (MoU) with Hyundai and Kia Motors for a market introduction of their FCEV.

[21] Niklas Janehag, Electrical Design Engineer, Saab Group, Interview 2011-02-08

[22] Rickard Ljungberg, CEO, GETT Fuel Cells AB, Interview 2011-02-15

[23] Anders Palmqvist, Professor, Chalmers University of Technology, Interview 2011-02-18

The idea is that northern Europe and the Nordic countries will be the demonstration arena for this new car, which will help the development of the infrastructure of hydrogen supply. Kia motors has recently (2011-03-02) also signed a MoU with the German Clean Energy Partnership (CEP) to ease the access of FCEV in Germany. The German government has a National Innovation Program with the intention to prepare the German market for FCEV. They have a budget of around EUR 1.4 billion, which spans from 2007 to 2016. (Vätgas Sverige, 2011)

GETT Fuel Cells, a company in Stockholm, will display a new SOFC Fuel Cell during the summer of 2011. This Fuel Cell will be able to work in a lesser temperature (300-600˚C), without losing its efficiency compared to the conventional SOFC. Thus GETT believe they will be able to reduce its costs to around USD 200/kW which is the goal for SECA (Solid State Energy Conversion Alliance, collaboration between federal government, private industry, academic institutions and national laboratories in USA) for 2011.

Another developing trend for Fuel Cells can be found in the consumer electronic market. The demand for small sources of energy which has longer uptime and faster charging time is the major incentive for the development of portable Fuel Cells (FMV, 2004).

Department of Energy in the USAs government will increase its R&D funding with 12 percent to USD 29.5 billion. However, they are cutting the R&D budget for hydrogen and Fuel Cell technologies by 41 percent to USD 100 million. It also eliminates funding of SECA, whom develops SOFC for range-extending auxiliary power units for electric trucks among other ting (Calem, 2011). Canada on the other hand plans to increase its R&D budget to USD 200 million for the hydrogen and Fuel Cell industry (Industry Canada, 2010).

4.1.1.3 Evaluation of Fuel Cell

Since there are no moving parts in the Fuel Cell there are few reasons for stops due to failure. Thus the mean time between failures is deemed to be very high, and the real need for stop is when the Fuel Cell reaches the end of its life span. One drawback is the Fuel Cell's ability to withstand load variation. The life span seems to decrease by a factor of eight (40 000 hours → 5000 hours) if there are great load variations according to a specific investigated product (or system). Despite this the *reliability* is deemed to be very high, 8 on a ten point scale.

Maintenance is depended on the operating temperature and the used fuel type. In low operating temperature Fuel Cells there is some need to change filters if a reformate is used (e.g. diesel). In higher operating temperature Fuel Cells like the SOFC this is not an issue. However, the higher temperature cause creep in the material which needs to be maintained. The maintenance is deemed to be 5 on the ten point scale.

There are many areas of application for the Fuel Cell (See Figure 7). It has been tried in cars, buses, planes and smaller applications such as phone battery chargers. However, is has not reached a critical mass market yet. Thus it is still in a sort of exploration (curiosity) stage. The performance/cost ratio is difficult to assess in comparison to the piston engine generator of today. The cost is rather high today, since there are few mass markets. Often the empirics regard prototypes of products and thus are depended on a lot of customizations. The overall *technical maturity* is deemed to 6 on the ten point scale.

The growth potential of the Fuel Cell is depended on the adoption rate of for example the automotive industry and the FCEV after 2015. In addition the technology improvements on for example catalysts (carbon based etc.) and material will be important. The potential for improvements regarding costs is deemed to be high. A larger market is needed but the cost will drop fast (by about three times) if a relative "small" volume of 50 000 units is produced. New patents from Chalmers University of Technology regarding catalysts and the coming SOFC prototype by GETT Fuel Cells (the one working in a lower temperature around 500˚C) shows that progress is being done. There are also many organizations, institutions and companies with an interest of developing and selling Fuel Cells, so the ease of trade is assessed to be reasonable and judged to have potential for improvements. In the scale of one to ten the *diffusion potential* is given a 6.

4.1.2 Gas Turbine

In Table 4 the compiled figures regarding Gas Turbine are presented. These data are mainly collected from Håll[24] and are complements to the following text. In addition, Gas Turbine per se does not generate electricity by itself and needs to be connected to a generator to do that. Consequently, the presented data in Table 4 is based on a Gas Turbine generator in order to be comparable to the other power generating technologies.

For a ~30kW-system	
Size	<< PE
Weight	0,05kW/kg
Operating Temperature (°C)	Same as PE
Upstart Temperature (°C)	Same as PE
Life Span (hours)	Same as PE
Sound Level	70 db at 10m
Efficiency	Same as PE
Fuel Flexibility	Everything
Cost	Slightly above PE
Robustness	Medium

Table 4 Compilation of the figures from Gas Turbine

Like a traditional Piston Engine, the Gas Turbine is an internal combustion engine. Usually, Gas Turbines consist of three major parts; a compressor, a fire chamber and a turbine. The basic idea behind a Gas Turbine is that air is sucked in and compressed in the compressor. Then the air is pressed in to the fire chamber where it will be mixed with the fuel that is injected. The combustion gas that is compressed drives the turbine which in turn drives the compressor. In addition, a generator can be added, in which the turbine drives. If the Gas Turbine is connected to an electrical grid, a transformer will be added in order to convert the produced electricity into high-voltage before it is sent to the electrical grid. (Bioenergiportalen, 2010; Vattenfall, 2011)

[24] Ulf Håll, Professor, Chalmers University of Technology, Interview 2011-03-02

4.1.2.1 Technology Today

Other than the difference in the processes in the engines between a Gas Turbine and a Piston Engine, there are differences in how the engines can handle sub-loads. The Gas Turbine loses efficiency during sub-loads and works best under maximum-load in terms of efficiency, while a Piston Engine is independent of the degree of loads. The reason for this is because the pressure in a Piston Engine is not affected by different degrees of loads. However, the maximum efficiency is basically the same for the two technologies. In addition, the fuel consumption has been improved the last years in the Gas Turbine. This has made it comparable to the fuel consumption as a Piston Engine in terms of passenger-kilometer[25].

Historically the Gas Turbine has been more expensive than a Piston Engine. The major reason for this trend is that the material used in a Gas Turbine is more expensive. In theory the same material as a Piston Engine can be used to build a Gas Turbine. Thus, the cost can be lowered. In addition, the reason for using more expensive material has been because of the main usage of the Gas Turbine. The airplane industry has been the main adopters of the technology. In this industry the weight has been the main factor and issue. This has lead to an increased focus on lighter and better material in expense of the price[25].

The size of the Gas Turbine is smaller compared to a Piston Engine. For the same power, the Gas Turbine is around 10-100 times smaller[25]. Additionally, micro turbines are becoming more developed. The advantage with this technology is its size (Bioenergiportalen, 2010). However, when the Gas Turbine is built smaller the rotation speed will increase which in turn will make the Gas Turbine to cause a more screeching sound because of the increase in frequency[25].

The Gas Turbine has been implemented both in the electrical generator industry and the automobile industry. For instance, Sahlgrenska University Hospital in Gothenburg uses Gas Turbine generators as a back-up system. The main advantage and reason for Sahlgrenska University Hospital to use this technology is because of its small size[25]. A company that develops Gas Turbine generators is the American based company Capstone Turbine Corporation (Capstone Turbine Corporation, 2011). Also, in the automotive industry the most notable usage has been in one of Jaguar’s cars. As explained, the Gas Turbine works best under maximum-load. This has made the developers in Jaguar to develop the Gas Turbine car as a hybrid system, i.e. the Gas Turbine is combined with a battery that handles the sub-loads which are common during driving[25].

4.1.2.2 Future Development

The development efforts in the Gas Turbine industry have, historically, been mainly from the Jet Engine companies. It is, hence, this industry that is the major driving force and driver in terms of research and development. However, there are increased usages of Gas Turbines in power generation and auxiliary power[25]. In addition, during the last years the development of micro turbines with bio fuels has been rapid (Bioenergiportalen, 2010). In 15 years all the production of electricity from biomass will most likely go through a Gas Turbine.

[25] Ulf Håll, Professor, Chalmers University of Technology, Interview 2011-03-02

Furthermore, the research in Gas Turbines is mainly focused on incremental improvements in most aspects in the Gas Turbine, where the efficiency can be expected to be improved[26].

4.1.2.3 Evaluation of Gas Turbine

In terms of *reliability* the Gas Turbine is poorer than a Piston Engine. However, this notion is built on the fact that the prime development for the Gas Turbine has been towards lessening the weight. By using material that enables less weight, the robustness has been deteriorated. In addition, the fact that the Gas Turbine cannot handle load variation, since the efficiency lessens during load variation, makes the Gas Turbine even less reliable in comparison to the Piston Engine. Consequently, in a scale from one to ten the Gas Turbine will be given the score 4 in terms of reliability.

The Gas Turbine has, as the Piston Engine, moveable parts which make it vulnerable to wearing. Hence, there will be need of regular services in order to maintain the engine. In addition, the choice of fuel type is freer in a Gas Turbine compared to a Piston Engine, but this can also increase the need for *maintenance* since some fuel types can include difficult rest products which can increase the wearing. As a result, the maintenance criterion is given a 4. Furthermore, the fact that there are no need for oil changes in a Gas Turbine further makes it better than a Piston Engine in terms of maintenance.

Historically the Gas Turbine has mainly been used in jet engines. However, the range of applications that the Gas Turbine can be used in is many. For example, there is increased usage of Gas Turbine with generators since the size of the Gas Turbine can be smaller compared to a Piston Engine with the same power. It is also used in the automotive industry which further increases the aspect of applications. Moreover, the cost has been high for a Gas Turbine, historically, compared to a Piston Engine. On the other hand, since the Gas Turbine can be built in cheaper materials there are great potential to lower the cost which in turn increases the performance/cost ratio. Accordingly, the *technical maturity* regarding the Gas Turbine is given a 7.

The growth potential of the Gas Turbine is high in terms of using it as a power generator. This is because there are several advantageous with the Gas Turbine, especially size, which makes it more lucrative than a Piston Engine. Still, the technology per se is relative mature and the future development will be focused on incremental improvements. In terms of the cost aspect, the Gas Turbine has a huge potential to be decreased. By using cheaper material the cost can certainly be lowered, and when Gas Turbine is used as a power generator the need for light material may not be as vital. There are several companies that have Gas Turbine solutions. The increased interest in using Gas Turbine as power generator will further increase the amount of actors and thus better the aspect of ease of trade. The overall diffusion potential is deemed to 6 in a scale to ten.

[26] Ulf Håll, Professor, Chalmers University of Technology, Interview 2011-03-02

4.1.3 Thermoelectric Generator

In Table 5 the compiled figures regarding Thermoelectric Generator are presented. These data are mainly collected from Palmqvist[27], Holmgren[28] and Mortensen[29] and are complements to the following text.

For a ~30kW-system	
Size	Not Relevant
Weight	0,05kW/kg
Operating Temperature (°C)	All
Upstart Temperature (°C)	Not Relevant
Life Span (years)	~10 (Same as exhaustion)
Sound Level	Very low
Efficiency	4 – 8%
Fuel Flexibility	Difference in Temperature
Cost	30 000 SEK/kW[30]
Robustness	High

Table 5 Compilation of the figures from Thermo Generator

Thermoelectric generators are devices which convert heat (temperature differences) into electricity by using the phenomenon of the Seebeck effect, which was discovered when two dissimilar metals with junctions at different temperatures deflected a compass magnet[27]. The deflected compass magnet showed that a magnetic field or that electricity was the reason for the deflected magnet. Charge carriers in the materials (electrons in metals, electron holes in semi conductors) will diffuse from the hot end to the cold end when there is a temperature difference. The thermal speed of the electrons is different in the hot region, which results in a charge difference or a potential difference i.e. a current when diffused[27]. The electrons and holes will keep diffusing as long as there is a temperature difference, thus it cools the material off while giving electricity[28].

4.1.3.1 Technology Today

A thermoelectric generator's efficiency is dependent on the size of the temperature difference and its material. It should have the attribute of a high electric conductivity and a low thermal conductivity in order to give the best effect; therefore semi-conductors are usually used. Since the efficiency is rather low, research is being made to find materials that indicate better attributes[27].

The technology is used to increase the total efficiency in a system. It has no moving parts and does not need anything more than temperature difference. Therefore it has a long life span. Another advantage is the increased interest (power management, the way of dealing with power loss, is getting better) of the technology and a lot of effort is put in research. For example thermoelectric generators conference attendances have increased from 150

[27] Anders Palmqvist, Professor, Chalmers University of Technology, Interview 2011-02-18

[28] Lennart Holmgren, CEO, Thermo-Gen AB, Interview 2011-03-18

[29] Paw Mortensen, CEO, Alpcon, Interview 2011-02-22

[30] Manufacturing cost for one prototype.

persons 10 years ago to 600 persons last year. Also Strategiska Forskningsinstitutet (the strategic research institute in Sweden) ranked thermo generators as their top 5 areas of interest[31]. The drawback is its low efficiency which gives a negative interest to the technology by many industries (FMV, 2004).

Applicable areas usually have a lot of waste energy in forms of heat. It is used in different combinations, thermo generators with Fuel Cells, internal combustion engines, Solar Cells etc. For example there is a project with Volvo Technology, Alfa Laval and Thermo Gen where the goal is to get 1 kW out of the exhaust gases in a Volvo truck, which would only be wasted otherwise[32]. Waste heat from houses can prove to be the most applicable area to use the thermo generators according to Mortensen[33] of Alpcon. Another area of application is portable mobile phone charger for hikers and such (FMV, 2004).

4.1.3.2 Future Development

Research in different materials will proceed[31], even though the science behind the thermo generators limits its theoretical maximum efficiency (FMV, 2004). They will always have a fraction of the maximum theoretical Carnot cycle efficiency, depending on the materials' figure of merit (which is dependent on the materials' composition as mentioned above). There has been research showing as high figure of merit as 20, resulting in about 50 percent of the Carnot cycle in efficiency (Rowe, 2006). Thus in a 10 to a 15 year span it is predicted to be products with an efficiency increase of around 15 percent. This can be done with the development in nanotechnologies, which can change the electronic structure with the reduced size[33]. Most of the research is focused on increasing efficiency, since with higher efficiency more industries will be interested in this technology which would give it a larger market which in turn would result in a lower cost[31].

4.1.3.3 Evaluation of Thermo Generator

The thermo generators do not have any moving parts and are able to generate electricity as long as there is a temperature difference. Thus its reliability is not dependent on the thermo generator but on its working environment in theory. Furthermore, with the same argument, load variations do not affect the thermo generator. On the scale *reliability* is given a 9.

Since the generator is exposed to large temperature differences, there is some possibility of creep in the material. Therefore service is a good idea, but how long the service intervals should be is dependent on what type of generator and in what temperature it operates. *Maintenance* is given a 6 on the scale.

Thermo generators have a lot of possible application areas but are not vastly used at the moment. It is probably since the efficiency is rather low so there has not been a market for it. Thus the costs are still rather high (projects with prototypes add to customization, adding activities which adds to the total costs) and the performance/cost ratio rather low. A major advantage for the technology is the increasing interest in power management and energy

[31] Anders Palmqvist, Professor, Chalmers University of Technology, Interview 2011-02-18

[32] Lennart Holmgren, CEO, Thermo-Gen AB, Interview 2011-03-18

[33] Paw Mortensen, CEO, Alpcon, Interview 2011-02-22

efficiency. A lot of companies want to handle the wasted heat energy, thus they have recently shown an increasing interest in the generators which could lead to a mass market which would bring the costs down. *Technical maturity* is deemed to be a 4 on the scale.

The fact that Strategiska Forskningsinstitutet has ranked Thermo Generators as its top 5 areas of interest shows that it will keep funding research in the area. Thus improvements are to be expected, for example efficiency could increase to 15 percent in the coming 15 years. The increasing interest by companies will also improve the ease of trade and with a big market as energy efficiency in houses, more institutions and governments could possibly want to turn further attention to thermo generators. This leads to a rather high potential for growth, which is of course dependent on the performance/cost ratio. *Diffusion potential* is deemed to be a 5.

4.1.4 Solar Cell

In Table 6 the compiled figures regarding Solar Cell are presented. These data are mainly collected from Palmblad[34] and Knoll (2011) and are complements to the following text.

For a ~30kW-system	
Size	0,1kW/m^2
Weight	3W/kg
Operating Temperature (°C)	Not Relevant
Upstart Temperature (°C)	Not Relevant
Life Span	Not Relevant
Sound Level	Very low
Efficiency	7 – 20%
Fuel Flexibility	Sun Light
Cost	USD 1,80/W
Robustness	Low

Table 6 Compilation of the figures for Solar Cell

The basic theory behind solar power is that a Solar Cell, also known as photovoltaic, transforms sun light directly to electricity in the form of electrical voltage (Knier, 2008). An electrical voltage between the cell's front- and back side arises when sun light hits the Solar Cell. This voltage drives the Solar Cells electrons in a given direction and consequently a current occurs. As seen in Figure 9, the front of the Solar Cell gathers the sun light and current while the back side of the Solar Cell is covered with a conducting material. The current is brought out from the cell with lines which is connected to both the front- and back side (Energimyndigheten, 2010).

[34] Linus Palmblad, Energimyndigheten, Interview 2011-02-16

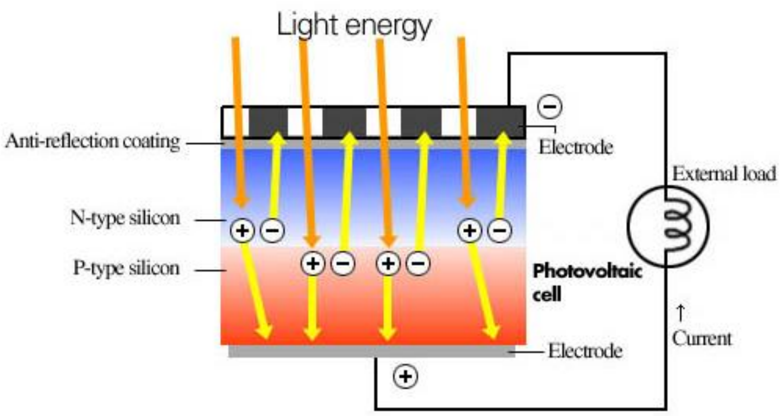

Figure 9 How a solar cell works (Apec Virtual Center)

Solar Cells are usually built in modules in order to create a more robust and wieldy unit which can resist damp. This is done by covering the cells with a protecting pane of glass and the cells are serial connected in order to increase the unit's voltage (Energimyndigheten, 2010). In addition, the modules usually consist of 30-40 Solar Cells (FMV, 2004)

The Solar Cell Modules are often serial connected as well in order to create a Solar Cell system with several hundred voltages. There are two main Solar Cell systems, the ones that are connected to an electrical grid or the ones that are stand-alone which thus is connected to an energy storing device such as a battery. The simplest form of a Solar Cell System consists of a Solar Cell module, the electronics that is driven by the Solar Cell modules and, in most of the cases, there is electronic equipment as well as an energy storing devices in the form of a battery or electrical grid (See Figure 10). The electronic equipments and energy storing devices are used in order to adapt the produced solar electricity after the needed output. The electronic equipments will also transform the electrical voltage, in which the Solar Cells create, so that it fits the electronics that is driven by the Solar Cell system. (Energimyndigheten, 2010).

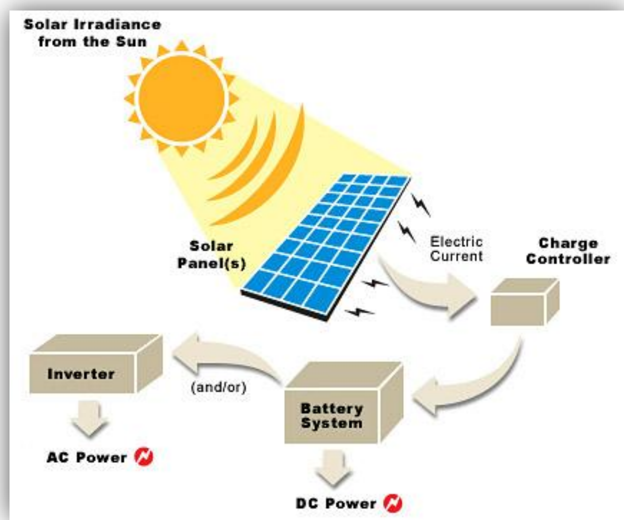

Figure 10 A Solar Cell System (Solar Energy Guide, 2011)

4.1.4.1 Technology Today

There are several types of Solar Cells, in which the silicone-based ones are the most common (Energimyndigheten, 2010). More precisely, 95 percent of the Solar Cells in the market are based on silicone as a semi-conducting material (FMV, 2004). Additionally, there are two ways to manufacture Solar Cells; either silicone plates which have efficiency around 12-5 percent or thin-film Solar Cells which have efficiency around 7-11 percent (Energimyndigheten, 2010). While the silicone plates are more common, the thin-film Solar Cells has increased from 6 percent market share in 2005 to 20 percent market share in 2009 (European Commission, 2010) . By using the thin-film method the high investment cost can be lowered. The thin-film design is done by coating the entire module with the semi-conducting material (Energimyndigheten, 2010).

The amount of energy from the sun light varies depending on where on earth you are. For instance, the sun light's energy is greater in the dessert than other places, i.e. the Solar Cell can get more power per square meter. However, one important issue with sun light is that it has a maximum output of around 1000 Watt per square meter. Consequently, even if the efficiency can almost get to 100 percent the Solar Cell must still be one square meter in order to generate 1000 Watt[35].

The Solar Cell technology has been available since 1950 and was first used in satellites. The development and improvements in the semi-conducting industry during the same period, lead to increased popularity of Solar Cells as well as a competitive alternative since the price dropped. The main application of Solar Cells has been in buildings where the distance to the electrical grid is far away (Energimyndigheten, 2010). Other applications that Solar Cell has been frequent used in are telecommunication stations, traffic lights and road lights and electricity production to electrical grids (FMV, 2004).

The growth of Solar Cells has been huge the last years. Between 2009 and 2010 alone the installed capacity has increased with 100 percent. The cumulative installed capacity has been increasing vastly to around 37 000 MW total, where Europe has been contributing the largest share of around 15000 MW. (EPIA, 2010)

4.1.4.2 Future Development

According to Palmblad[35] the Solar Cell development can be compared to Moore's Law, where it has an exponential growth. The manufacturing cost of Solar Cells can either be lowered by increasing the efficiency, improve the production process, etc. In the electronics industry, a doubling in production volume in components often leads to a percental decrease in manufacturing price and this trend continues in principle consistently over an infinite time.

The Solar Cell technology is predicted to continue its recent rapid development. Germany has been in the forefront in terms of Solar Cell development. The large oil companies have shown interest in this technology and have joined the organizations that lead the future development and manufacturing of Solar Cells (FMV, 2004). According to Palmblad[35] the

[35] Linus Palmblad, Energimyndigheten, Interview 2011-02-16

technology can in a sense be classified as mature, meaning that the necessary knowledge and technology is available. However, there will still be a need for increasing the efficiency, price as well as to revolutionize the manufacturing process. Also, most of the development effort is to build in better functionality in the products such as the manufacturing of integrated building systems with Solar Cells in both the walls and roof (FMV, 2004).

Furthermore, the market outlook until 2015 is a planned capacity of around 70 000 MW worldwide. This is based on China's ambitious plan to expand their capacity to 34,7 percent of the world's capacity, Taiwan increase their capacity to 15,9 while Europe have a capacity of 14,6 percent. (European Commission, 2010)

4.1.4.3 Evaluation of Solar Cell

The Solar Cell is reliable as long as there is sun in the sky. No moving parts so there are no reasons for stops due to failure. Load variation of the radar system does not matter since the Solar Cell produces electricity continuously and must store the electricity in a battery of some sort. Thus the load variation affects only the battery. However, the robustness of the Solar Cell is depended on the ductility of the glass panels, which protects the Solar Cells from damp, and the operating environment. If there is a high possibility for the panels to break then the reliability lessens. The overall r*eliability* is given a 4 on the ten point scale.

The only need for service would be if the glass panels break for some reason or to keep dirt from covering the panels. Operating temperature does not affect the materials either, unless it is put in combinations with mirrors and parabolas to increase temperature. The overall *maintenance* is given an 8.

There are many different applications for the Solar Cell; however most are intended for stationary use. The fact that the installed base has increased by 100 percent the last year shows that governments and institutions are getting more aligned and venture in the Solar Cell market. However, for mobile use it is not as applicable. Partly because of the limit of the energy of the sun light (which means you need huge Solar Cells) and partly because the protecting glass panels make the Solar Cell weigh a lot. The costs are different for the thin film compared to the traditional silicon based photovoltaic cells, but so is the efficiency which is a part of the performance measurement. Thus the performance/cost ratio is assessed to be about the same for the different kinds. Although since the sun light is free, the operating costs are extremely low and is therefore deemed not to be exposed to any major substitution threat. The overall *technical maturity* for mobile use is given a 2.

Many countries have ambitious goals about increasing the generated electricity by Solar Cells. Thus there will be an increased need for more efficient cells. The growth potential is also assumed to be good due to the increased environmental demands from politicians (and society) and the low environmental influence of the Solar Cell. However this is possibly only for stationary use. The potential for mobile applications is not assessed to be that great. In order for it to have any potential is if improvements of the efficiency (made for stationary systems), can be leverage to the mobile applications to such an extent s that it would justify a feasible use for Solar Cells in them. However, even if the efficiency reaches close to a 100 percent, a system of 30 kW would need 30 m^2. Therefore the overall *diffusion potential* for these kinds of mobile applications is assumed to be 2.

4.1.5 Stirling Engine

In Table 7 the compiled figures regarding Stirling Engine are presented. These data are mainly collected from Baumüller[36] and are complements to the following text.

For a ~30kW-system	
Size	11 W/dm^3
Weight	120W/kg
Operating Temperature (°C)	-10 - 60
Upstart Temperature (°C)	-40 - 60
Life Span (hours)	60 000 – 100 000
Sound Level	Low
Efficiency	Slightly above PE
Fuel Flexibility	Heat (Anything that burns)
Cost	EUR 2000/kW[37]
Robustness	High

Table 7 Compilation of the figures from Stirling Engine

The Stirling Engine was already developed in the beginning of nineteenth-century by Robert Stirling. The idea behind this machine is, basically, a heat engine with external combustion which works with either air or gas (Nationalencyklopedin, 2011). Gas or air is heated up and thus expanding. Then the air or gas is cooled down and sucked back, i.e. the gas or air in the engine is distributed back and forth between a hot and a cold end. This movement can then be converted to electricity through a generator. Moreover, one major difference between an internal combustion engine and a Stirling Engine is that a Stirling Engine has an open source configuration whereby power is generated by an external heat source. A Stirling Engine has also the most efficient thermo dynamic process in terms of converting heat to mechanical electrical energy[36].

4.1.5.1 Technology Today

The Stirling Engine had some promising development in the 1970s when serial production was expected around 1977. However, the high price compared to an internal combustion engine made it not lucrative, especially in the automotive industry (Vetenskapens Värld, 2010). Instead, the first notable application was in submarines from the Swedish company Kockums. Stirling Engine's advantageous in terms of higher efficiency than the internal combustion engine, low heat loss to the environment, low noise level, low magnetic and infrared signals and low maintenance were prioritized first (Kockums, 2010). Consequently, Sweden has been world leading when it comes to Stirling Engine technology. Today besides from Kockums, the company Cleanergy is one of the few companies in the world that produces and develops the Stirling Engine technology (Vetenskapens Värld, 2010).

[36] Andreas Baumüller, CTO, Cleanergy AB, Interview 2011-02-25

[37] Manufacturing cost for Cleanergy AB.

Furthermore, because of the historically low interest in Stirling Engines it has not been much development in the technology. Today there are only a few companies that are active in the Stirling Engine industry (Vetenskapens Värld, 2010). It is a niche market, for instance UK combines this technology with other for use in houses and in solar applications. Hence, it is not competing directly with the internal combustion engine[38].

The main advantageous with Stirling Engines are that it allows different types of fuel such as liquid or solid fuels or combustion gas, the low service intervals and no need for oil changes. However, the main disadvantage is the high cost which is due to the heat exchangers in the engine[3838].

4.1.5.2 Future Development

There are few companies in the Stirling Engine industry, as mentioned. Even though the technology has been around for a long time it has not been successful in terms of commercialization. It is important to increase the positive opinion around the engine in order for the industry to grow. (Vetenskapens Värld, 2010)

Moreover, the main development forward will be to lower the cost. This can be done by putting it more and more in industrial use in order to gain legitimacy try to ramp up the volume production and improve the manufacturing process. Also, in terms of solar application, in which Cleanergy is involved in, the Stirling Engine can be expected to have incremental improvements in all the aspects since it is a relatively new application for this technology[38].

4.1.5.3 Evaluation of Stirling Engine

The Stirling Engine has fewer moveable parts compared to a Piston Engine. This makes it less probable to stop because of failures. In addition, the Stirling Engine does not need any oil changes and the fact that it is an external combustion engine makes it more *reliable* than a Piston Engine. This is, basically, fewer parts can be broken down in a Stirling Engine compared to a Piston Engine and makes it more robust. Hence, the reliability of a Stirling Engine is given a score of 6.

The *maintenance* aspect for a Stirling Engine compared to a Piston Engine is much better. Since the Stirling Engine has fewer movable parts and do not need any oil changes the service intervals is not as frequent as for a Piston Engine. Hence, the score regarding the maintenance aspect for a Stirling Engine is high and given 7 out of ten.

The applications for the Stirling Engine are currently quite limited. From being a promising technology with many potential applications, the interest of the technology has been halted for various draw-backs. It is mainly used in niche markets and predicted to continue to be used in niche application. Also, the fact that there are only a few companies involved in the development of the technology, the growth potential for Stirling Engine is quite bounded. Moreover, the cost for the Stirling Engine today is quite high. This is due to the production capacity. Since it only serves a niche market it is still manufactured in a limited amount

[38] Andreas Baumüller, CTO, Cleanergy AB, Interview 2011-02-25

making it difficult to scale up the production. Together with the fact that the Stirling Engine is predicted to only serve the niche market in the future as well, the performance/cost ratio may be considered as low. Consequently, the overall *technical maturity* for the Stirling Engine is given 3 out of ten.

The *diffusion potential* of the Stirling Engine is given a 3. As mentioned above, the technology is serving a niche market and expected to still only serve this niche market in the coming future. In addition, there are only a handful of companies involved in the development and diffusion of Stirling Engine which obstruct the tradability. As a result, the diffusion potential is low for the Stirling Engine and given 3 out of ten.

4.1.6 Wankel Engine

In Table 8 the compiled figures regarding Wankel Engine are presented. These data are mainly collected from Backlund (2011) and Andersson[39] and are complements to the following text.

For a ~30kW-system	
Size	< PE
Weight	< PE
Operating Temperature (°C)	Same as PE
Upstart Temperature (°C)	Same as PE
Life Span (hours)	N/A
Sound Level	Same as PE
Efficiency	Slightly lower than PE
Fuel Flexibility	Same as PE
Cost	N/A
Robustness	Medium

Table 8 Compilation of the figures from Wankel Engine

The Wankel Engine is an internal combustion engine that, instead of having moving pistons, has a triangular rotor that orbits around a shaft in the middle of the engine (Duffy, 2003). The basic idea is that the rotor is moving from the impact of the combustion pressure. The power is then transferred from the rotor to the excentric on the engine shaft. The rotor's corner forms three holes between the rotor's flared areas and the engine's surface area. These volumes shrink and expand during the rotor's rotation (Backlund, 2011). When the rotor rotates one rotation around the engine the rotary engine produces three complete cycles. During the intake phase, the rotor face allows the mixture of air and fuel to take place. Then the mixture is tightly squeezed as the rotor keeps moving. During the power phase the ignition of the compressed mixture take place. Finally, the rotation pushes the face into its final cycle where the exhaust gases produced exit the combustion chamber (Duffy, 2003).

4.1.6.1 Technology Today

The Wankel Engine was already developed during the 1950s. The simplicity of the engine has been its main advantageous and attracted considerable attention. The first introduction of a

[39] Sven Andersson, Professor, Chalmers University of Technology, Interview 2011-02-23

diesel Wankel Engine in terms of automobile use was by Rolls Royce Motor Car Division (Duffy, 2003). However, since then the engine has mainly been used in Mazda's RX-series cars[40]. The main reasons for its use in the automobile industry are because of its size and vibration-free operation. Still, it has not been widely spread and adopted in the automobile industry. This is mainly because of its large, chilled, column shaped combustion rooms which makes the engine less efficient with large losses and consequently high fuel consumption (Backlund, 2011). The relatively chilled combustion rooms also contribute to the high emission rate of unburned hydro carbon which makes the engine to require a complicated emission control system (Duffy, 2003).

4.1.6.2 Future Development

In the future Wankel Engine can be used in an electrical car as a "range extender" since the small size can make the hybrid system relatively compact[40].

4.1.6.3 Evaluation of Wankel Engine

A Wankel Engine has less moving parts than a conventional PE. Thus it will in theory have lesser reasons for failure. It is also vibration-free which is positive for the reliability. The load variation and robustness is assessed to be similar to the PE. Therefore the overall *reliability* is assumed to be 3.

Service intervals are assumed to be similar to the PE. There might be a slight difference in favor of the PE since one of the drawbacks with the Wankel Engine is the higher fuel consumption and unburned hydro carbon which could mean an increased need to change filters etc. which would decrease the service intervals. Operating temperatures are the same as PE. *Maintenance* is given a 3.

The Wankel Engine is basically only seen in some of Mazda's models. The performance/cost ratio is assumed to be lower than the PE. If it was higher the Wankel Engine would have been adopted to a larger extent than it has. It is (and has been for a while) in a sense already substituted by the PE. *Technical maturity* is assumed to be 2.

There might be a market for the Wankel Engine as a range extender to electric vehicles, however the low amount of information found is deemed to be an indication that it is not the main idea as a range extender. Thus the potential for improvements and for growth is assumed to be low. *Diffusion potential* is given a 2.

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[40] Sven Andersson, Professor, Chalmers University of Technology, Interview 2011-02-23

4.1.7 Piston Engine generator

In Table 9 the compiled figures regarding the Piston Engine technology are presented. These data are mainly collected from Backlund (2011) and Andersson[41] and are complements to the following text.

For a ~30kW-system	
Size	17 W/dm3
Weight	800 – 900kg
Operating Temperature (°C)	90
Upstart Temperature (°C)	-40
Life Span (hours)	N/A
Sound Level	70 db at 7 m
Efficiency	30 %
Fuel Flexibility	Diesel
Cost	N/A (Secret)
Robustness	High

Table 9 Compilation of the figures from Piston Engine Generator

The technology used today by Saab EDS is an engine generator, which is a combination of a Piston Engine (PE) run on diesel and a generator. The PE converts the chemical energy in the diesel through combustion with the oxidizer air which creates a high temperature expansion (builds up a pressure) that applies a direct force to the pistons to form mechanical energy in the system. The generator applies the mechanical energy to a sliding magnet which moves back and forth trough a solenoid (a spool of copper wire) which induces a current. Since the generator only needs the mechanical energy to convert it into electricity it can be combined with other power sources and is therefore not depended on the PE[42].

4.1.7.1 Technology today

The technology is incumbent and has been used for decades. PE can be run on different fuel types. For example gasoline, diesel, ethanol, compressed natural gas, biogas etc. One thing that differentiates the diesel engine to the gasoline engine is that it is generally heavier, noisier but more powerful at lower speeds. They are also more fuel-efficient in most circumstances[41].

PE generators are used to supply electrical power in places where utility power is not available, or where power is needed only temporarily. Small generators are sometimes used to supply power tools at construction sites. There are also generators used as standby power generators. They are permanently installed and kept ready to supply power to critical loads during temporary interruptions of the utility power supply. Hospitals, communications service installations, data processing centers are some examples that uses this. Thus they can become quite customized depending on its needed purpose[43] [44]. Saab EDS for example

[41] Sven Andersson, Professor, Chalmers University of Technology, Interview 2011-02-23

[42] Sven Olsson, System Designer Electrical Installations, Saab Group, Interview 2011-01-19

[43] Paul Keeley, Harrington Generators, Interview 2011-01-30

[44] Ken Croft, Harrington Generators, Interview 2011-01-30

had previously customized generators that fit the rest of the product better but they have now changed to standard generators in order to bring the final costs down[45].

The development for the PE the last couple of years has been driven by environmental demands from politicians. Emission demands to lower NO_x, CO, HC and particles has been the focus for some time. Today other issues are also to lower the CO_2 level and optimizing the fuel consumption[46]. A lot of efforts are put into this but the problem is to do all at once. There has usually been a tradeoff, for example when you lower the NO_x you lower the combustion temperature and particles increase and vice versa. But researchers are working on different catalysts to solve the issue. However, the diesel engine that Saab EDS is using for its power generation, does not have the same improvement potential as the gasoline engine since it is already powerful at lower speeds[47].

4.1.7.2 Future Development

In the future, the development of the PE will be focused on the energy efficiency and to rationalize the consumption of energy in the engine. Different fuel types, such as Biogas, could then become more interesting to the PE[46].

Another important trend in PE development is downsizing, which means that you turn a four cylindrical to a three cylindrical engine for example. It is best suited for an alcoholic based fuel and it improves the average efficiency of the system and thus decreases the fuel consumption. It can also be done to the gasoline engine but there are some side effects to it[47].

The generator supplier of Saab EDS is working on a variable speed changer. It captures the variable speed of the PE and through electronic conversion units fixes the frequency of the current and thus improves the fuel efficiency of the PE. To manage this, different sensors will be controlled by software. A so called electronic governor will optimize the fuel injection and overall it will, besides the improvement of the fuel efficiency, lower the wear and tear of the system and lower the noise[48] [49].

4.1.7.3 Evaluation of Piston Engine generator

The PE has a lot of moving parts which are exposed to wear and tear. In other words they break from time to time, which affects the mean time between failures in a negative way. A PE that runs on diesel has a good ability to withstand load variations since it works almost as good (in terms of efficiency) in low rotation speeds as in high rotation speeds. *Reliability* is deemed to be around 4.

Due to the constant wear and tear, there is a need for service intervals to add lubricant oil etc. There can also be, due to failures, unpredicted stops which need service and this shortens the service intervals significantly. Maintenance is given a 3.

[45] Lennart Steen, Senior Product Manager, Saab Group, Interview 2011-02-08
[46] Sven Andersson, Professor, Chalmers University of Technology, Interview 2011-02-23
[47] Petter Dahlander, Assoc. Prof., Chalmers University of Technology, Interview 2011-03-02
[48] Paul Keeley, Harrington Generators, Interview 2011-01-30
[49] Ken Croft, Harrington Generators, Interview 2011-01-30

Applications of the engine generator can be seen in many different industries. Its purpose to produce power in places where power is not available or act as a standby system, gives the engine generator a vast industry segment. Thus there are great possibilities to reap economies of scale, and drive the costs down and in turn the price. In accordance with Paranko et al 2001, if the PE generator on the other hand is largely customized to fit each customer's unique need; then the extra needed activities will add to the cost and the benefit of economies of scale could become negligible. The performance/cost ratio of the engine generator is judged to be rather high. The production cost of the PE is rather low and the technology behind the PE is common knowledge i.e. there is a low cost to learn. Although, the cost of usage seems to be rather high since maintenance is something the customers point out to be an issue with the current product. Also, the prices for the generators seem to drive up the prices on the engine generators. Thus the valuated risk for substitution is deemed to be possible, but that is not to say how high a risk it could be. From this, *Technical maturity* is deemed to be a 9.

Potential for improvements for the PE was low according to the interviewed specialists at Chalmers University of Technology. There will be some improvements regarding energy efficiency and emission but nothing radically is expected. However, with the increasing CO_2 demands it will force car manufacturers to meet that in some way and it might lead to more radical changes in the PE. For the generator, the same things are pursued with the variable speed changer, energy efficiency and reducing emissions. Although these changes are still considered as incremental and the overall potential for improvements are deemed low. Furthermore, the growth potential, imitability and tradability are evaluated not to be important for this particular technology since it is ubiquitous (common knowledge) with a low growth potential, i.e. imitated and traded for years. *Diffusion potential* is given a 2

4.1.8 Free Piston Engine

In Table 10 the compiled figures regarding Free Piston Engine is presented. These data are mainly collected from Backlund (2011) and Andersson[50] and are complements to the following text.

For a ~30kW-system	
Size	N/A
Weight	N/A
Operating Temperature (°C)	N/A
Upstart Temperature (°C)	N/A
Life Span	N/A
Sound Level	N/A
Efficiency	> PE
Fuel Flexibility	Same as PE
Cost	N/A
Robustness	Low

Table 10 Compilation of the figures from Free Piston Engine

[50] Sven Andersson, Professor, Chalmers University of Technology, Interview 2011-02-23

The main difference between a traditional Piston Engine and a Free Piston Engine is that the Free Piston Engine does not have any crank system. This means that the Free Piston Engine's piston movement is controlled by forces from the combustion, load, friction, mass and return device. (Backlund, 2011)

The Free Piston Engine can convert mechanical energy directly to electricity. This is done by surrounding the piston with magnets and when the piston moves back and forth electricity is induced. However, this engine is difficult to control and currently there is much research effort that, especially, is targeting this area[51].

4.1.8.1 Evaluation of Free Piston Engine

During the testing phase of the Free Piston Engine it did not fail, however it was only run for a couple of minutes. There are no data regarding the Free Piston Engine's ability to withstand load variations so that cannot be considered. The overall *reliability* is given a 1.

Theoretically the Free Piston Engine could have lesser need for service since it has fewer moving parts than the conventional combustion engine. The operating temperatures are assumed to be the same as the PE. *Maintenance* is given a 2.

There is only one prototype in the testing phase and the performance/cost ratio is very low at the moment. The function of generating electricity directly from the chemical energy in the fuel is an interesting notion, however there are substitutes that already does this (e.g. Fuel Cell etc). *Technical maturity* is given a 1.

The Free Piston Engine is only at its testing phase, thus it has probably a lot of potential for improvements. It needs a better engine control for instance in order to work properly. It could have a growth potential if car manufacturers decides to research more in the technology than what is (assumed) already being done. *Diffusion potential* is given a 3.

4.2 Energy Storage Technologies

Following the same rationale as the power generating technologies some energy storage technologies were neglected due to few articles to prove the seriousness of the technology (such as a self powered battery, Alternative Energy 2010). The identified energy storage technologies were Lithium-Ion battery and Super Capacitor, that stores power/energy will be presented and evaluated. The alternative fuel types; DME, Hydrogen gas and Biogas will only be presented and not evaluated since they are not technologies per se.

4.2.1 Lithium-Ion Battery

In Table 11 the compiled figures regarding Lithium-ion (Li-ion) battery are presented. These data are mainly collected from Stravrevski[52] and Lindberg[53] and are complements to the following text.

[51] Sven Andersson, Professor, Chalmers University of Technology, Interview 2011-02-23

[52] Robert Stravrevski, EVP Marketing & Sales, Alelion Batteries AB, Interview 2011-02-08

[53] Göran Lindberg, Professor, KTH Royal Institute of Technology, Interview 2011-02-21

For a ~30kW-system	
Size	N/A
Weight	340W/kg & 250Wh/kg
Operating Temperature (°C)	10 - 30
Upstart Temperature (°C)	N/A
Life Span (Cycles)	1000
Sound Level	Very low
Efficiency	N/A
Fuel Flexibility	Electricity
Cost	USD 0,5/Wh
Robustness	High

Table 11 Compilation of the figures regarding Lithium-Ion Battery

Lithium-Ion chemistry has evolved as a way to provide more energy in a lighter format. There is no lithium metal in the battery cell, only ions of lithium which makes it possible for the cell to cycle reversible i.e. making the battery cell rechargeable. The high costs/prices so far are due to low production volumes and the development cost recovery (Gold Peak Industries, 2000).

The three primary components of the Lithium-Ion battery are the anode, cathode and the electrolyte. The anode is usually made of carbon, the cathode of a metal oxide and the electrolyte is a lithium salt in an organic solvent. The most commercially popular material for the anode is graphite. The cathode is generally one of three materials, a layered oxide (such as lithium cobalt oxide), a polyanion (such as lithium iron phosphate, commonly used in car batteries) or a spinel (such as lithium manganese oxide) (Elforsk, 2009).

The main principle of the Lithium-Ion cell is that current is carried by the ions from the cathode to the anode during charging and vice versa during discharging. During the discharge the metal oxide oxidizes due to the lithium ions which release electrons that are transmitted as current to an external source, such as an electric motor etc (Gaines & Cuenca, 2000).

The usual form of the Lithium-Ion cell is cylindrical as can be seen in Figure 11. All the gaps between the separators, cathode and anode are filled with the electrolyte. Another shape is the prismatic shape (used in mobile phones etc). The cylindrical is the cheapest to produce at the moment and therefore the most commonly used. The prismatic however gives a higher energy density, but needs an external source of containment as it has a tendency to expand when the state of charge is high[54].

[54] Robert Stravrevski, EVP Marketing & Sales, Alelion Batteries AB, Interview 2011-02-08

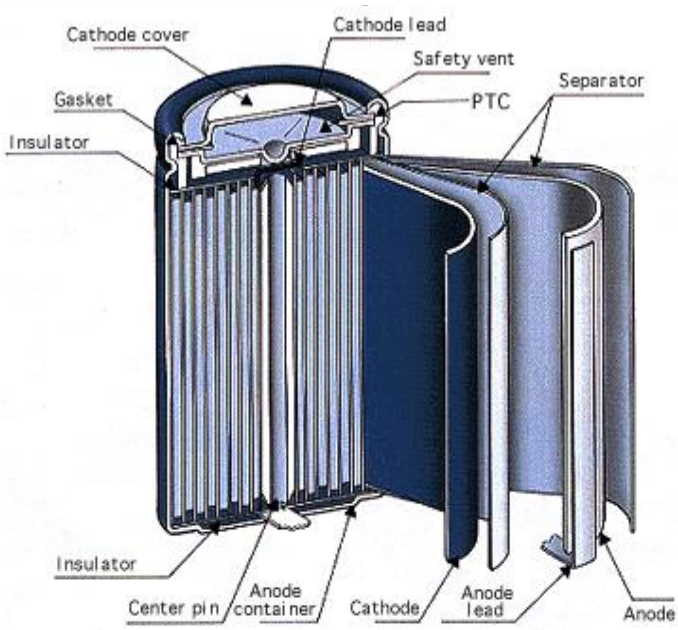

Figure 11 Cylindrical Lithium-Ion cell (Gaines and Curenca, 2000)

4.2.1.1 Technology Today

The Lithium-Ion cell is small, a little thicker than a pencil and about half its length. Cells of around 6 to 12 are usually put together into modules with a control circuit and modules are put together to form battery packs (Gaines & Curenca 2000). They can be put together in all kinds of shapes, thus it is rather flexible depending on where you would want the battery pack in the product. The energy density is around 250 Wh/kg or 500 Wh/L and the specific power is around 340 W/kg at a discharge efficiency of 90 percent depending on what type of cathode materials and the design of the cell[55].

Li-ion batteries can be found in all kinds of consumer electronics, such as laptops, mobile phones etc. The batteries can also be found in aerospace applications and electric vehicles, both military (Smith Electric Vehicle, 2010) and civilian. Alelion has also tried it with an airplane dragger at Kastrups airport. They managed to drag an Airbus for 8,5 hours and still have around 40 percent of the capacity left[55]. The Li-ion battery has been around for almost 20 years so basically it can be found in all applications where it would be economically viable to use a light weight battery which can be recharged. One great advantage with these batteries is its high open circuit voltage which means it increases the amount of power that can be transferred at a lower current. A disadvantage with the battery is that its capacity diminishes over time[56].

The biggest cost of today is the production costs, the material costs for the cathode and the electrolyte salts. The production costs are going down but naturally they are dependent on the volume and the total market for the batteries. Cathode materials are different kinds of metal oxide and there is usually a trade-off of between costs, energy density, shelf life (often

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[55] Robert Stravrevski, EVP Marketing & Sales, Alelion Batteries AB, Interview 2011-02-08

[56] Göran Lindberg, Professor, KTH Royal Institute of Technology, Interview 2011-02-21

in terms of amount of recharging cycles) and safety[57]. Cobalt, Nickel and Manganese have the highest capacity in terms of energy density but they are also more expensive (cobalt most expensive) and not as safe or has as high shelf life as the iron phosphate type (Cringley, 2006).

4.2.1.2 Future Development

One of the most important things for the future development is to increase the amount of applications, the volume and the production capacity in order to get the costs down even further[58]. The greatest boom will be due to the automotive industry in USA, Europe and Japan[57]. They want to decrease the oil dependence through hybrids, both because of the environmental issue and of political power struggle within the oil countries. In 15 years there will be a need for high capacity batteries like never before, which means that not just more batteries are needed but the world needs better batteries to be developed[58]

This can be seen in the amount of money and interest that is spent in R&D. For example, in the next five years, BASF one of the leading chemical companies will be investing a three-digit million sum in Euro for battery related activities. These include the company´s own R&D programs dedicated to optimization of Li-ion technology and new battery concepts, and co-operations with partners such as the research network Electrochemistry and Batteries. The aim of this is to translate research findings more rapidly into products for high-energy battery systems. The partners will jointly be investing further EUR 12 million into these activities (SpecialChem, 2011).

Japan is putting a lot of interest in the battery development in general. According to the Japanese ministry of economy trade and industry (METI), they have an ambitious goal that by 2030 batteries should be able to hold a charge capacity seven times higher than the Li-ion batteries of today and cost 40 times less (Sweden-Japan Foundation, 2009).

In the coming 15 years one can expect an increase of about 100 percent in energy density and around 50-75 percent lesser cost[57]. However, the energy density is not expected to get much higher than that since the Li-ion battery is chemically limited. A new lithium-air battery can be the future solution to this. It is still only in laboratory phase and historically it has taken around 10 years (which would mean in the year 2021, maybe earlier since it has been in lab phase for a couple of years) from laboratory to a commercially available product. It is showing a specific power of 4000 W/kg, which is about 10 times more than the Li-ion battery[58]. It would reach an energy density of around 5000Wh/kg which would translate into an electric vehicle getting around 80 miles (metric system) in one charge cycle (Abrahamson, 2009). With air as a reagent you can decrease the size of the battery and with it, its weight. Also it means replacing for example the metal oxide of lithium and cobalt with porous carbon which would drive down the costs even further as well (Westerholm, 2009).

Another interesting research that is being conducted is for different designs of the battery cell. Since researchers are working to improve power and energy density, safety, recharge

[57] Robert Stravrevski, EVP Marketing & Sales, Alelion Batteries AB, Interview 2011-02-08

[58] Göran Lindberg, Professor, KTH Royal Institute of Technology, Interview 2011-02-21

cycle and cost, a solid-state design seems beneficial. It has the potential to deliver three times the energy density of a typical Li-ion battery at less than half the cost per kilowatt-hour. This is because a solid-state would eliminate binders, separators and liquid electrolytes and getting a 95 percent of the theoretical energy density (Voith, 2010).

One issue that needs to be address, which is essential for the development of electric vehicles, is the infrastructure to recharge them. Who should build it and how should it be financed are questions that need to be answered[59].

4.2.1.3 Evaluation of Lithium-Ion Battery

The Li-ion battery has no moveable parts, which makes the aspect of *reliability* high. Adding to this, the Lithium-Ion battery is usually used as a complement to another power source. For instance, the hybrid system used in automotive industry combines an engine with a battery. One reason for this is that the battery can handle the load variation well and thus increase the efficiency as well as the life span of the engine. Moreover, since the robustness is considered as medium for Li-ion battery the reliability is given 8 out of ten.

The fact that the Li-ion battery has few moveable parts makes the *maintenance* aspect advantageous. In addition, the main reason for servicing the Li-ion battery is to check of it needs to be replaced since it can only be used a fixed amount of cycles. Consequently, the score regarding maintenance for the Li-ion battery will be given 9 out of ten.

The Li-ion battery is used in many applications. From smaller versions in for example mobile phones, laptops, etc to larger applications in for example cars. This makes the Li-ion battery a well proven technology with a wide range of possible applications. Also, the increasing interest can certainly boost the production volume in order to lower the cost which still is quite high. Therefore, the performance/cost ratio is currently medium but will certainly be lowered in the coming future when the cost goes down further. As a result, the *technical maturity* of Li-ion battery is deemed 6 out of ten.

As mentioned, the Li-ion battery can be used in a wide range of applications. The interest in the technology is increasing and there are several companies involved in the development and production. This makes the tradability of Li-ion battery easier and hence the *diffusion potential* is given the score 7 out of ten.

4.2.2 Super Capacitors

In Table 12 the compiled figures regarding Super Capacitor are presented. These data are mainly collected from Lindberg[60] and are complements to the following text regarding Super Capacitors.

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[59] Robert Stravrevski, EVP Marketing & Sales, Alelion Batteries AB, Interview 2011-02-08

[60] Göran Lindberg, Professor, KTH Royal Institute of Technology, Interview 2011-02-21

For a ~30kW-system	
Size	N/A
Weight	6kW/kg & 30Wh/kg
Operating Temperature (°C)	-40 - 105
Upstart Temperature (°C)	N/A
Life Span (Cycles)	500 000
Sound Level	Very low
Efficiency	95%
Fuel Flexibility	Electricity
Cost	USD 5/Wh
Robustness	High

Table 121 Compilation of the figures regarding Super Capacitor

Super Capacitors are electrochemical double-layer capacitors (EDLC) which have the energy density of about a thousand times more compared to conventional electrolytic capacitors[61].

The idea behind capacitors is that energy is stored physically by the removal of charge carriers, typically electrons, from one metal plate and places them on another. Thus an electrical potential is created between the two plates which can be harnessed when an external circuit is connected. Energy stored is proportional to potential between plates, the amount of charge stored (which is depended on size of the plates and material of plates) and material (the insulator or dielectric) between plates. A Super Capacitor polarizes an electrolytic solution to store energy electro statically in double layers with only a few nanometers apart (FMV, 2004).

4.2.2.1 Technology Today

In general Super Capacitors are compared to conventional batteries, both primary (consumable such as alkaline batteries) and secondary (rechargeable such as the Li-ion battery). It cannot generate or convert anything into electricity, thus it goes in the same category "energy/power storage" as batteries. The amount of energy stored per unit weight is around 30 Wh/kg, lower than Li-ion batteries (and about 1/1000th the volumetric energy density of gasoline) but has a higher power density 6 kW/kg than the Li-ion battery (See Figure 12). However the picture might understate some values for the newer technologies Fuel Cell, Li-ion battery and double layer capacitors, where higher values (both energy and power density) have been seen in products. Super Capacitors have considerably a higher self-discharge compared to batteries and a linear discharge voltage prevents use of the full energy spectrum[61]. On the advantage side, they have extremely long lifespan in terms of charge cycles, 500 000 cycles or more which makes them very environmental friendly (FMV, 2004). Currently, they are more expensive (per energy unit) than Li-ion batteries, but the long life span might make it up in the long run (U.S Department of Energy, 2009). Also they have very high rates of charge due to its low internal resistance (charges fast and easy) and discharge and high efficiency (around 95 percent)[61].

[61] Göran Lindberg, Professor, KTH Royal Institute of Technology, Interview 2011-02-21

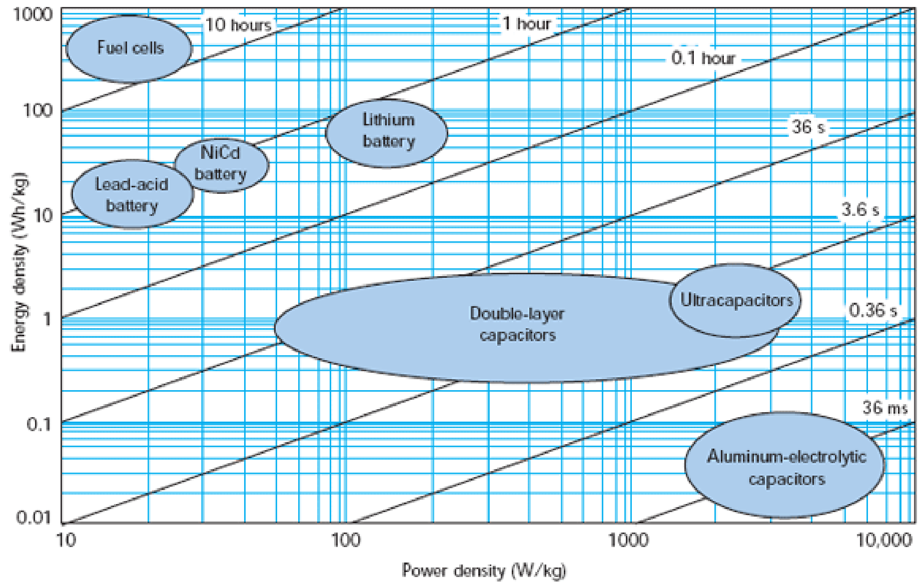

Figure 12 The Ragone Chart illustrates different energy devices and their relative power and energy densities. (Electronic Design Europe, 2009)

One practical application for the Super Capacitors is starting help for the internal combustion engine (Pastos, 2009). Internal resistance in a conventional battery of today increases in an external environment with a temperature of -40˚C, causing it to lose its power by a factor of 30[62]. Super Capacitors will not be affected much with such a low temperature (Pastos, 2009).

Super Capacitors' easy and fast recharging skills make them ideal for regenerative braking applications. This has been tried in different hybrid cars, buses and light rail vehicles (trams in cities etc) (Railway Gazette, 2006).

According to a market analysis study of the potential increase of sales in the coming 5 years, Super Capacitors will have an average annual growth rate of around 21 percent (Innovation Research and Products Inc, 2010).

4.2.2.2 Future Development

Research in EDLCs focuses on improving materials that offer higher usable surface areas. Both in terms of increasing the area of where to place electrons, and to use nanoporosity materials instead of the insulating barriers (the dielectric, material between the plates) that is used today. The purpose is to increase the power and energy storage capacity. Carbon nanotubes are one such material researchers are looking into[63]. MIT is working on nano-scale ultra capacitors. They have a higher energy density than the Li-ion battery of today, but they are still in the developing phase (Mulroy, 2010).

[62] Sven Olsson, System Designer Electrical Installations, Saab Group, Interview 2011-03-16

[63] Göran Lindberg, Professor, KTH Royal Institute of Technology, Interview 2011-02-21

Super Capacitors are also tried in different prototype cars where they are put in combinations with a battery to create a ultra battery, which creates an electric vehicle that lasts longer, costs less and is more powerful than a regular plug-in hybrid electric vehicle (U.S Department of Energy, 2009).

4.2.1.3 Evaluation of Super Capacitors

Super Capacitors do not have any moving parts which could negatively affect the reliability of a system. The fast recharge and charge abilities, the high robustness and the main function of applications today (act as a backup system, starting system, brake energy regeneration etc.) makes the Super Capacitor ideal for withstanding powerful load variations. *Reliability* is deemed to be a 10.

There is no need for maintenance during the useable life of a capacitor (Lev, 1999) and with the extreme long life span, the Super Capacitors is the best of all the investigated technologies in terms of maintenance. It also has high resilience to different operating temperatures (works about the same in the span -40 to 105˚C). *Maintenance* is given a 10.

Application areas have been mentioned above. It shows that the Super Capacitor, due to its limited energy density, has found its niche markets. Whether these markets are enough to reap scale economics is not known, however the prices of Super Capacitors are even higher than Lithium ion batteries. Thus it is assumed that Super Capacitors need more markets to lower its costs. Performance/cost ratio is high when performance regards the specific power density but low when it regards energy density. Substitutability is deemed to be low since there is no known technology (mind you technology, thus better capacitors does not count) that has better specific power density. Overall *technical maturity* is given a 5.

The potential for improvements will probably mainly be in the areas of increasing energy density (area of storage electrons with different materials and nanotechnology) and in new applications. Research with battery could evolve into a new kind of battery that uses both techniques in order to combine the strengths of both. Growth potential could be large if the automotive industry decides to use, in a larger extent than today, the technology in all produced cars. Same goes for ease of trade, which will be better if more players of the automotive industry get involved. *Diffusion potential* is given a 6.

4.2.3 Alternative Fuels

Ecological friendlier fuels compared to diesel or petrol are DME (Dimethyl ether), Hydrogen gas, Biogas among others. The common challenge for all of the eco fuels is the infrastructural/political issue, which of them should the government or private companies invest in[64].

4.2.3.1 DME

DME is often produced from natural gas or coal and is often used as a refrigerant in households and industries in China. DME is a promising fuel in diesel engines, petrol engines and Gas Turbines, only moderate modifications are needed to convert a diesel engine to

[64] Magnus Karlström, Analyst, Vätgas Sverige, Interview 2011-02-10

burn DME. DME meets even the most stringent emission regulations in Europe (EURO5) (International DME Association, 2010). Now it is also being produced as a synthetic second generation Biofuel (BioDME) from lignocelluloses biomass in Piteå Sweden (Chemrec, 2010). It is being manufactured from black liquor gasification from the paper pulp industry which is waste from the production of paper[65]. The potential is huge and could supply over one million heavy trucks from the available black liquor feedstock (Chemrec, 2010).

4.2.3.2 Hydrogen Gas

Hydrogen gas is mainly produced from the steam reforming of natural gas, and less often from more energy-intensive methods like the electrolysis of water (Florida Solar Energy Center, 2007). If the energy used in the electrolysis of water is from renewable sources, the production process becomes completely environmental friendly. And since its development follows the development of Fuel Cell (the process is the same but in reverse) an improvement in the energy efficiency and cost will decrease proportionally. Most of the produced hydrogen is used near its production site, with the two largest being fossil fuel processing and ammonium production for the fertilizer market. Other applications for it can be found in automotive, power generation, aerospace etc[66]. A difficulty with handling hydrogen is its property to react to any oxidizing element. It can spontaneously in room temperature. This makes it a concern in the design of pipelines and tanks for storage since the oxidizing process embrittles many metals[67].

4.2.3.3 Biogas

Biogas is a renewable fuel which can be produced through anaerobic digesters (break down by microorganisms in absence of oxygen) of biodegradable wastes including sewage sludge, waste paper, grass clippings, animal waste, and food waste (U.S Department of Energy, 2010). Thus it can be produced everywhere[66]. Biogas can be compressed, much like natural gas and used to power motor vehicles. In the UK, for example, it is estimated to have the potential to replace around 17 percent of vehicle fuel (Baldwin, 2008).

[65] Henrik Thunman, PhD, Chalmers University of Technology, Interview 2011-02-14

[66] Magnus Karlström, Analyst, Vätgas Sverige, Interview 2011-02-10

[67] Per Ekdunge, Vice President, PowerCell AB, Interview 2011-01-25

4.3 Summary of all the Energy Technologies

Below are two tables, power generators and energy storage, which summarizes what have been discussed above.

Power Generators	PEM	SOFC	Gas Turbine	Thermoelectric Generator	Solar Cell	Stirling Engine	Wankel Engine	Piston Engine Generator	Free Piston Engine
Size (W/dm^3)	100	100	<< PE	N/R	1 W/dm^2	11	<PE	17	N/A
Weight (W/kg)	2000	500	50	50	3	120	<PE	33	N/A
Operating Temperature (°C)	60-80 or 300-400	800–1000	Same as PE	N/R	N/R	-10-60	Same as PE	90	N/A
Upstart Temperature (°C)	-25-60	-25–800	Same as PE	N/R	N/R	-40-60	Same as PE	-40	N/A
Life Span (hours)	5000 – 40 000	N/A	Same as PE	~10 years	N/R	60 000-100 000	N/A	N/A	N/A
Sound Level	Very low	Very low	70 db at 10m	Very low	Very low	Low	Same as PE	70 db at 7m	N/A
Efficiency (%)	40-60	50-65	Same as PE	4-8	7-20	Slightly above PE	<PE	30	>PE
Fuel Flexibility	Hydrogen or Reformat	Everything	Everything	Diff. In Temp.	Sun Light	Heat	Same as PE	Diesel	Same as PE
Cost (SEK/kW)	>> 1000	40 000	Slightly above PE	30 000	11 340[68]	18 000[69]	N/A	N/A	N/A
Robustness	High	High	Medium	High	Low	High	Medium	High	Low
Reliability	8	8	4	9	4	6	3	4	1
Maintenance	5	5	4	6	8	7	3	3	2
Technical Maturity	6	6	7	4	2	3	2	9	1
Diffusion Potential	6	6	6	5	2	3	2	2	3

Table 13 Compilation of the figures for the investigated Power Generation Technologies

[68] Based on the exchange rate 1 USD = 6,3 SEK

[69] Based on the exchange rate 1 EUR = 9 SEK

Energy Storage	Li-ion Battery	Super Capacitor
Size (W/dm^3)	N/A	N/A
Weight (W/kg & Wh/kg)	340 & 250	6000 & 30
Operating Temperature (°C)	10-30	-40-105
Upstart Temperature (°C)	N/A	N/A
Life Span (Cycles)	1000	500 000
Sound Level	Very Low	Very low
Efficiency (%)	N/A	95
Fuel Flexibility	Electricity	Electricity
Cost (USD/Wh)	0,5	5
Robustness	High	High
Reliability	8	10
Maintenance	9	10
Technical Maturity	6	5
Diffusion Potential	7	6

Table 142 Compilation of the figures for the investigated Energy Storage Technologies

4.4 Selecting the Most Interesting Energy Technologies

In this section the most suitable power generation technologies and energy storage technologies will be selected. By examining the Tables 13 and 14 the most promising technologies are Fuel Cells (both PEM and SOFC), Gas Turbine, Li-ion Battery and Super Capacitor. This is based on the fact that they satisfy Saab EDS's and their customers' demands. However, the remaining technologies will not be preceded with since they are not suitable for the intended application based on some of their parameters. Also, the criterions in Table 13 and 14 are almost equally important, but it is important to keep in mind that some are considered as order qualifiers and some as order winners within certain values which affects the selection. Moreover, the main reasons for not choosing some of the technologies are the following:

Thermo generator was not chosen because of the difficulties with having a system that is totally dependent on temperature difference. This is also evident in the analysis of the present applications, namely that the thermo generator main function is to make a power supply system more efficient. Another reason was that the cost efficiency ratio is high. With the low efficiency and the high cost it is somewhat hard to motivate a change of the current system.

Solar Cell is advantageous in terms of usage in remote areas since it uses sun light as fuel. This could also be beneficial in military applications because the need for transporting external fuel, such as diesel, will be eliminated. However, Solar Cell is more suited for stationary applications. In order to satisfy the required power output in a radar system the size will be too large and not manageable. This is because the theoretical maximum output from sun light is 1 kW/m^2 and with an efficiency of 15 percent the size would have to be close to $200m^2$. For this reason, the Solar Cell will not be proceeded with.

From Table 13, Stirling Engine may look like a promising technology that can satisfy Saab EDS's and their customers/users demand. However, the reason for not proceeding with Stirling Engine is the fact that it only serves a niche market and is expected to only serve this niche market in the future as well. Adding to this, there are not many companies active in developing and pushing this technology. Consequently, the technical maturity and diffusion potential is too low and will most likely not be increased which make this technology not attractive and well enough proven for the intended usage.

Wankel Engine was not chosen since the lesser weight and size of the engine does not outweigh the higher efficiency of the current system. The technology is incumbent but has still not been adopted to any significant extent which makes one wonder if it ever will be. This together with the low technical maturity and diffusion potential makes the technology one of the technologies with the less believed potential.

The Free Piston Engine is still in its developing stage. It have not been tried or used in any commercial applications. In addition, this technology only exists in laboratories and research facilities. Consequently, this technology is not technical mature enough to be proceeded with, especially since Saab EDS wants a technology that is reliable and well proven.

5 Looking into the Future

In this chapter the selected energy technologies from the previous chapter will be analyzed in accordance with possible future development. More precisely, a scenario analysis will be conducted in order plan the future. Thereafter, the selected energy technologies; Fuel Cell, Gas Turbine, Li-ion Battery and Super Capacitor will be fitted into the developed scenario and analyzed. The energy technologies will be mainly analyzed with the frameworks; Qualities for evaluating a technologies adoption potential and Conditions for a large scale transformation. This is done in order to understand the development of each technology in relation to the present technology, the Piston Engine generator, in the possible future scenarios.

Moreover, the chapter will start with the theoretical framework. Next, the empirical data that concerns the trends, driving factors and critical uncertainty will be presented in order to create the future scenarios. After that, the technologies will be analyzed in each scenario. Finally, the implication each scenario will pose for Saab EDS as well as the signals that can help to indicate which direction the critical uncertainties is taking will be presented.

5.1 Theoretical Framework

In this section the theoretical framework used to create future scenarios will be presented as well as the theoretical frameworks used to analyze the energy technologies in each scenario. This includes Scenario Planning, Qualities that determines a technology's adoption rate, Conditions for large scale transformation and S-curve for technical performance and technology adoption.

5.1.1 Scenario Planning

Planning for future event is difficult and, adding to this, when forecasting the future the predictions are usually wrong. For instance, using traditional forecasting techniques such as extrapolating the past have been less successful for many US industrial companies (Bood and Postma, 1997). This is because it is difficult to make the prediction accurate when there are many uncertain factors as well as when the world is changing rapidly (Chermack, 2003).

When future events are relative static and less uncertain the traditional forecasting techniques are certainly more useable. This is usually true in a shorter time span in terms of prediction horizon. However, when looking further away into the future it becomes less and less predictable (Börjesson, 2011). One way to plan for future events when there are many uncertainties is using Scenario Planning (Bood and Postma, 1997). The traditional forecasting techniques focuses on giving one forecast while Scenario Planning focuses on the uncertainties and as a result presents multiple outlooks regarding future events.

The basic idea behind Scenario Planning is that instead of predicting one specific future, several scenarios are created in order to cover plausible future scenarios depending on the uncertainties. Also, it is important to keep in mind that Scenario Planning is done in order to highlight the large-scale forces that push the future in different directions. By making the driving forces visible the possible future events will be more easily recognized when it happens. (Wilkinson, 1995)

In order to successfully carry out scenario planning it is important to start wide, by generating a list of possible factors, and then classify and narrow them down in order to flesh out scenario plots and thus becoming wide again. Moreover, there are probably many driving forces and uncertainties which create an infinite number of possible future scenarios. Hence, it is vital to know how to narrow the possible scenarios into a more managerial numbers, preferable three to four scenarios. (Ogilvy and Schwartz, 2004)

The first step in Scenario Planning is to formulate the focal issue. In this step it is important to gather information and decide the time frame, i.e. how far into the future to plan. By doing this, the focal issue can be derived which should be central and related to the future development in the specific topic. The next step is to identify influencing factors. These factors should then be grouped in clusters with clear and specific headings. After this, the driving forces from the external environment need to be identified. These forces can be identified with for example PESTEL-analysis. The fourth step is to prioritize and rank the driving forces as well as the influencing factors. They should be ranked with regards to their impact and uncertainty in a diagram. The fifth step is to identify the scenario logic. This means that the two most significant driving forces and influencing factors in terms of their uncertainty and impact should be selected. These two factors/forces should then be formulated in their extremes in order to create a scenario cross where four possible outcomes can be derived depending on the forces/factors extremes. The sixth step is to develop the scenarios. This means that the four scenarios which are created from the scenario cross should be described in more detail in terms of what happens in each specific world. For instance, who is the winners and who is the losers, what happens with the focal issue and so on. The seventh step is to write the stories in each of the scenarios. It is important to describe each scenario with a story of how the development from now has lead to the future settings in the specific scenario. In the eighth and last step, the indicators should be identified. The indicators are the signs which help to signal that a specific scenario is starting to unfold. This can be done by searching the causes upstream step by step and identify the visible effects. (Börjesson, 2004)

5.1.2 Qualities that Determines a Technology's Adoption Rate

It is not always the superior technology that gets widespread (Rogers, 1995). For example, the QWERTY keyboard was invented in order to slow down the typist because the typewriters in 1873 could easily get jammed if the keys where pressed too rapidly. As the typewriter improved the QWERTY keyboard-design was not needed anymore. This lead to a new keyboard-design called Dvorak keyboard which was superior in terms of possible typing speed. However, even with the overwhelming advantages with Dvorak keyboard it never replaced the QWERTY keyboard. One reason for this is that vested interests are involved in hewing the QWERTY keyboard. Another related observation is that advantageous technologies will not, for the most of the time, sell themselves. Many inventors make the mistake and focus solely on their invention and believe that the advantages will be easily understood and that the innovation will diffuse rapidly. Still, most innovations diffuse in a disappointedly slow rate (Byers et al., 2011). Hence, it is important to understand the reasons that determine the rate of adoption.

According to Rogers (1995), innovation refers to an idea, practice or object that is perceived as new by its audience or other unit of adoption (Rogers, 1995), as was mentioned in section 3.1. In addition, in Rogers (1995) definition of innovation it does not matter if the idea is objectively new in terms of its first use and discovery. Instead, as long as the idea seems new to an individual it is an innovation.

As explained earlier, the rate of adoption regarding a technology differs in its lifecycle. It is the perceived characteristics of a technology from the individuals that is the main factor that determines the rate. Rogers (1995) introduces five qualities that the adopters (individuals) perceive of the innovations and determines the success of an innovation. By having greater perceived degree of these following qualities, by individuals, an innovation will be adopted more rapidly:

Relative Advantage, this concept refers to the degree which an innovation is perceived as favorable compared to the innovation it is superseding. As mentioned earlier, even if an innovation is superior if looked at objectively it does not matter. The important aspect is if the innovation is perceived as more advantageous by the individuals. Additionally, the relative advantage is measured mainly in economical terms but social prestige, convenience and satisfaction is important measurement as well. The rate of adoption will, thus, increase as greater the relative advantage of an innovation is.

Compatibility, in this aspect the existing values and practices have a crucial role. It is important that the innovation introduced is compatible with the current value systems in order to adopt more rapidly. This means that the degree to which the existing values, past experiences and needs of potential adopters is perceived as consistent with the innovation. If the innovation is incompatible, a new value system will be needed prior to the adoption of the innovation which is a relatively slow process.

Complexity, basically this refers to the simplicity of the innovation. New ideas that are easily understood will be adopted more rapidly than innovations that require new skill sets and abilities. Hence, complexity is the degree to which an innovation is perceived as difficult to use and understand.

Trialability, this concept refers to the degree the innovation may be tested on a limited basis. By allowing a trial period such as an installment plan the adoption rate can increase. This is because it represents less uncertainties to the individuals as it enables learn by doing.

Observability, this refers to the degree the innovation is visible to the individuals. If the individuals can see the results from an innovation and it is a positive result, the individuals will be more likely to adopt it. With high observability, the uncertainties may be reduced and can generate peer discussions of the innovation as the surrounding of an adopter often request information about it.

A key principle in diffusion of an innovation is reinvention. Besides from the above qualities, it is essential that the innovation evolves in order to meet the needs from more and more demanding individuals. Hence, an innovation cannot rest on its laurel and must continuously improve in order to spread (Rogers, 2003).

5.1.3 Conditions for a Large Scale Technological Transformation

Except for the above mentioned qualities regarding the characteristics of a technology, there are other factors that are important to understand. It is not only the internal aspects that determines the adoption rate, there must be enabling external factors as well in order for a large scale transformation of a new technology to happen. Jacobsen and Lauber (2006) present four conditions which determine the possibility for a large scale technological transformation. These four conditions capture the characteristics of the early phase, i.e. formative stage, in such a transformation and how to shift the new industry into the growth phase.

First, there must be an *institutional change* since there are limited resources in research and new technologies always compete with each other to gain recognition. The new technology must be supported by investment in research, technology and education that is linked to it (Jacobsen and Lauber, 2006). There must be available knowledge in the new field in order for the new technology to grow and generate competing designs (Jacobsen and Bergek, 2004). Thus, institutional change sets the sparks for a technological transformation.

The second condition is *market formation* since there will be a need for available markets in order for the early entrants, in the new technology, to sell their new products and progress as well as to take the risk to enter. The early market formation gives the firms a nursing market, i.e. a protective space, which often is a small niche market or area where the new technology is an effective solution. Also, these markets provide the firm with a place to try out their new technology and improve it by learning. (Jacobson and Lauber, 2006)

Thirdly, there must be a formation of *technology-specific advocacy coalitions*. In addition to firms, a new technology needs support from other types of organizations such as universities, non-commercial organizations and politicians. By forming these advocacy coalitions, the new technology can engage in political debate in order to influence institutions and secure institutional alignment. (Jacobson and Lauber, 2006)

The fourth condition is the *entry of new organizations.* This condition is central to the transformation process since each firm that enters brings additional knowledge, capital and other resources to the industry. The new entrants can also generate positive external economies by building up a skilled labor force and specialization, between the firms, which can lead to greater efficiency. Moreover, when well established companies enter the new market the legitimacy of the new technology and market will increase. (Jacobson and Lauber, 2006)

5.1.4 Patterns of Technical Performance and Diffusion: Technology S-Curves

The diffusion of a technology and the technology’s improvement over its lifetime has been shown to exhibit s-shape curve (Schilling, 2010; Lindmark, 2006; Rogers, 1995). The idea behind the S-curve is that major innovations enables opportunities and increase the marginal returns to technological effort. The curve is steeper (performance/effort) further away from the technical limit and levels out as the limit is approached. Naturally, there exist a relation between the improvement in performance of a technology and its diffusion (the spread). Both the performance improvement and the diffusion exhibit the S-curve in shape. When a technology is getting better it motivates faster adoption and vice versa. However, there are some differences which suggest a separate description among these two S-curves.

5.1.4.1 S-Curves in Technological Improvements

The improvements of a technology usually follow an S-curve (figure 13). The reason behind these phenomena is that in the early stages of a new technology the potential may not be realized. There is limited knowledge regarding the fundamental of the technology. In addition, if the technology is very different compared to the previous ones there are probably barriers such as no evaluation routines that enable researchers to assess its progress or potential.

However, a technology can increase its legitimacy (for example overcoming such barriers) when scientists, incumbent firms and new entrants gain deeper knowledge about it. As a result, expected returns on investments in technical development may be raised and thus improvements begin to accelerate since more resources will be devoted to improving the technology. (Schilling, 2010; Lindmark 2006)

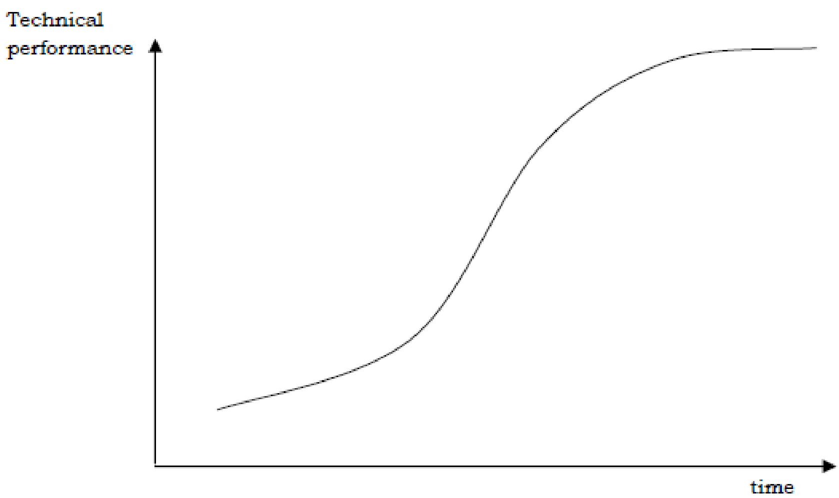

Figure 13 S-Curve: Technical Performance against Time (Lindmark, 2006)

The technical performance can be expressed (as was mentioned earlier) in several factors such as speed, capacity, etc. It is usually either plotted against time or effort. But, it is important to be careful when plotting it against time since the effort invested may not be constant over time. Instead the resulting curve could appear to flatten much more quickly or not flatten at all. If the effort is constant over time the technical performance's S-curve plotted against effort will result in the same pattern as plotted against time. (Schilling, 2010)

Looking at the S-curve, the technical improvements regarding a specific technical solution cannot go on forever. As seen, after a certain time the S-curve flattens meaning that the technical improvements have almost reached it limits. Eventually there are physical limits which cannot be exceeded, for example traveling faster than the velocity of light (Lindmark, 2006). On the other hand, these limits are not fixed and may vary depending on the technology. Some technologies have higher performance limits as well as steeper S-curves. This conception is important to keep in mind since it is often greater returns from effort invested in a current technology in early stages. Consequently, many firms are reluctant to change into new technologies. As a result, incumbent firms has a difficult time to choose between investing in the new technology or in incumbent technology while new firms entering the industry are likely to choose the new technology. In the long run new technologies often displace the incumbent technology if it has much greater performance potential for a given amount of effort (Shilling, 2010).

Furthermore, technologies do not always reach its limits since they could be disrupted by new technologies. This means that, before the flatten pattern in the end of a technology's S-curve is reached a disruptive technology that fulfills a similar market need is introduced and thus creating another S-curve. In addition, the disruptive technologies' S-curves usually have steeper or higher performance limit (Schilling, 2010).

5.1.4.2 S-curves in Technology Diffusion

The technology diffusion S-curve is obtained by plotting the cumulative number of adopters of the technology against time. As the technology improves and becomes better understood and utilized, the adoption accelerates until the market is saturated and thus the rate of new adoptions declines. (Schilling, 2010)

An interesting feature regarding technology diffusion is that it usually takes far more time than information diffusion. For instance, Mohr (2001) give the example of the diffusion regarding industrial robots. Even though, the industrial robots' advantageous where known by the potential users it took 12 years for half of them to adopt the industrial robots. One reason for the slow adoption rate of an innovation, even though it is superior to the existing solutions, may be the complexity of the knowledge underlying new technologies as well as available complementarities (as was mentioned earlier) (Schilling, 2010). In addition, Moore (1995) explains that knowledge that is necessary to utilize a technology may not only be transmitted manual or other documentation. The need of sharing tacit knowledge and experiences between the potential adopter is necessary in order to fully realize the potential. Hence, despite awareness of the technology and its potential advantages the potential adopters will not adopt it until such knowledge is available.

As explained in the previous section, complementarities are an important aspect when it comes to commercialization of an innovation. Without complementarities an innovation may not fully realize its potential or even not be useful at all. Especially when it comes to power generation technologies, there must be available infrastructure regarding the specific fuel in order for the technology to be widely spread. Byers et al. (2011) give an example where they explain that there must be suitable widely located electric recharge stations, otherwise the future of electrical vehicles is very limited.

Furthermore, the characteristics of a technology will be important in terms of diffusion rate. With higher degrees in these qualities the adoption rate will have a higher diffusion rate. These aspects have been explained in section 5.1.2.

5.2 Empirics and Analysis to develop the Scenarios

This section will present the driving forces and the important trends, which are deemed to be important for the future development regarding the focal issue "How will power supplies in the range of 50 kW develop in the coming 15 years ". 50 kW is used since it is likely that the power need will increase in the coming future. In the final sub chapter the factors and trends are plotted into a diagram (Impact/Uncertainty) using the framework of scenario planning, in order to select the most critical uncertainties for the next stage; developing the scenarios.

5.2.1 Driving Forces

There are many factors that influence the development of 50 kW power supplies. Considering factor such as political decision, investments in environmental friendly technologies, oil price, social life-style and technology development can help in understanding and determining the future development and employment of the investigated technologies.

Political decisions are an important factor that can certainly influence the development of power supplies. Agreements and regulations from governments can hinder or promote different energy technologies. For instance, the Kyoto protocol which is about reducing emissions globally and deregulating the electricity market as well as the agreement from both the European Union and G8 leaders to lower the $C0_2$ emission (FMV, 2004; IPHE, 2011).

The *investments in new energy technologies* and complementarities are crucial in order for them to develop and diffuse. This can both be done by government and/or private actors. In addition, the political factor is especially important since they are the main driving force behind investments in many cases[70]. According to IEA (2008) additional investments are needed in order for certain emission goals to be realized. For instance, the investment needed to reach a 50 percent reduction in CO_2-emission compared to the investment needed to keep the CO_2-emission at current level in 2050 differs a lot. In order to keep current CO_2-emission in 2050, an investment of USD 0,7 Trillion is needed and to decrease the emission with 50 percent an investment of USD 3,6 Trillion is needed (IEA, 2008). Moreover, investments and political decisions regarding developing and expand a certain technologies infrastructure is vital for its future progress. For instance, according to Ekdunge[71] and Karlström[72] the diffusion and adoption rate of Fuel Cell technology will certainly depend to a high degree on the available infrastructure. Consequently, increase in investments in environmental friendly technologies will certainly influence the development of future power supplies.

[70] Anders Palmqvist, Professor, Chalmers University of Technology, Interview 2011-02-18

[71] Per Ekdunge, Vice President, PowerCell AB, Interview 2011-01-25

[72] Magnus Karlström, Analyst, Vätgas Sverige, Interview 2011-02-10

Another important driving factor is the *oil price*, which in turn is based on the demand and supply of oil. Also, if peak oil is achieved due to the lack of new reserve discoveries, the demand will certainly increase while the supply decrease and thus making the oil price raise (Campbell, 2003). Adding to this, the population growth in the world together with the fact that developing countries getting modernized will increase the energy consumption in the world. The energy consumption includes burning of oil (EIA, 2010). Hence, if oil price goes up because of diminishing supply the need for new technologies will be important in order to match future demand (NPC, 2008). In addition, a main reason for the low diffusion rate of alternative technologies today is the fact that the cost is too high compared to traditional Piston Engines. Although if price of oil increases to a certain level the PEs total cost advantage will diminish[73] [74].

Furthermore, the *life-style in the current society* is an important factor (SEVS, 2011). Even though there are political decisions and driving forces regarding emission rates and support for alternative technologies, the people must employ it and support it in order for it to fully diffuse and be adopted. Adding to this, the need for transport among the people will be an important factor as well (SEVS, 2011). If the need for transportation increases the need for alternative technologies might increase as well, especially since there are emissions goals from political and no-political organizations.

The *technology development* is a vital factor which in turn will depend on the support from different actors. Greater support will certainly lead to increased improvements in a certain technology. Consequently, the technology might be more lucrative since for example it is finally good enough and/or cheap enough. The support from the automotive industry will therefore be an important factor as well since if they employ a technology the manufacturing volume can increase vastly. (SEVS, 2011)

5.2.2 Trends

Several factors affect trends in the energy demand of the world. Two of the major drivers are the growing world population and growth of the world GDP. Over the last 35 years the energy demand as increased by 96 percent compared to an increase of the GDP by 167 percent and a population growth of 66 percent (IEA 2009). These trends will likely continue in the same direction. Some reports expect the population to be around 8.2 billion people by the year 2030 (IEA 2009). Regarding the global financial position, the world's total GDP is expected to grow in a steady state of around 7 percent per year in the coming years (The World Bank, 2010). This means there will be an increase in the demand of energy.

In EU, the oil consumption is still the dominant energy source (European Commission, 2009). However, in recent years the oil consumption has gone down in terms of percentage of total energy consumption. In addition, IEA (International Energy Agency) member countries have also diversified their energy mix in production, supply and consumption (IEA, 2009). The main reasons for less usage of oil among the IEA member countries are the increase usage of nuclear energy and in recent years the increase development of non-hydro renewable,

[73] Sven Andersson, Professor, Chalmers University of Technology, Interview 2011-02-23

[74] Per Ekdunge, Vice President, PowerCell AB, Interview 2011-01-25

especially wind power. This will probably progress in the same direction with increasing development of non-hydro renewable, such as solar and wind power, in the near future (IEA, 2009).

There is an increasing environmental awareness among society. More people are taking an active environmental responsibility and top management has for example become increasingly involved in green/sustainable decision and solutions (Akel, 2006). However, regarding the industry where Saab EDS acts it is difficult to see whether this global trend will have the same development. It has not been any major environmental demands earlier; however there could be changes in the future. Although, another argument could be that due to the sensitive issue of country defense this industry could still be overlooked[75].

5.2.3 Critical Uncertainties

In order to formulate possible scenarios two influencing factors has been selected based on their impact and uncertainty. The identified trends are most certainly going to follow the same trajectory in the coming years. However, some influencing factors may be more uncertain than others. By prioritizing the identified influencing factors, as seen in Figure 14, the two most uncertain factors has been chosen as the basis for the future scenarios. The prioritization was made after interpreting the information from interviews, documents and reports and making a subjective joint assessment of it.

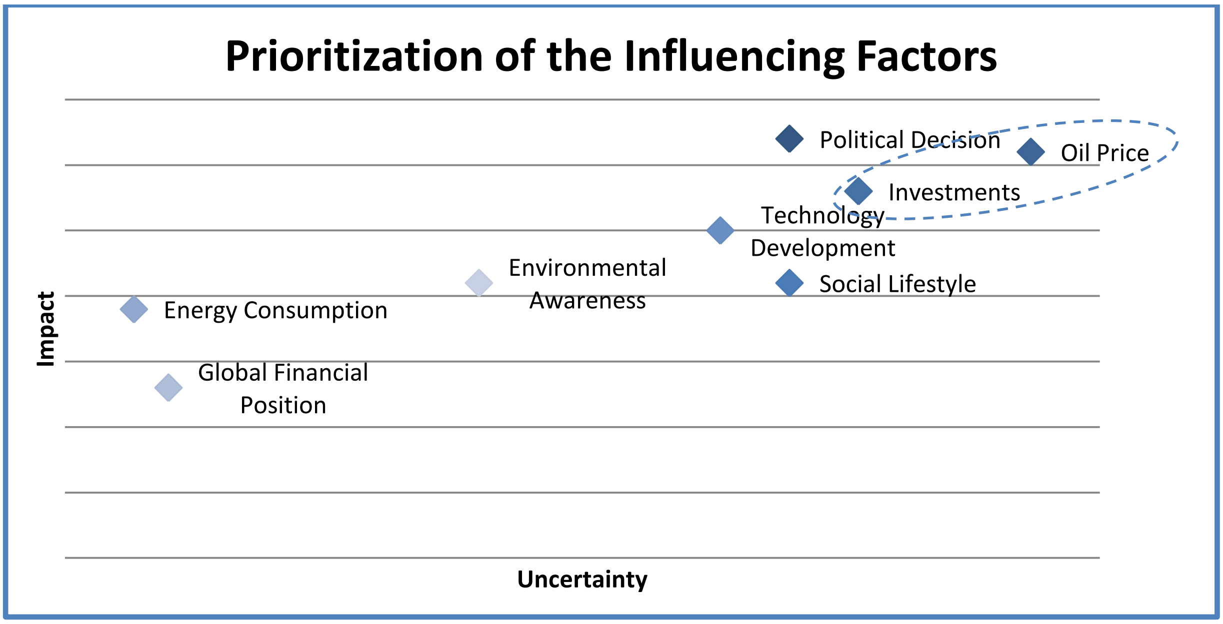

Figure 14 Prioritization of the Influencing Factors

Investments in new energy technologies have a high impact on the development of future power supplies. If there are more support, in terms of resources and knowledge, from private actors as well as governments the future may certainly be different from without the support. As seen today, the many alternative energy technologies could make it difficult for only one technology to gain greater support. Different actors may support different

[75] Jan Rydén, Senior Specialist System Mechanics, Saab Group, Interview 2011-04-15

technologies. This could lead to decreases in willingness to invest because it may not be lucrative to invest in something that is not going to be diffused. On the other hand, the increase environmental awareness may advocate increase in investments in order to reach the desired goals. The *oil price* will most likely have a huge impact on the future power supplies as well. If the oil price rises to a level that is too high the power supply industry may be forced to switch to technologies that uses alternative fuels. While if new oil prices decreases the technologies that uses alternative fuels will perhaps instead be forgotten. These critical uncertainties and how they will influence the future scenarios will be further investigated later in the report.

5.3 The Four Scenarios

In this section the critical uncertainties from the last chapter are given a value from low to high. They are then combined into four different scenarios (see Figure 15); "End of the fossil fuel era", "World of efficiency", "Business as usual", "Battle for dominance". After that each scenario is described separately into further detail.

Figure 15 Scenario Matrix

5.3.2 Scenario 1 "End of the Fossil Fuel Era"

The oil price has been increasing vastly the last years and has reached a level where it is too expensive for everyone to use. Main reason for this is that the peak oil has been reached several years ago at the same time the demand has been increasing because of the increase in population and better financial position world-wide. This has created a situation where oil price skyrocketed and the need for alternatives has been a must if people are going to keep their way of life. Moreover, the instability in the Middle East has also fuelled the situation making oil even more scarce and rare. The tensions in the Middle East that started in year 2011 have created a domino effect in which the neighboring countries have seen the positive effects from resisting the unfair authority. As a result, the demonstrations and disturbance has spread like fire and, consequently, put a halt on the existing oil production in these countries.

The increased environmental awareness has pushed the authorities to create laws and regulation that support new energy technologies. Instead of only putting up goals that do not get realized, governments have been stricter and have realized that it must be reached in order for our way of life to be sustainable. As a result the investments from government have increased vastly in terms of new energy technologies. The need to find new and sustainable solutions has been a priority question. These investments have created a situation where institutions has aligned their research towards new energy technologies and thus made alternative technologies adapt a strong development curve. In addition, the strong support from governments have sent a signal to the private actors and made it more lucrative to invest in new energy technologies. This positive trend with increase investments from both private and government actors has in turn made the technologies available to more people since there are more actors that offers new energy technologies. The investments, especially from the government side, have also lead to a strong development of infrastructures that support different alternative technologies. Furthermore, the better financial position world-wide has helped to increase the availability of new energy technologies. Since people are getting richer they demand a better and better way of life. Consequently, new energy technologies have replaced the traditional energy technologies in many areas and are becoming more and more widely used.

The high oil price together with the increased environmental awareness and investments in new energy technologies has made the world less dependent on fossil fuel. As a result, new energy technologies have had a huge innovation rate and been developed to the level where they can compete with the traditional technologies. The traditional technologies using oil as fuel has instead been phased out. Only some applications are still using the traditional technologies since they have not been fully replaced yet. Moreover, mainly the larger energy technology that has a power output in the range of MW has been fully replaced by new energy technologies. The mobile systems in the range of 50 kW are getting replaced and technologies that use fuels other than oil are the dominant ones.

5.3.3 Scenario 2 "World of efficiency"

When there are low investments in new energy technologies, the set environmental goals are still only kept as goals and there are few incentives to form new goals. Governments around the world are at variance on what should be done which leads to a decrease in international environmental programs. Governments, private companies and society are not convinced that investments in new technology and infrastructure will help against the increasing energy demand and oil price (the high oil price comes from similar reasons discussed in "End of the Fossil Fuel Era"). This skepticism about new technology comes from years of misjudged so called "saving" technologies, i.e. the earlier new technologies did not have the expected effect on the energy demand as it first promised. Thus the few investments are put in the present technologies with the purpose of making them more efficient. In other words, private companies have low incentives to invest in R&D on new technologies since there are no such demands from the market or enough funding supports from institutions and governments.

The high oil price and the low investments in new technologies have lead to a streamlining of today's technologies and systems. Even though the R&D is minimized and few innovations are expected, the increased oil price has made it necessary to decrease the oil dependency. Thus the focus is on increasing the utilization factor, i.e. energy conversion steps are being minimized and there is an increased life cycle thinking on the total system. An example is that energy storage systems are to a higher extent being integrated to balance power supply in order to maximize the utilization of power producing products. Similar technologies, for power supply in the range of 50 kW in mobile systems, are used in this scenario as the technologies in 2011. The slight difference is that many oil dependent machines has been remodeled (to the extent they can) to be able to use more alternative fuel. Diesel driven Piston Engines can now use alternative fuels such as DME and Biogas.

The oil has become an expensive trading resource and is mainly used in emergency areas/ backup of important systems which involve a lot of people, e.g. hospitals. Thus the oil based power generating products covers a broad range of application areas but has the largest appearance in a range of above 1 MW. The lower supply of oil has resulted in a slight change in its infrastructure. Its pipelines are now gradually being used for biogas etc. Thus during the time when the supply has decreased, society has gradually decreased its demand as well.

5.3.4 Scenario 3 "Business as usual"

The low oil price is due to an increasing supply in comparison to demand which drives the prices down. The increasing supply is due to the discovery of new sources of oil. These sources are not disputed over since they are situated within clear country boundaries. This has lead to more actors in the oil market and in turn more oil produced to the market. Also there are new ways to extract oil which prolongs the current sources' extraction life. Furthermore, there are no concerns or disturbance in the oil producing countries, i.e. there is a political stability. All this contribute to a secure access to oil.

The trend of the decreasing oil consumption in percentage of the total energy consumption in 2011 continued due to the increase of usage of nuclear and wind power. Hence the only investment that is spent in the field of energy generation is spent in nuclear and wind. These are stationary systems and do not affect the power supply of mobile systems in the range of 50 kW. Thus these systems have not been developed much since 2011 and is expected to be similar to the products used in 2011.

The consequence of this is that fewer companies are active in the development of new technologies. The trend of increasing environmental awareness is not enough to drive companies to work proactively in innovating in new, incumbent or greener technologies for auxiliary use. Moreover, the environmental goals are kept as goals and are not accepted by all countries. For example, developing countries such as the BRICS (Brazil, Russia, India, China, South-Africa) countries (most of which is now more or less considered as developed) thinks that they should be given equal rights to emit the same amount of emissions as the developed countries in 2011 have emitted until today. This has led the world into a scattered thinking about the consequences of the oil's emission. This has in turn enhanced the uselessness of the environmental awareness trend for companies to want to develop greener technologies. Thus there are many reasons for the technologies of 2011 to stay about the same up to this present day.

5.3.5 Scenario 4 "Battle for dominance"

The low oil price together with large investments in new energy technologies has lead to a market where many different technologies are competing. The difficulties in finding and deciding on a main technology have made users shattered in their decision making. Instead, the energy technologies are used in their area they are most suited for and thus create niche market for respective technologies. In addition, the low oil price has kept the traditional fossil fuel engines alive and still widely used. However, the fragmented market because of the many varieties has segmented the users in terms of what type of technology they use. The traditional fossil fuel technologies are mainly used by the ones that do not demand high quality or any advance technologies. The new energy technologies are generally used by the customers that demands high quality and new technology. As a result, the companies that offer the new energy technologies are differentiating themselves by brand and product technology.

Moreover, the low oil price has been possible mainly because of the increase in supply from new sources but also from the decrease in demand. The increase investments have made new energy technologies available and possible to replace the traditional fossil fuel technologies in almost every application. Even the technologies that use fossil fuel have been improved vastly in terms of efficiency. In addition, the environmental awareness has increased to the point where it is a central question and prioritized. Together with the improved global financial position the need for new energy technologies has been a must. Governments are supporting different institutions that conduct research in these areas which has been a great success in new energy technologies as well as improvements on existing energy technologies.

The success and increase in new technologies has created a situation where users are in a larger extent demanding alternative technologies. This has made it more lucrative for new actors to enter the market which has created a huge industry. However, one major obstacle is that the many available technologies have made it difficult for the industry to choose a standard. Also, the infrastructure has therefore not been expanded for any new technologies and the infrastructure for oil is still the dominant one. As a result, the traditional fossil fuel technology is still widely used since many users are reluctant to change to something that perhaps is not going to be dominant in the future. The low oil price has been a contributing factor to this development as well because many people prioritize cost first. Especially in terms of 50 kW auxiliary power in mobile units the traditional fossil fuel technologies has been difficult to replace because of the mentioned reasons.

5.4 Development of each Technology in the Different Scenarios

In this section the development and role of each technology (Fuel Cell, Gas Turbine, Li-ion battery, Super Capacitor) are described in each scenario. This is done by using the theoretical frameworks regarding Qualities that determine a technology's diffusion rate, Conditions for large scale technological transformation and S-curves for technical performance and diffusion.

5.4.1 The Technologies in the Scenario "End of the Fossil Fuel Era"

Comparing the identified energy technologies Fuel Cell will be the dominant technology in the scenario. The high oil price makes new energy technologies that use alternative fuels more lucrative. The large investments in new energy technologies will also improve the performance of the technology as well as lower the cost to manufacture. As a result, the traditional technologies that use fossil fuels will halt and a new era of technologies that use other fuels will arise.

5.4.1.1 Fuel Cell

The large investments from both governments and private actors have decreased the cost to produce the technology. The price is thus competitive compared to the alternative such as the Piston Engine generator, making it lucrative in economical terms. Another important development is the increased manufacturing from the automotive industry (and the FCEV in 2015) which has lowered the manufacturing cost because of the large volumes. The technology development has also contributed to the lowered price. For instance, the development in nanotechnology has made it possible with lower temperature for SOFC. In addition, the increased focus and prioritization of the environment world-wide has made Fuel Cell technologies even more lucrative since its only emits water when hydrogen is used. As a result, since Fuel Cell is a technology that fosters the environment it will certainly be aligned with the norm and value of the society. The aspect of complexity is favorable for Fuel Cell. The technology per se is not revolutionary in terms of the need for new abilities or skill sets to use it. The basic idea is the same where the engine needs fuel in order to run. However, the skill sets that needed to develop and maintain a Fuel Cell engine will differ. Then again, the difficulty to use and understand is perceived as relative easy and will not pose as a problem. Moreover, the trialability and observability will not pose as any problem. The increase adoption of Fuel Cells because of the advantageous created a positive loop where more people use it and thus more people can observe other people using it. In addition, the positive effects from using hydrogen as fuel will be directly observed by being cheaper compared to diesel.

The strong support from governments in new energy technologies has created a situation for Fuel Cells where education, technology development and research have been developed strongly. This has made knowledge widely available as well as creating competing designs such as SOFC and PEM and thus set a spark for a technology transformation. The usage of Fuel Cell technology in the automotive industry, airplane industry as well as mini-APUs has made it available for a market formation to take place. As the range of applications with Fuel Cells increases together with the strong support from governments, advocacy coalitions has been more easily been formed. This has in turn made it possible for new organization to enter the industry and further increase the support Fuel Cells. The many firms available that offers Fuel Cells technology has increased the legitimacy of the technology and made it a dominant technology especially in the 50 kW power span.

Rendering from this, the technology performance can be said to be high in this scenario for Fuel Cells. The strong support from governments and private actors has made it possible by large investments. In terms of S-curve in technology performance, Fuel Cell is relatively developed and mature. This has also contributed to the increasing entry of new organizations in this field. Since the characteristics of Fuel Cells, as analyzed above, are beneficial the diffusion of the technology can be seen as high and widely spread in this scenario.

5.4.1.2 Gas Turbine

The Gas Turbine will be more advantageous compared to the Piston Engine generator for the 50kW power range. The smaller size together with the possibility to use a wide range of fuels has made it more suitable since the environmental goals have become rules and regulations in which the need to reduce emissions is a priority. Thus, the majority of the Gas Turbines use fuels such as DME and natural gas. However, there will still be emissions from these fuels which make the Fuel Cell superior in this aspect and more advantageous overall. Since the Gas Turbine can be manufactured to use a wide arrange of fuels the aspect of compatibility is favorable. By using more environmental friendly fuels the rules and regulations can be met as well as the increased environmental awareness world-wide. Again, comparing Gas Turbine with Fuel Cell in this scenario Fuel Cell will be more suitable and compatible with the existing values and norms. In the aspect of complexity the Gas Turbine will be favorable. The technology per se is not new and has been around for decades. The skills set and abilities needed to handle the technology can even be argued to be less demanding than a Fuel Cell. Hence, comparing Gas Turbine and Fuel Cell the Gas Turbine will be less complex. The aspect of trialability and observability will not pose any hinder. Especially since alternative fuels can be used that lower the cost of use compared to using a Piston Engine generator. Furthermore, the Gas Turbine as a power generating technology is less advantages in the 50 kW power range across the five criterions compared to Fuel Cell in this scenario. Making it less diffused in than Fuel Cells.

The available knowledge in this technology is vast mainly because it has been a technology that has been around for quite some time. Also, Gas Turbine's dominance historically in the airplane industry has further contributed to the great available knowledge. However, the Gas Turbine will still not be widely diffused and used in this scenario in the 50 kW range. Main reason for this is that the characteristics for this technology is not as favorable compared to Fuel Cells which has made many companies and other organizations reluctant to enter this industry. As a result, the legitimacy has not been high and the negative feedback has been hindered the Gas Turbine to effectively transform the 50 kW power supply industry in this industry.

The Gas Turbine is a technology that has been around for a long time making it a relatively developed technology. There are not many competing designs and the innovations regarding this technology are mainly based on incremental improvements. The technical performance has reached its flatten line in the S-curve. Consequently, the innovations regarding this technology will not be revolutionary and make it more attractive than Fuel Cells for the 50 kW power range in this scenario. Moreover, the diffusion of Gas Turbine has not been high for the 50 kW power range because of the more attractive advantageous of Fuel Cells.

5.4.1.3 Lithium-Ion Battery

The Lithium-Ion batteries are more widely used in this scenario. One of the main reasons is the decrease in price which has made the technology more advantageous in economical terms. The energy density has also been improved because of the better design of the batteries. In view of the fact that the environmental aspect are getting prioritized world-wide the Li-ion batteries has gained a more important role in the world. This has made it more compatible with the existing norms and values world-wide. In terms of complexity the Li-ion battery does not differ significantly from other batteries. Similar as the technologies above, the Li-ion battery diffusion will not be affected by the trialability. The benefit from the Li-ion battery is easy to identify. The battery can store handle load variation and thus make the total system more efficient and stable. In addition, the Li-ion battery is denser in terms of energy than the traditional batteries. As a result, the diffusion of this technology is high in this scenario because of the beneficial characteristics of the technology.

Moreover, knowledge in this field has been vast which has made it possible for Li-ion technology to develop and spark the technological transformation. The use of Li-ion batteries in many portables devices such as laptops and increase uses in the automotive industry has certainly made it possible for market formation. This has created a protective space for the technology where it has been able to improve and become as good as it is. In addition, the strong support from for example universities by investing great amount of research into this field has further strengthen the advocacy coalition in this field. Adding to this, the superiority of the technology has increase the amount of actors that offers and support it. As a result, the Li-ion battery has been a dominant energy storing technology for almost any power generating systems, nevertheless the 50 kW power range, in this scenario as well as a highly diffused technology world-wide.

The technical performance has more or less reached its peak in terms of energy density since the limits in its chemical settings has been reached. The diffusion S-curve has also been reaching its higher end in this scenario. The superiority of this technology over other batteries as well as the need for using more efficient systems has been the main contributors.

5.4.1.4 Super Capacitor

The large investments in new energy technologies have made it possible to develop the Super Capacitor further. This has certainly decreased the price for Super Capacitors and made it more lucrative in economical terms. Also, there are no other technologies available that can perform the same tasks as a Super Capacitor. By incorporating Super Capacitors into the power supply system the efficiency have been able to rise. Consequently, this technology has strong advantageous especially when the environmental aspect is a prioritization. In this scenario, where investments in new technology is high and the need to decrease the dependency in fossil fuel is high as well as the higher environmental prioritization, Super Capacitor will be very much compatible. As mentioned, by implementing this technology the efficiency of the system can be lowered which certainly is favorable. Also, the large investments in new energy technologies have further made it possible for this technology to develop and emerge. In the aspect of complexity the Super Capacitor will not pose as any problem. The investments have made it possible for abilities and skills set to develop as well as made vast knowledge available. The benefits from using Super Capacitor can also be observed quite easily. For instance, the increase efficiency and especially in the 50 kW power range which is mostly used for Auxiliary Power Unit-systems (APU-system) where the need for it to be able to start up quickly is important.

The large investments have made it possible for knowledge to emerge regarding Super Capacitor in this scenario. Primarily since this technology is favorable in increasing the efficiency of a power supply system. The application of Super Capacitor in power supply systems has also been providing the technology with a market where it has been able to gain popularity. Particularly in APU-systems as well as in the automotive industry Super Capacitor has been proven to be a beneficial complement to the entire power system. The legitimacy has further been strengthened by increased support from organizations such as universities and politicians. Super Capacitor has increased its support mainly because of the mentioned advantageous that make the system more efficient which has been in line with the norms and values of the society. Furthermore, the stronger support as well as the vast available knowledge has made it lucrative for new organization to enter this industry and thus further increased the legitimacy.

From the above development, the Super Capacitor can be said to have develop in a fast phase in this scenario. As a result, the S-curve regarding technical performance for Super Capacitor has been reaching its upper levels. The diffusion rate for this technology has also been high, none the less for the 50 kW power supplies, in this scenario which makes the technology diffusion curve reaching its higher limits.

5.4.2 The Technologies in the Scenario "World of efficiency"

This scenario is believed to favor the diffusion of *Li-ion battery* and *Super Capacitor*. World of efficiency is dominated by ideas of making systems more efficient (for example less conversion steps) and with better power management. Power supply systems which stores pure electricity will then be higher demanded since it means less storage of expensive oil and a decreased total oil dependency.

5.4.2.1 Fuel Cell

The Fuel Cell has been adopted in some niche markets within power supply in the range of 50 kW where a decrease of oil dependency is of most importance. Its relative advantage has become slightly better since 2011 compared to the Piston Engine generator due to the increased oil price and a small decrease of Fuel Cell prices. Prices have decreased due to some small sales of the FCEV in 2015. However, the market stagnated fast since there was little economic support by organizations and governments in terms of infrastructure investments etc. Also there were some successful tests with a carbon based catalyst for the PEM Fuel Cells between 2011 and 2015 but the increased system (the whole Fuel Cell system) costs it brought did not change the total price by much. The increased environmental awareness and increased oil price makes the Fuel Cell compatible with the existing values of society which could have been positive for the potential adoption rate. However, the low complexity of the technology which could have led to new entrants such as imitators, society's skepticism in new technologies made the market less attractive. A small market with low observability has halted the adoption of Fuel Cells.

The low support by governments in terms of investment in research and education, no institutional change, has not been positive for the market formation. FCEV could have been the nursing market for PEM Fuel Cells but discussions/debates from different advocacy coalitions and politicians only led to ambiguous decisions. Politicians rather support alternative fuels and efficient systems than Fuel Cells. Therefore it has not been many new entrants of new organizations. Although the variance from different countries i.e. some believe in Fuel Cells while others do not, has created some new organizations with the intention of increasing the legitimacy of the Fuel Cells to spark a technological transformation in power supply of 50 kW.

Without this spark the Fuel Cells are still rather far to the left in the two s-curves. Neither performance nor technology diffusion has yet reached its peak. The new organizations are struggling with getting more efforts into R&D by firms and increasing adoption interest in the markets.

5.4.2.2 Gas Turbine

The relative advantage of the Gas Turbine compared to the Piston Engine generator is slightly better now than in 2011. Gas Turbines are built with a battery system in order for the Gas Turbine to work in a more even pace which increases the overall efficiency. Prices of the light weight material in turbines have decreased some due to material developments during the past 15 years which have brought overall prices down. Due to the increased environmental awareness and the expensive oil, Gas Turbines are nowadays built to use non fossil produced fuels. This makes the technology compatible with the existing values of society. Complexity of the core product has not changed much, however the additional battery system and new fuel system requires more knowledge to use the product. The increased use of these new Gas Turbines in APUs has increased the observability for the market of power supply in 50 kW as well.

There are few investments in research and education in this incumbent technology. However there are some supports regarding development of the new fuel systems since governments around the world are still focused on decreasing the oil dependency. This has sparked a small institutional change which affected the market formation of APUs. Although there are too few advocacy coalitions and new organizations to really influence institutions in order to boost a technological transformation in favor of these environmentally friendlier Gas Turbines.

Even though there are some new improvements on the Gas Turbines it is still rather far to the right on the s-curves. Even more so, on the performance/time curve since there has only been small performance increases with the battery systems.

5.4.2.3 Lithium-Ion Battery

Prices have gone down quite a bit in the last 15 years due to improved production processes from learning effects and an increased demand from more hybrid systems. In general Li-ion batteries are perceived as a rather cheap way to store energy when there is no need to tie capital in expensive oil. The relative advantage is in favor for Li-ion batteries compared to the Piston Engine generator since it is more compatible with the values of today, which has been stressed before. The architecture of the steering systems of the batteries is often quite complex which gives producers their competitive edge but also a difficulty for users to understand. Nonetheless, there is still an increased market for hybrid systems which affects the technology's observability which is positive for its adoption rate.

The small investment in research and education by institutions means that the Li-ion battery has not had any major commercialized improvements of its energy and power density. Although, smaller incremental innovations has been made around the design of the battery which has had positive effects on the densities. Batteries have received a "3D" design (see Figure 11 and imagine that instead of "layers" in a cylindrical form they are "waffled" in a net design) in order to fit different hybrid systems. This new design type started a new market formation where it evolved to fit more markets. There are some new organizations who are trying to increase the legitimacy of the new designs and lower society's worry about the safety of the new designs.

Breakthroughs have been made in laboratories for years but the safety concerns and lack of investments has kept them in the laboratories without being commercialized. Thus the Li-ion batteries are struggling to get upwards (are considered to be around the middle) on the s-curve but it would need more effort to be able to go further.

5.4.2.4 Super Capacitor

The Super Capacitors development in this scenario has been similar to the Li-ion battery above. Due to the supreme ability to recharge fast with high efficiency, the Super Capacitors are present in every car as a mean to regenerate energy from braking. With a large market as the car market, the prices have decreased which has triggered the interest of other markets as well. It has been used in different power supply systems to aid the start-up process in extreme weather conditions and to balance demand pikes from the supplied system i.e. the system of which the power supply system is meant for can demand different amount of electricity at different times. Thus the relative advantage for a power supply system with a Super Capacitor is stronger than a system without. It is the compatibility of the Super Capacitor with the existing values of efficiency in this scenario that has created the new markets and the increased adoption. With the new markets observability is increased, many actors have seen the results with the power supply systems with Super Capacitors and have started to adopt it.

Some institutions have invested money in research and education but the main investment comes from private actors who want to make their products work more efficiently. The Super Capacitors in the power supply systems are not enough for a market formation. There is however a positive attitude by politicians and different advocacy coalitions towards incorporating Super Capacitors since it increases the efficiency of systems. With the increased usage of Super Capacitors in cars, there has been an increase of new suppliers which has brought additional knowledge to the technology.

The Super Capacitors are rather far to the left still. The few incremental innovations have not had a major impact yet on its performance. However, the rate of adoption over time has increased due to the new markets which have been explained earlier.

5.4.3 The Technologies in the Scenario "Business as usual"

This scenario is reckoned to favor the incumbent technology *Piston Engine generator*. Even though there is an increased environmental awareness there are few laws for firms to follow since governments are at variance on what is fair in terms of emission rights. It is therefore a constant trade-off between using the low priced oil and doing something for the environment. However, few will invent something green for the sake of branding; in other words, similar systems will be used as in 2011.

5.4.3.1 Fuel Cell

There was never a serial produced FCEV in 2015, it was only sold in few numbers to different municipalities (for "greener" cities) for organizations such as post offices etc. Neither were there any investments in the infrastructure (regarding fuel such as hydrogen gas) which limited its diffusion. The Fuel Cell is therefore still rather expensive and has a low relative advantage compared to the Piston Engine generator. The few Fuel Cells present on the market of power supply are either high temperate Fuel Cells such as the SOFC or are Fuel Cells sold with a reformer system. This is compatible with the existing values in some markets where the environmental issue is more important than the price. Some firms who are branding themselves as environmental friendly might have a Fuel Cell product in its portfolio. So even though the complexity is low and observability is high, diffusion is and has been low.

No institutions have bothered to make any investments in education or research regarding Fuel Cells in power supply products. Thus there has not been any real market formation for Fuel Cells to protectively evolve into something feasible in this industry. Fuel Cell is discussed in some public forums and debated by different advocacy coalitions and some politicians, on the potential of a society with more Fuel Cells but nothing is ever decided about the issue.

Fuel Cells in this scenario are still stuck far to the left on the s-curve with little adoption over time and small performance improvements. There are still some of the earlier adopters who experiment with the idea of fuel cells but it is not enough to draw attention to the fuel cell technology and increase its adoption rate.

5.4.3.2 Gas Turbine

Gas Turbines are still the primary engine type used in the air craft industry. However, not much development has happened since 2011 and the material used is still rather expensive. Therefore there is a low relative advantage compared to the Piston Engine generator regarding price. The advantages (e.g. lighter and smaller) in 2011 with Gas Turbines are still the same and they are therefore still used in some applications where this is valued as the most important. It is not particularly compatible with the increasing environmental awareness, although there have been some few incremental innovations which has increased its efficiency slightly. All in all, the Gas Turbine has not been further diffused to other markets than the ones in 2011.

No investments are being made by governments regarding research or education. The main investments are from aircraft producers. When people get richer and the oil cheaper more people have money to travel to long distant targets with planes. Thus there is a drive to keep developing air planes but from private companies only.

Gas Turbines have not been adopted much in the power supply industry. It is far to the left on the S-curve regarding adoption over time. On the S-curve's performance over time, the Gas Turbines are still far to the right even though the technology has made some improvements in the airplane appliances. But this is not enough for the power supply industry to switch their attention to Gas Turbines.

5.4.3.3 Lithium-Ion Battery

With the low oil price it is cheaper to store oil than electricity as an energy source. This makes the Li-ion battery still expensive to use for the industry of power supply. And there are therefore no incentives or motives to develop a system with Li-ion batteries. Thus the relative advantage is in favor for the Piston Engine generator in economical terms. So even though Li-ion batteries are more compatible with the environmental values of the society, the price is just too high for the customers in the industry of power supply to want to pay the little extra for an environmentally better alternative. There have been some developments though, but in other markets. Cellular phones, laptops etc have all gotten a better Li-ion battery with lower charging times and higher energy density. However, these developments have been hard to apply to larger batteries (the ones needed in a power supply system). The reason is a combination of higher complexity and a too low market demand.

There have been little investments from institutions. The main investments in research of Li-ion battery are from private actors in other industries, as was mentioned above. These investments have only led to small incremental innovations. No new technology has come from these innovations that would need nursing markets with low risks for new entrants and a protective environment to progress in. Neither are there any advocacy coalitions or new organizations to debate, bring knowledge or bring other resources that would help a technology transformation of the Li-ion battery.

When analyzing the s-curve in this scenario the Li-ion battery is deemed to be on the left side of the slope. It has not gotten the major performance increase which could be possible with a Li-air battery for example or other designs (3D etc) for example. The battery needs more effort and more support from governments in order to peak its performance and adoption rate.

5.4.3.4 Super Capacitor

The Super Capacitors' development has been similar to the Li-ion battery. Due to the low oil price and low investments they did not have the expected annual growth as was projected in different reports in 2011.They were only developed for niche markets, often seen in consumer electronics markets such as digital camera, flash photography and flash lights but also in the health care industry in emergency appliances etc. In other words the Super Capacitors have not been used yet in for example the power supply industry. The prices have gone down but not enough to have a relative advantage to the incumbent Piston Engine generator in economical terms. Price seems to be the major diffusion factor unfortunately. This is because even though the compatibility of the Super Capacitors with the increasing environmental values of society is favorable (high efficiency of 85-90 percent and stores electricity), the diffusion rate have been lower than it could have been. Also, complexity (is low since the structure of the Super Capacitors is old knowledge) and observability are favorable but it has not helped the Super Capacitor diffuse to the power supply industry.

Some institutions have invested money in research and education regarding health care and emergency appliances. This has strengthened the advantage area of high power, fast recharge/discharge of the Super Capacitor, not increasing the energy density by much. This might have induced further specialization of the Super Capacitor in that area (area of high power in a short amount of time) which makes it not so applicable to other industries. Thus there has been no market formation in power supply for the Super Capacitor. Advocacy coalitions support the need in health care and the new organizations that have entered are forming in this industry.

The Super Capacitors are still rather far to the left in the s-curve. The few incremental innovations of its advantage area have not had a major impact yet on its performance. However, the s-curve regarding adoption rate over time has increased due to the new markets in the health care industry which have been explained earlier.

5.4.4 The Technologies in the Scenario "Battle for dominance"

In this scenario there will be several energy technologies competing for dominance. The main reasons for this are that the large investments have made many energy technologies available and competitive while the low oil price keeps the older technologies lucrative. Basically, there will not be any dominant design in terms of 50 kW power supplies. Instead, different technologies will be strong in different factors. As a result, the 50 kW power supply market will be more fragmented where the different energy technologies will be chosen based on what the user prioritize.

5.4.4.1 Fuel Cell

The large investments in new energy technologies have decreased the cost of Fuel Cells. By improving the manufacturing processes and having stronger support from the automotive industry, e.g. the FCEV initiative, the cost has been able to be reduced. However, in economical terms the Fuel Cell technology has not been able to outcompete the traditional energy technologies such as Piston Engines. This is mainly because the low oil price which has kept the older technology alive. Instead Fuel Cells have become a choice for premium users where other factor such as quality has been the priority. The low oil price has also made it more favorable with reformers that transform diesel to hydrogen when using Fuel Cells. Adding to this, the infrastructure supporting hydrogen has been less developed mainly because of the low oil price. Another important development is that Fuel Cells that can use diesel directly as fuel has been increasing in popularity because of the obvious reasons. Thus, the compatibility of Fuel Cells is quite high in this scenario. The skills and abilities needed to handle Fuel Cells are enough especially since there are large investments. The aspect of trialability will not pose as a problem, but the observability might. The usage of Fuel Cell technologies is more expensive compared to traditional technology. It is mainly the quality and environmental aspect that mainly benefits from using this technology which might not be as obvious as lower cost.

The available knowledge in this technology is sufficient and there is consistent development. There are also markets for this technology where it has been developed as well as enable it to further develop. For instance, it targets a niche market where premium users demands quality and more environmental friendly products. Moreover, the main condition that has not been achieved yet and still hinders a large scale transformation of Fuel Cells is the advocacy coalitions and entry of new organizations. The low oil price has made the more traditional technologies such as Piston Engines and Gas Turbines more lucrative and thus created a strong support base. This in turn has lessened the legitimacy of Fuel Cells which has obstructed its further diffusion. As a result, Fuel Cell technologies only serve a specific segment that prioritizes the benefits with the technology.

From the large investments in new energy technologies, Fuel Cell technologies have been able to improve and develop. However, the technology has been improving towards a niche area, because of the above mentioned reasons, and thus not reached its maximum potential. For this reason the S-curve regarding the technical performance is slightly above the middle phase and still has some large potential improvements before its full potential is reached. Furthermore, the diffusion of Fuel Cells is still quite limited. It serves a niche market where certain factors are prioritized. Thus, the S-curve for technological diffusion can be said to still be in its early phase and has not reached the steep section yet.

5.4.4.2 Gas Turbine

The large investments in new energy technologies have made it possible to use other materials for Gas Turbines. This in turn has made it possible for a wider arrange of applications for this technology because of the lowered cost. Consequently, in terms of 50 kW power supplies the lowered cost for Gas Turbines has made it more advantageous and comparable to the traditional technologies such as piston power generators. Also, the advantageous with smaller size makes this technology further favorable. Since Gas Turbines can use a variety of fuels it is very much compatible with the norms and values. For instance, when the economical aspect is prioritized Gas Turbines can use diesel as fuel since the oil price is low. If environmental aspect is prioritized for a specific user a more environmental-friendly fuel such as bio-fuel can be used instead. The aspect of complexity and trialability will not pose as any problem. The technology has been around for quite some time which has made vast knowledge available as well as proven. The benefits from using a Gas Turbine in 50 kW power supplies can be observed quite easily. The main benefit being that it is smaller especially compared to the traditional piston power generators but also the fact that it has become cheaper.

Since the Gas Turbine technology has been around for a while there is available knowledge in this field and enough for it to further develop. Adding to this, the strong support from the airline industry and frequent use in airplane engines has created a protective space for this technology to grow. Moreover, there are strong advocacy coalitions behind this technology where organizations that supports airplane engines are behind. However, there are still tensions between different technologies which have created a scattered industry in the APU-industry where there is no one dominant technology.

The S-curve concerning the technical performance has almost reach its flatten line to the right for the Gas Turbine in this scenario. The technology has been around for quite some while and been improved a lot especially by the airplane industry. However, in the APU-industry this technology is still quite new which have made it possible for new designs and improvements to be made that are specific for this usage. Further, the diffusion of this technology in the 50 kW power supply industry is still in its early phase in this scenario. It has not really reached the steeper phase yet in the curve because of the many available solutions such as Fuel Cells and the traditional ones which has created strong competition.

5.4.4.3 Lithium-Ion Battery

The large investments in new energy technologies will have decreased the price for Li-Ion batteries. This in turn will make this technology more lucrative and advantageous in economical terms. Comparing to other alternatives, the Li-Ion battery will be far more advantageous especially compared to the old led-types batteries. The compatibility will be high for lithium batteries as well. The principle behind the technology is almost the same as for most other battery technologies in terms of usage. Connecting to this is the aspect of complexity. The need for new skills and abilities will not be high because of the similarities. Also, the large investments in new energy technologies have also made new and vast knowledge available. The aspect of trialability will not be a problem for this technology. Since the technology per se is not new and has been used in many other applications such as laptops and mobile phones there are less uncertainties. In addition, the benefits from this technology can be easily observed. Higher energy density as well as higher power density will make Li-ion batteries a favorable technology which will be difficult to compete with in terms of energy storage.

There is a lot of knowledge available regarding Li-ion technology. This will certainly make it possible for it to grow and create competing designs. For instance the different combinations with lithium which can further improve the batteries energy as well as power density. Another favorable aspect that suggests a large scale transformation in this scenario for Li-ion batteries is the fact that there are market formations. It has been able to develop and grow in markets such as laptop-batteries and mobile phone-batteries. The strong advocacy coalition behind this technology further supports this notion. Universities are contributing with research and large investments from both private actors and governments have made this possible. As a result, more firms enter this industry which further strengthens the legitimacy and the large scale transformation.

The Li-ion batteries are reaching its limits in the technical performance S-curve in this scenario. This is because the maximum energy density for this specific combination is almost reached. However, in terms of Lithium based batteries, which can be combined with other material, is still in its steep phase in the S-curve. There are still great improvements that can be made which can improve it vastly. The diffusion of the technology is high in this scenario. Many old battery technologies have been replace with Li-ion batteries because of its superiority. Also, with the lowered cost it has become more available and thus more adopted. In the S-curve for technical perfromance for Li-ion batteries it can be said that it is reaching its limits.

5.4.4.4 Super Capacitors

Super Capacitors are getting more developed and available in this scenario, mainly due to the large investments in new energy technologies. This has lead to lowered cost which has enabled the Super Capacitor to be comparable to regular capacitor in economical terms. Since Super Capacitors are basically the same as capacitors in terms of functionality it can easily be replaced. Also, the superiority of Super Capacitors makes it more environmental friendly, since it makes the power supply more efficient, which strengthens the aspect of compatibility. The knowledge needed to handle the technology will be available mainly because of the large investments made in new energy technologies as well as the similarities between a Super Capacitor and capacitor. Thus, the aspect of complexity can be regarded as low in this scenario. Moreover, the trialability will be low since Super Capacitor will be incorporated in a power supply system. On the other hand, the observability will be high since 50 kW power supplies will certainly be improved, especially in terms of energy density, when Super Capacitors are used instead of capacitors.

The knowledge available in Super Capacitors is vast in this scenario. Large investments from both governments and private actors have mainly made this possible. The strong research in improving and making the capacitor technology better has and is making the technology grow in this scenario as well as creating competing designs. For instance, the Super Capacitor is in itself an improvement and new design from the capacitor. In addition, the benefits with using a capacitor as well as the, historically, frequent usage of this technology in engines and power generators have made it possible for a market formation. The investments from governments and private actors suggest that there is advocacy coalition that supports the technology. Since there is no other technology that can compete directly with Super Capacitors it will be difficult to replace it. The change from capacitors to Super Capacitors in popularity will certainly enable and make more organizations to enter this technology. As a result, the analysis regarding the characteristics for a large scale transformation supports the notion that it would happen for Super Capacitors in this scenario.

The S-curve for technical performance can be said to be reaching its limits for Super Capacitor in this scenario. The large investments have made it possible to skyrocket the development and improve the technology vastly. In addition, the S-curve regarding adoption can be said to be high and reaching its limits, especially for the 50 kW power supplies. This is mainly because of Super Capacitors superiority and almost every factor compared to capacitors as well as the decreased cost which has made it lucrative in economical terms.

5.5 Implications for Saab EDS Based on the Scenarios

In this section the implications for Saab EDS in each identified scenario will be presented. The implications starts with how the scenario will affect Saab EDS and their current system and continues with some suggestions on, what needs to be done and/or changed and how Saab EDS could work in order to implement the change

5.5.1 End of Fossil Fuel era

In this scenario the energy technologies that do not use fossil fuel will increase and become widely used. As a result Saab EDS's current system which uses diesel as fuel will be obsolete and not competitive compared to the alternatives. One of the main reasons for this change is that the customers demand technologies that use other fuels than fossil fuel because the infrastructure is more favorable for alternative fuels. In addition, the stricter environmental laws as well as the large investments in new energy technologies have further paved the way for the change.

In order to not lag behind, Saab EDS should start working with changing the current power supply to Fuel Cell technology. In order to face this change Saab EDS needs to initiate projects and look into the possibility to incorporate Fuel Cell power supplies into their mobile radar systems. It will also be important to search for appropriate suppliers and investigate the technical compatibility. This is because there are several competing designs within the Fuel Cell industry, such as SOFC and PEM, and by exploring the availability and usage of the different designs Saab EDS can better assess the compatibility of respective design with the mobile radar systems. In addition, there are usually three options if you want to switch or incorporate a new technology; develop internal capabilities and skills to do it in-house, acquisition of a smaller actor or form a joint venture. Hence, different projects should be initiated with a couple of suppliers in order to develop possible Fuel Cell systems, either finished prototypes to test or computer based ideas to simulate testing. The switch to Fuel Cell technology should in the early phases start with a reformer based version or SOFC which is beneficial for Saab EDS's customers since current diesel fuel can be used.

5.5.2 World of Efficiency

The World of Efficiency scenario means that the 50 kW power supplies are getting more and more efficient. The high oil price makes it expensive to run and as a result the users demands more efficient power supplies. Since there have been low interest in supporting new energy technologies, due to the low investments, the technologies that could replace fossil fuel technologies have been few and not widely spread. Instead, hybrid technologies have become more popular even in 50 kW power supplies because of the better efficiency.

In this scenario Saab EDS should improve their current system. The low availability in alternative technologies makes it difficult to replace the current power supplies, especially since Saab EDS and their customers demand a well proven technology. Instead, hybrid technologies will be beneficial to explore. The use of Li-ion battery together with Super conductors offers a more efficient system while it is well proven at the same time. Also, Saab EDS's main focus is the radar system and not the power supplies, thus, it will be advantageous for Saab EDS to collaborate with suppliers to develop a suitable hybrid power supply for their mobile radar systems. Furthermore, Saab EDS should in the early phase initiate projects to investigate the possibility to incorporate hybrid power supply into their mobile radar systems. In other words, develop prototypes together with suppliers. An alternative to the Piston Engine in hybrid systems is the Gas Turbine which can be a viable solution. The technology has been used for a while and is certainly well proven. The light weight and possibility to achieve good efficiency can be a competitive solution. Again, it will be important to work closely with the suppliers in order to develop a suitable and efficient power supply for the mobile radar systems.

5.5.3 Business as Usual

In this scenario the demand and availability of new energy technologies for 50 kW power supplies is low. The low oil price together with low investments in new energy technologies makes it more lucrative to keep the current technologies that uses diesel. The low investments indicate a low interest from different actors in new energy technologies which in turn could make the users even more reluctant to change. Adding to this, the low investments and availability makes the new energy technologies less proven which makes the new energy technologies even less attractive.

In this scenario Saab EDS should keep the current Piston Engines and rely on incremental improvements, from the suppliers, to make the system better. The Piston Engine power generators are well proven and when the oil price is low the users will not, in a larger scale, switch to other energy technologies.

5.5.4 Battle for dominance

This scenario is reflected by many new energy technologies that are struggling to gain the upper hand in order to become the dominating technology in their markets. This means that the industry environment of power supply is fast and ever changing with many new suppliers and constantly changing customer behavior. How this will implicate Saab EDS depends on how they want to build their image and their brand. The scenario will likely segment the customers of Saab EDS into a range from lower end (more prices sensitive) to a higher end (more technology demanding). In other words, depending on if Saab EDS wants to reach all segments or focus on a special segment the implications on the current system will be different. If Saab EDS decides to focus on the lower end, the current system with an integrated Li-ion battery system could be used vis-à-vis a Fuel Cell based system if Saab EDS focuses on the high end segment.

Thus the first thing to do for Saab EDS is evaluate its functional strategy (meaning marketing strategies, product development strategies etc) in relation to what their customers prioritize and for example, decide what segment they want to compete in and what they want to offer to that segment. In this work there would probably be a need to do (or buy) more extensive analyses of the market about changes in customer behavior, competitors behaviors and market trends to be able to identify the most economically appropriate option. If it is for example economically best to expand the product portfolio and have a couple of different power supply systems for the different customer segments; then Saab EDS needs to start multiple projects (together with suppliers and customers) to develop one system for each customer segment. The best thing in this case would be if the different systems developed have the same interface i.e. are module based, so they all fit with the rest of the radar system in the same way which makes it easy to customize a product depending on the segment. Another important thing for Saab EDS in this scenario is to have connections with multiple suppliers so they can be more flexible (low switching costs) in this ever changing environment.

5.6 Signals for what Scenario that will eventuate

There are some important signals that affect the direction (low or high) of the oil price and investment level. Depending on what happens with these signals, the direction can be projected. The signals will show what scenario the world is approaching. In other words, if the signals are kept under supervision the future will be more easily approached and planned for.

5.6.1 Low or High Oil Price

First thing that affects the oil price is the *economic activity* or the *business cycle* (which refers to the demand). If the economic activity grows, the oil consumption will also grow in a rather proportionally way. The most interesting countries to follow are the BRICS and the USA (the largest oil consumer in the world, 25 percent of total). (Svan, 2010)

Second thing that affects the price is the *supply*. If supply of oil increases at a higher rate than the consumption, the price of oil decreases. OPEC (Organization of the Petroleum Exporting Countries) has market reports on the planned oil production. These reports are often free and can be downloaded from their homepage. (Svan, 2010)

Storage levels, which are connected to supply, is the third thing that affects the oil price. These are often reported in news and in similar reports like OPEC's above. Speculations about the storage levels affect the oil price in the short run. However, the most interesting are storage levels that affect the price in the long run. (Svan, 2010)

The fourth and last thing is *geopolitical events*. It is important to have political stability in the oil producing countries, in particular the largest producing countries like Iran, Iraq, Nigeria, Russia and Saudi-Arabia. So for example a conflict (nothing is produced) in Iran, who normally produces the total consumption of Japan each day, will certainly increase the price level of the oil. (Svan, 2010)

5.6.2 Low or High Investments in New Energy Technologies

The entering of new actors, for instance firms and non-profit organizations, can indicate an increase in investments in that industry. As Jacobon and Lauber (2006) emphasizes, there will be a need for entry of new organizations in order for a large scale technological transformation. Hence, following the amount of actors in new energy technologies can point towards which direction the investments in new energy technologies are taking.

According to Andersson[76] and Dahlander[77] *the emission laws and regulation* will have a huge impact on the future development. If the current technologies do not meet the future laws and regulations regarding for example emissions there will be need for new energy technologies. Consequently, stricter laws and regulation indicates a need for larger investments in new energy technologies.

The user's preferences of energy technologies will be an important factor in order to understand the direction of the amount of investments in new energy technologies. For instance, instead of only being aware of the environment people can start to prioritize the environment and thus starts to demand environmental-friendly technologies in a larger scale. As SEVS (2011) states, the life-style in a society is important since it is the people that buy the technologies in the end. As a result, if the society starts to adopt environmental-friendly energy technologies more frequent it can indicate a need for large investments in new energy technologies.

Patents can be a useful indicator to understand the direction of a certain energy technology. According to Mogee (1997) patents can be used to analyze technology trends as well as to ensure that they keep up with the new developments. There are several methods to employ when exploring patents. A practical approach to investigate if there are increasing investments in new energy technologies is by exploring the number of patent families which indicates the activity in a certain technology. A great increase may suggest much interest as well as large investments.

[76] Sven Andersson, Professor, Chalmers University of Technology, Interview 2011-02-23

[77] Petter Dahlander, Assoc. Prof., Chalmers University of Technology, Interview 2011-03-02

6 Conclusions and Recommendations

The purpose in this thesis was to investigate the industry of power supply and the linking industries in order to understand what developments are under way, what future technologies one can expect and their future potential to replace the present system. In this section the research questions developed from this purpose will be answered. Thereafter, the recommendations on how Saab EDS should work with the findings will be presented.

6.1 Conclusions

Before finding the energy technologies of most interest for Saab EDS an evaluation of each identified technology was made with a set of quantitative and qualitative criterions which were developed in chapter 3. The evaluation rendered in Tables 13 and 14 in the end of chapter 4. From them the most promising technologies were deemed to be Fuel Cells (both PEM and SOFC), Gas Turbine, Li-ion Battery and Super Capacitor. Some reasons for not choosing the other technologies were the following (for further reasons, see chapter 4):

Thermo generator was not chosen for further analysis because it was deemed to be too difficult to build a power supply system that is totally dependent on temperature difference. Solar Cell is most suitable for stationary applications since the maximum output from sun light is 1 kW/m^2, which would mean cells of around 300 m^2 to power the current system. The Stirling Engine and Wankel Engine was not chosen because it only exists in niche markets and according to interviewed experts and companies it is expected to stay that way in the near future. The Free Piston Engine was deemed to not be able to evolve enough in the coming 15 years to be able to replace the current system.

In the coming 15-20 years the development of the selected energy technologies, Fuel Cell, Gas Turbine, Li-ion battery and Super Capacitor, will be dependent on trends (such as increasing energy demand, see chapter 5 for more) and driving factors (such as oil price) that influences the future. In order to explore the potential contingencies from these; four possible future scenarios were developed. The selected energy technologies will unfold differently depending on the emerging scenario and this in turn will reveal what technology will prevail.

In the scenario “End of Fossil Fuel Era” when the oil price has increased greatly and there are large investments in new energy technologies from different actors the Fuel Cell technology will improve vastly and has become dominant in the 50 kW power supply segment. The Piston Engine has been totally phased out. The large investments will enable the technology to grow and widely spread which will make it well proven and more reliable. In the scenario “World of Efficiency” with low investments in new energy technologies and high oil prices, more hybrid systems (e.g. Li-ion batteries and Gas Turbine) with complex steering systems to improve the total systems efficiency will be dominate in the market. Due to expensive oil prices, Piston Engines and Gas Turbines are run on non fossil fuels (such as biogas) but the main focus is on storing pure electricity in the batteries which favors the development of Li-ion batteries and Super Capacitors. In the third scenario “Business as Usually” the low oil price together with the low investments will promote the traditional Piston Engine technology. The Fuel Cell technology will only serve a niche market for the customers who demand more environmental-friendly products. It is the same for Li-ion batteries and Super Capacitors who serves as the energy storage technology in these products. Lastly, in the scenario “Battle for Dominance” the competitive environment in the 50 kW power supply industry will be fierce. The large investments in new energy technologies will show a strong support in new energy technologies and make them vastly improved. However, the low oil price will make the traditional Piston Engine cheap to operate and hard to compete with in terms of price and cost. As a result, there will not be one dominant technology. Instead, the energy technologies will be chosen based on what factors the users prioritize.

The different future scenarios will pose different implications for Saab EDS. In the scenario “End of Fossil Fuel Era” Saab EDS current power supply will be obsolete. Hence, Saab EDS must work to switch to Fuel Cell technology. It will be advantageous to start projects in order to investigate the possibility to incorporate Fuel Cell technology into the mobile radar systems. Multiple projects with different suppliers should be initiated in order to find the perfect match for Saab EDS, since there are many competing designs. The early designs should be reformer based Fuel Cells or SOFC (diesel can be used as fuel) in order to make the transition phase to Fuel Cell power supplies smoother.

In the scenario “World of Efficiency” the main implication for Saab EDS is to make their power supplies more efficient. The high oil price makes the users more conscious about the fuel consumption and the operating cost. Hence, power management will be a key factor for Saab EDS in order to handle this change. For instance, by making the mobile radar systems use less power. The power supply used must also be more energy efficient. This makes it vital to work closely together with the suppliers in order to develop a power supply that best matches the radar system. In addition, it can also be beneficial for Saab EDS to move towards a more integrated hybrid system of Li-ion battery/Super Capacitor and a Piston Engine or Gas Turbine with a possibility to run on non fossil fuel.

In contrast, the scenario “Business as Usual” does not pose any major implications for Saab EDS. The current system they use will still be the dominant power supply technology. The low investments in new energy technologies show low support from different actors and the fact that the oil price is low the traditional Piston Engine will be difficult to beat and replace. Lastly, in the scenario “Battle for dominance” the most important implications will be dependent on how the constant shifting industry affects the suppliers (many new suppliers enter or leave) and the customers of Saab EDS. With many more opportunities for each technology (from the Piston Engine to the Fuel Cell) to develop and compete it could lead to a larger segmentation of the market, from low end to high end customers. In this environment, the most important thing for Saab EDS is to decide what or which market segments that is economically best to focus on. If multiple segments are best then multiple projects need to be started in order to create a power supply system for each customer category. The goal in this case should be to work towards a joint interface, i.e. module based so the power supply system is easily replaced depending on what type of customer is buying the entire radar system.

6.2 Recommendations

Currently there are no technologies that are viable or proven enough to replace the Piston Engine generating system. However, following the conclusions of this thesis it is recommended to start working proactively with the technologies within the close future. Since there are no safe bet on which of the scenarios that will eventuate and in turn which of the technologies that will be the best fit for Saab EDS and their customers; the recommendation is to proceed in an early phase with smaller projects with combinations of all of the four technologies. The projects could be other cost effective master thesis with the purpose of developing different concepts incorporating the different technologies with different suppliers. For example, is a SOFC together with a Li-ion battery technically possible? If so, how would such a system look and cost etc. Another recommendation is to put together a group at Saab EDS with the purpose to put up listening posts in order to follow the development of each technology. This can be done by making the group create a network with professors in universities and firms (the ones developing the technology), attending seminars, following industry magazines etc. The last recommendation is to follow the signals (since they determine what scenario that will eventuate and will help Saab EDS focus on one predicted dominant technology) of each of the critical uncertainties. By keeping an insight in e.g. geopolitical events within oil producing countries like Russia, Nigeria, Iran, Iraq and Saudi-Arabia and the economic activity of the BRICS countries, the oil price can followed. The level of investments in new energy technologies in power supply can be followed by using the listening posts of the network (from last recommendation) to follow startups and new entrants, counting patents and reading technical magazines for example.

In short, the recommendations can be divided into short termed and long termed. The only exception is the last recommendation of following the signals, which should be done both in short and long term. Short termed refers to a time close to the present time, at least within a 1 year period. Long termed refers to the time thereafter up to a 5 year period.

Short Term Recommendations

- Start master thesis projects with different combinative systems of Fuel Cell, Gas Turbine, Li-ion battery and Super Capacitor with the purpose of investigating the technical possibilities with each system and its costs
- Start a group at Saab EDS with the purpose of setting up a network (universities and firms) with listening posts in order to follow the development of each technology and signals
- Set up a roadmap on when this group should hold coordinated presentations on this development to the rest of the concerned departments of Saab EDS.

Long Term Recommendations

- Following the master thesis projects, the network of possible suppliers can be used to explore more serious cooperative projects (with the suppliers) with the purpose to develop prototypes of systems depending on what scenario the world is approaching
- Thereafter the prototypes should be tested and matched with possible customers

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Appendix A – List of Interviews

The table below shows the interviewees which have served as source of information for this study.

Subject	Name	Title	Date
Alternative Fuels	Henrik Thunman	Professor, Combustion Engine, Chalmers of Technology,	12th February 2011
Battery	Patrik Johansson	Assoc. Professor at Chalmers University of Technology	20th February 2011
	Göran Lindbergh	Professor, KTH Royal Institute of Technology	23rd February 2011
	Robert Stavrevski	EVP Marketing & Sales Alelion Batteries AB	8th February 2011 (first contact)
Environmental Politics	Viktoria Chlot	Department Secretary, Swedish Government	29th January 2011
Fuel Cell (PEM)	Mikael Alatalo	Researcher, Chalmers University of Technology, Elteknik	25th January 2011
	Per Ekdunge	Vice President, PowerCell AB	27th January 2011 (first contact)
Fuel Cell (SOFC)	Richard Ljungberg	CEO, GETT Fuel Cells International AB	25th February 2011 (first contact)
Future Energy Technologies	Stefan Montin	Surrounding World Analyst, Elforsk	3rd March 2011
Gas turbine	Ulf Håll	Professor, Turbo machinery, Chalmers University of Technology	2nd March 2011
Hydrogen production	Magnus Karlström	Surrounding World Analyst, Vätgas Sverige	15th February 2011
	Claes Tullin	Researching Director, SP Sveriges Tekniska Forskningsinstitut	22nd January 2011
Nanotechnology	Eugenia Perez	Doctoral Student, Environmental System Analysis, Chalmers University of Technology	25th January 2011
Piston/Wankel/Free Piston Engine	Sven Andersson	Professor Chalmers, Combustion Engine	23rd February 2011
	Ken Croft	Harrington Generators	30th January 2011
	Petter Dahlander	Assoc. Professor, Combustion Engine, Chalmers University of Technology	2nd March 2011
	Paul Keeley	Harrington Generators	30th January 2011

Subject	Name	Title	Date
Saab Group	Rolf Andersson	Programme Manager, Saab Group	15th March 2011
	Daniel Dermark	Senior Design Engineer, Saab EDS, Saab Group	6th February 2011
	Niklas Janehag	Electrical Design Engineer, Saab EDS	5th February 2011
	Sven Olsson	System Designer Saab EDS	24th January 2011 (first contact)
	Jan Rydén	Senior Specialist System Mechanics, Saab EDS, Saab Group	18th January 2011 (first contact)
	Mattias Skogsberg	Manager Power and Cabling Saab EDS, Saab Group	20th January 2011 (first contact)
	Lennart Steen	Senior Product Manager, Saab EDS, Saab Group	31th January 2011 (first contact)
	Jan-Ove Winnberg	Senior Product Manager, Saab EDS, Saab Group	27th January 2011 (first contact)
Solar Cell	Ola Carlson	Professor, Power generation, Solar, Chalmers University of Technology	18th February 2011
	Linus Palmblad	Energimyndigheten	16th February 2011
Stirling Engine	Andreas Baumüller	CTO, Cleanergy AB	25nd February 2011 (first contact)
	Niklas Martinsson	R&D Manager, Cleanergy AB	14th February 2011
Thermo Generator	Lennart Holmgren	CEO, Thermo-Gen AB	14th March 2011
	Anders Palmqvist	Professor, Energy Conversion, Chalmers University of TEchnology	18th February 2011
Thermo generator & Fuel cell (SOFC)	Paw Mortensen	CEO, Alpcon	17th February 2011

Appendix B – Semi-Structured Interview Guide 1

The semi-structured interview guide 1 was constructed to gather data regarding the current power supply as well as Saab EDS' and their customers' preferences.

- Main Question
    - Supporting Question

Interview with [Name] [Title]

- How does the current power supply work?
- How has the development been in the last years (around 10 years)?
- What do the customers think works good in the current power supply?
- Will there be any changes in the coming years?
    - What do the customers want?
- What factors are important in the power supply?
    - What does the customer focus on?
    - What about the size?
    - What about the weight?
    - What about the fuel?
    - What about service/maintenance?
    - What about the sound?
- Do you know how much the current power supply cost?
- Have you explored any substituting technologies before?
    - Do you have any ideas/visions on interesting technologies?

Appendix C – Semi-Structured Interview Guide 2

The semi-structured interview guide 2 was constructed after the first guide in order to gather data about interesting energy technologies.

- Main Question
    - Supporting Question

Interview with [Name] [Title]

- Can you give an overview of the [Technology]?
    - How does it work?
    - Pros & Cons?
- How has the development been in the last years (Around 10 years)?
- How well does the [Technology] meet these criterions?
    - Size
    - Weight
    - Fuel
    - Maintenance
    - Service
    - Sound level
    - Heat
- How will the development look like ahead?
    - Will there be any changes?
    - Do you have any estimation on the presented criterions future development?
- What are the important factors regarding [Technology] development ahead?
    - E.g. political?
- What do the users think about the [Technology]

Appendix D – Structured Interview Guide

The structured interview guide was constructed to collect complementary information regarding the important criterions for the respective energy technologies.

Interview with [Name] [Title]

- What are the values for [Technology] in the following factors if produced to generate around 30 kW?
  - Size (W/dm^3)?
  - Weight (W/kg)?
  - Operating Temperature (°C)?
  - Upstart Temperature (°C)?
  - Life Span (hours)?
  - Sound level?
  - Efficiency (%)?
  - Fuel Flexibility?
  - Cost?
  - Robustness?