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Framework for Identifying Technological Shifts

A case study on the gas engine market

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Abstract

In order to create and sustain a competitive advantage in a rapidly changing economy it is essential for companies, not only to be in the forefront of the technological development, but also to identify and manage technological shifts that have the potential to overtake incumbent technologies and transform markets and industries. Today, one important potential future technological shift is the shift from diesel driven engines to gas driven engines. This, as it will not only affect the engine industry but also decrease emissions and decrease the global oil dependency.

This thesis aims at developing a framework that identifies potential technological shifts and facilitates decision-making on how to approach these potential shifts. Furthermore, the framework will be utilized on a case study, in order to evaluate the potential technological shift from diesel to gas driven engines. To fulfil the purpose, existing frameworks, strategy models and analytical tools has been deconstructed and combined in order create a dynamic and general framework, applicable in different industries and situations. The framework has then been utilized when studying and analysing the diesel engine industry and the potential of the gas engine technology in order to assess the potential technological shift and create support on how to approach it. Primary data from interviews with both engine manufactures and engine customers and an extensive survey sent out to engine sales offices in the entire world combined with secondary data from previous research serves as a base for the analysis, discussion and conclusion.

The empirical findings show that the global gas engine market has not grown significantly during the past five years. There are important aspects currently hindering and undermining the development and adoption of the gas engine technology. The gas infrastructure is globally insufficient and many countries are currently subsidizing oil. Furthermore, no dominant design for gas engines is set and thus there are uncertainties among industry actors on which technology to invest in. However, key aspects such as an increasing price gap between gas and diesel and the large supply of gas are implying that the probability for a technological shift is arguably high.

The analysis is supported by an uncertainty assessment and a scenario analysis and it can be concluded that few aspects indicate an increased growth pace of the gas engine market is impending. Thus, the diesel technology and the gas technology are likely to co-exist with potentially a marginal increase of the gas engine market. Furthermore, presuming that the influence from negative aspects will decrease and considering aspects of s-curves and dominant design, once the gas engine technology adoption has reached a critical mass the pace of the market growth will potentially rapidly increase, resulting in a technological shift. Consequently, it is essential for industry actors not only to closely monitor the development but also to consider and develop future strategies on how to handle the technological shift.

Acknowledgement

This thesis is the result from the work performed by the authors during the spring semester of 2013. The project has been conducted in collaboration with the company. To have the opportunity to work with this project has been exciting and rewarding from the first day and until the very end.

To have access not only to the company but also its employees and network has been invaluable and helped us along the challenging work. On this behalf we would like to express our greatest gratitude towards the company and its employees for providing input to the thesis and supporting the work throughout the project. We would like to express especially thanks to our two supervisors David and Krikor at the company, for entrusting us with this project, which has been stimulating and challenging for both of us. David and Krikor have contributed with unique experience and input to the project but also directed the work.

We would further like to thank all the people from both the company and external actors participating in our case study through interviews, surveys, discussions, phone conferences and email correspondences. The project had not been possible without your help and input.

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Gothenburg, June 6th 2013

Martensson Erik

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Discussion

1 Introduction

The following chapter will introduce the topic and provide an understanding of why this thesis has been written, as well as the background to the purpose and the research questions to be answered in the thesis. Furthermore, delimitations of the thesis will be presented.

1.1 Background

Today, society undergoes a shift towards a more knowledge intense economy, focusing on activities that contribute to an increased pace of scientific and technological improvement, as well as increased pace of obsolescence. (Powell & Snellman, 2004) In order to stay competitive in this rapidly changing economy, companies increase their focus on innovations, in order to keep the pace of technological and scientific advances and, thus sustain a competitive advantage. Manufacturing does not create the same competitive advantages as previously, partly due to global competition and entry of new low cost manufacturers in developing countries offering similar manufacturing capabilities to a lower price. (Granstrand, 2010)

Kim & Mauborgne (1999) argues that in a knowledge intense economy, companies' business strategies must focus on expanding existing markets or creating new ones, rather than beating the competition in existing markets in order to become prosperous. This should be done by innovating value by offering new superior products or services, which makes the current competition irrelevant, through offering fundamentally new and superior customer value in existing markets, or by satisfying a leap in buyer's value and create new markets. Questions as "*In what way can we offer customers more value that will result in rising profit growth regardless of industry or competitive environments*" questions everything about a particular industry and the competition within it, and thus explore a far wider range of strategic options than focus on beating the competition in existing markets. (Kim & Mauborgne, 1999) Furthermore, increased global competition increases the importance of innovation and the offering of new superior products or services to ensure a sustainable business. (Powell & Snellman, 2004)

As the importance for innovation and offering new superior market-leading products or services increase, companies are facing new challenges. Companies must constantly monitor the technological development to identify technological shifts to new dominating technologies. (Powell & Snellman, 2004) A technological shift is defined as the point in time when a new earlier inferior technology overtakes an older dominating technology within the same field. Furthermore, the technological shift induces a disruptive development where a new technology offers superior performance compared to existing ones (see figure 1). (Granstrand, 2010; Schumpeter, 1919)

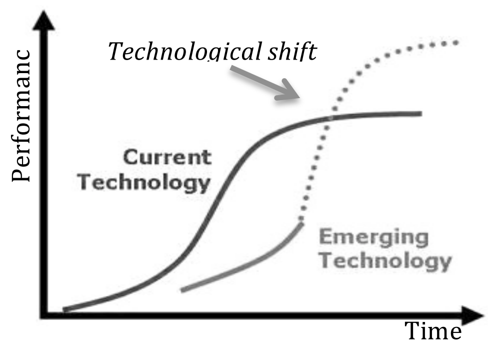


Figure 1 Illustration of technological shift (Granstrand, 2010)

In order to stay competitive and innovate value by offering new superior marking-leading products or services, companies must be in the forefront of the technological development. Thus, it is of highest importance for companies to monitor the technological development in order to identify potential technological shift changing the market, and position themselves after this development. (Kim & Mauborgne, 1999)

Technological shift can be identified in all industries and take various forms. Some can impact the entire society while some are of minor value. Today, one important future potential technological shift is the shift from diesel driven engines to gas driven engines. This, as a shift from diesel fuels to gas fuels will decrease emissions effect on global warming, decrease greenhouse gases and their negative effect they exert on the ozone layer, as well as increasing the supply of energy globally. All these aspects are of global concern affecting the entire world. Moreover, gas fuels offer several benefits compared to diesel fuels, such as: (Frost & Sullivan, 2013)

- Higher efficiency / $ spent on fuel
- More emission compliant
- Clean burning

Today politics has tried to force this shift but with little success. The basic technology for gas-fuelled engines have been around for decades, but diesel fuelled engines still dominates. However, due to the increasing diesel price and government investments in terms of infrastructure and low gas prices, the market shows some serious tendencies for a growing gas usage, and a potential technological shift from diesel driven engines to gas driven engines. (Frost & Sullivan, 2013)

In Europe the oil dependency is too large to neglect according to EU and a change must come in place by gradually replacing oil with alternative fuels. Building up the necessary infrastructure for alternative fuels could bring savings on EU's oil import bill of € 4.2 billion per year in 2020 and € 9.3 billion per year in 2030. (European Commission, 2013a)

Today, the market for alternative fuels is held back by technological, commercial and governmental shortcomings, as well as the lack of consumer acceptance and the insufficient infrastructure. Currently, several initiatives to support the transition to alternative fuels exist around the world both on national level as well as on a global level. However, no coherent and stable overarching strategy with a feasible investment strategy exists. (European Commission, 2013a)

1.2 Purpose and Research Questions

In light of the background, the increased importance for companies to identify and position themselves before potential technological shift is clear. Being able to create customer value through offering cutting edge technologies, sometimes even before they spread across the industry are strong drivers. Thus, identifying technological shifts are of highest importance. However, this might appear complex and difficult. Consequently, the purpose of this thesis is to:

> *Develop a framework that identifies technological shifts and facilitates decision-making on how to approach these potential shifts. Furthermore, the framework will be utilized on a case study, in order to evaluate the potential technological shift from diesel to gas driven engines.*

To develop a framework supporting decision-making on how to approach potential technological shifts and our specific case situation, current strategy models, methods and frameworks will be deconstructed and combined with analytical tools, in order to create a dynamic appropriate framework for identifying potential technological shifts. This framework shall not only be applicable but also adequately evaluate the variables affecting technological shifts. Moreover, the case will be conducted in collaboration with a company active as a manufacturer within the diesel engine industry, hereafter referred to as "the company".

The framework will need to take into account future applications and markets for gas fuelled engines, thus evaluate current applications as well as the development on the gas engine technology and market with the intention to understand the current demand, but also to map out potential future demand. In order to fully assess the gas engine market and its development the current situation on the market needs to be identified, thus current market needs and trends will be identified. This will map the existing customer's needs and indicate what needs that can be expected in future. Further, buyer incentives indicate what aspects that influence the buying decision. Market drivers as infrastructure availability, fuel prices, incentives by governments and/or environmental organizations and emission legislations need to be identified and assessed based on their impact on the development of the gas engine market.

Today, gas can be extracted in different ways and from different sources, which results in gas with different quality. This aspect greatly influences the possibilities and usage of gas engines globally, where some regions have gas more suitable as fuel. The differences in gas quality also have diverse effects on different gas engine types, thus it is a determinant of which technology that will become the dominant design. Hence, mapping and understanding of the supply of different gas types and its effects is of fundamental importance. Furthermore, benchmarking gas fuel against alternative energy sources will map out the benefits with gas, but also identify where the gas fuel is inadequate.

To fulfil the purpose, following questions will be answered:

1. How can a framework for identification of technological shift be composed
    a. What current frameworks supports identifications of technological shifts
    a. What aspects can be used for identifications of technological shifts
    b. How do these aspects reveal technological shifts

A theoretical reference framework will be created as a base for the analysis and the conclusions in order to obtain univocal and reinforced results. The framework will be composed from different tools and methods for market and industry analysis. The sources of information for the theoretical framework will mainly be databases such as Chalmers's database Chans, Google Scholar and the library database LIBRIS.

2. What is the current status of the gas engine market
    a. What technologies exist
    b. What are the characteristics of the market and its customers
    c. What environmental aspects influences the market
    d. How does the competitive situation look like

Information for the empirical part of the project will mainly come from primary data obtained from e.g. interviews, surveys, and questionnaires. However, secondary data will also constitute for a large part of the obtained data used to map the current status of the market. This to maximize the usage of already available information and focus primary data searches on complementary data.

3. How will the gas engine market evolve
    a. In what direction will the technological development advance
    b. How will the customer situation change on the gas engine market
    c. How will environmental aspects related to the gas engine market advance
    d. What direction will the competitive situation of the gas engine market take

The proposed theoretical framework will be utilized to analyse the empirical data gathered in the case study. The analysis will follow the structure described in the proposed framework. Data to support future predications will come from e.g. primary sources as interviews, surveys and questionnaires. Moreover, secondary data from industry reports and other documentation will be utilized so far the data answer to the question and adds valuable information, this as they provide as valuable information source of already gathered data.

4. How should an actor approach the potential technological shift from diesel engines to gas engines
    a. How will the market development align with potential technological shifts
    b. How should an actor approach different technological shift scenarios
    c. When should an actor adopt the potential new technology
    d. How should a competitive advantages be created and sustained
    e. What uncertainties affects the decision

Recommendations for the case study will derive from an analysis using the proposed theoretical framework and in this thesis gathered empirical data. Different scenarios will be considered to provide a nuanced view.

1.3 Delimitations

Secondary data will constitute a large data source as the intention with the thesis in not to provide primary data in all empirical areas, but rather to utilize already existing data from multiple existing external sources as data bases and industry reports and compliment with primary data from e.g. interviews and surveys. This data will not provide a holistic representation of the situation but rather represent the view of the individual primary and secondary sources.

The thesis will focus on two segments for gas fuelled engines; power generators (genset) and off-road engines which includes off road vehicles used in material handling, raw material exploration and construction. Based on the analysis on these two segments, general conclusions about future trends and opportunities for gas engines will be made. Because of the wide scope of the assignment some aspects of the future for gas engines will only be briefly addressed. For example, the technical aspects will, apart from a separation between three different types of gas engines, be kept on a general level.

The thesis will limit the geographical aspect to the major countries/region in Europe, North America and Asia. The scope of these regions will be developed in collaboration with the employer, this in order to get a sufficient in depth knowledge of each region but still limit the scope to counties/regions of commercial interest for the company. Thus, these areas are probably the most relevant for actors in the industry as they constitutes for the largest part of the market.

1.4 Theory

To fulfil the purpose of this thesis, research will be conducted in business strategy theories. This with the intention to provide in depth understanding on how strategic market analysis should be conducted in order to provide useful data and insights to develop a thorough and adequate framework to conduct analysis of technological shifts on the market. Research will be conducted on how strategic market theories can be combined with external analysis such as IP analysis, with the intention of creating a more holistic standpoint from which adequate analysis can be conducted. IP analysis address technological aspects where data on the technological development both among customers and competitors can be assessed. This will provide indication on which competing technologies competitors and the market are developing as well as the technologies customer possess, which indicates current and future needs. The analysis will further serve as a base for facilitating decision-making regarding how to strategically approaches a potential technological shift.

The first part of the theoretical study aims to deconstruct different market analysis models and combine them with analytical tools in order to create a framework suitable to fulfil the purpose of this thesis. To create a comprehensive analytical framework this part is divided into four sections. First a technological analysis, where concepts and tools such as S-curves, technology life cycle, IP analysis and dominant design will be combined. The second section focuses on customer and market analysis. The third section is a competition analysis focusing on competitors and their business. Lastly a section regarding environmental analysis, where external factors, such as legal and governmental aspects will be considered. The purpose of this first part including the four sections is to develop a framework to evaluate the potential technological shifts occurring on market, and the market attractiveness in itself by identifying potential opportunities and threats as well as customer incentives and drivers.

The second part of the theoretical study will focus on potential business strategies and how to facilitate decision-making on how to approach markets facing potential technological shifts. The purpose of this part is to create a business analysis framework including concepts and tools for dealing with strategic uncertainties. A scenario analysis will be used in order to create pre-conditions that enable adequate and comprehensive conclusions and business strategies regarding how to approach markets facing potential technological shifts.

1.5 Definitions

Gas engine market: Defined as potential customers for the gensets or off road segment

Power Generator (Genset): Devices that convert mechanical energy to electrical energy (see appendix 1 for included applications)

Off-road: Includes off-road vehicles (see appendix 1 for included vehicles)

Application segments:

Industrial: Comprises factories and manufacturing units such as semiconductors, paper and pulp, food processing units, construction, marine, chemicals, petrochemicals, rubber, metals, and mining.

Commercial: Comprises high-rise buildings, restaurants, resorts, offices, shopping malls, the telecoms industry, IT companies, data centres, small enterprise and commercial warehouses

Institutional: Comprises hospitals, schools, universities, rural communities, government buildings, utilities, airports railways and various other power capacities

Residential: Comprises smaller end-user groups, which vary from apartment complexes to condominiums

Natural gas (NG): Gas found naturally through natural extraction

Artificial gas: Gas manufactured from artificial materials

Liquefied Natural Gas (LNG): Natural gas stored in the liquid chemical phase

Compressed Natural Gas (CNG): Compressed Natural gas stored in the gas chemical phase under pressure at 200-240 bar.

Methane number: An index over the Knock Tendency. It is a product of the different constituent gases within the natural gas, particularly the proportions of methane, ethane, propane and butane

Knock Tendency: An engine pre-ignites of the fuel

Wobbeindex: The Wobbe Index [MJ/m^3] is a measure of the interchangeability of gases when they are used as a fuel. It compares the energy output of different gases during combustion

Gas engine – Defined as all engines fuelled by natural gas or any other types of gas

Diesel engine - Defined as all engines fuelled by diesel

Diesel Substitution Factor (DSF): Identifies the proportion of gas in relation to diesel

2 Method

This chapter describes the methodologies and research approaches used in this thesis. The chapter will first describe the different research methods that have been used throughout the study. Secondly the research procedure is presented and discussed; here focus is on how the work has been conducted throughout the thesis. Finally, the quality of the research is discussed to provide a nuanced image of the obtained results.

2.1 Research Methods

The methods, which research is based on, can greatly affect the outcome of the research. Thus, it is vital to use appropriate research methods, which take vital and relevant aspects into consideration. (Bryman & Bell, 2011) The purpose of this thesis aims to capture significant factors for identifying and analysing potential technological shifts. Thus, methods enabling this purpose have been used throughout the thesis. After capturing the significant factors they are put together, and a framework for how to approach technological shifts is proposed. The framework is further validated on a case study on the potential technological shift from diesel to gas.

2.1.1 Primary and Secondary Data

Data is divided into primary and secondary data. Primary data is data collected by the authors in order to support the thesis and answer the purpose. Primary data consist of for example historical and legal documents, eyewitness accounts, results of experiments, statistical data, interview material, studies, research, experiment and observation. (Arbnor, 2008) Secondary data consist of data that has been gathered by, to this thesis, external parties and for another purpose. Secondary data can consist of literature, reports, articles, journals etc. (Saunders, Lewis, & Thornhill, 2007) Both primary and secondary sources should preferable be used to minimize the dependence on single individual sources. (Bryman & Bell, 2011)

2.1.2 Qualitative and Quantitative Research Methods

Research methods can be both of a qualitative and a quantitative approach. Qualitative methods are used for in-depth research, with the aim of providing extensive data and understanding of the behaviour behind an action and the reasons that are crucial in decision-making in specific areas of interest. (Biggam, 2008) Thus, Qualitative methods examine how and why certain decisions are taken. This results in fewer, but more in-depth studies. Furthermore, qualitative studies only provide information about the studied cases and thus, no general conclusion should be made from the results. In qualitative methods the actual process is not predetermined, it is instead possible to change and adapt the process in order to obtain a more qualitative result. (Dalen, 2008)

Quantitative methods are used to gather a large amount of data with the purpose of generating a representative overall picture of a situation or population. Quantitative methods are not as in-depth as qualitative methods as they do not examine the underlying reasons but merely needs and motivations, or test different hypotheses. Different quantitative methods are surveys, telephone interviews, postal surveys, Internet surveys or "on the town interviews" etc. Quantitative methods follow a strict scheme as a large amount of data is gathered and it needs to be comparable. (Dalen, 2008)

2.2 Research Procedure

A research procedure can follow three general approaches; deductive, inductive or abductive. A deductive approach starts from the formulation of a hypothesis, i.e. used on a specific framework in a specific setting to investigate if the hypothesis is true or false during specific circumstances. An inductive approach does not take standpoint from an existing theory or hypothesis, but instead theory and hypothesis are developed and evolved based on findings from the study. An abductive approach is a combination of the deductive and inductive approach, where hypothesis are evaluated and modified based on a study, in order to fit the specific research content and surrounding. (Davidsson & Patel, 2003)

This thesis uses an abductive approach as the study origins from existing theories and frameworks, which then are modified to fit the unique purpose and research questions. The work has been conducted after a linear sequence of phases with an iterative approach (see figure 2). This, as the purpose demands a thorough understanding of important concepts in order to fully answer the purpose. Each phase provides the foundation for the next phase and together they collectively are building on each other towards answering the purpose and research questions.

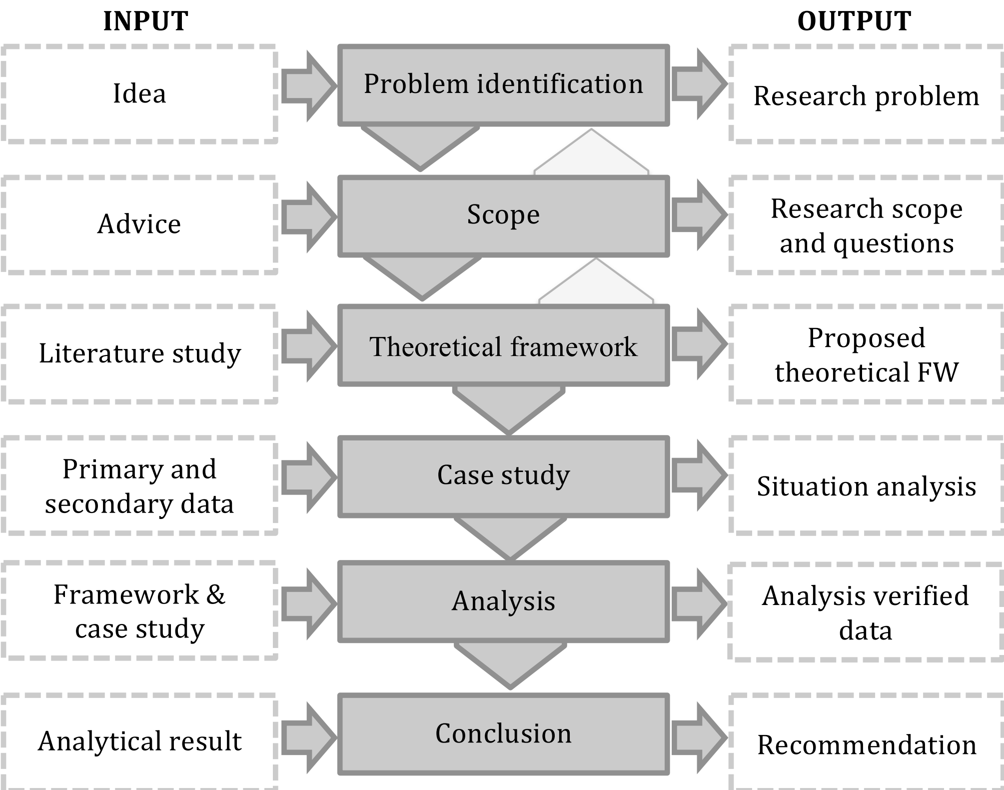


Figure 2 Work process

The first phase identifies the problem from which research will be conducted, followed by framing the scope of the research and defining the research questions the thesis aims at answering. The scope was verified with the problem identification before developing the theoretical framework so that the scope answers to the problem identification and the purpose of the thesis. Then a theoretical framework was developed from a literature study. The framework was verified against the scope to check that it was relatable to the scope and the research questions. Furthermore, the initial scope and research questions were modified according to theoretical findings from the literature study.

After the creation of a framework, primary and secondary data was gathered in a case study. This process has mainly followed an iterative process as questions used in interviews and surveys has been altered and modified to better support good results from the data collection. The case study provided data, which was used together with the proposed framework in the analysis. Finally, the analysis provided a conclusion that lead up to a final discussion and conclusion, which provided answers to the initial purpose and research questions.

2.2.1 Problem Identification

The subject of the thesis origins from the employer's request. The problem origins from requested results from the employer and by reviewing a large number of articles, journals and after discussion with people involved in the industry and academia. The intention was to identify the problem as a problem spanning over multiple sectors and industries and thus, not only relevant to one specific industry. With this in mind several multiple mutually exclusive sources have been used to identify the problem.

The authors took a final decision after a thorough discussion and careful deliberation of the alternatives. The chosen problem is in today's rapidly changing knowledge economy a very common problem amongst companies and industry actors and, thus makes the problem highly relevant and important for multiple actors.

2.2.2 Scope

In a project as this thesis it is vital to have a well-defined scope, as it will direct efforts towards activities answering the purpose and research questions. (Saunders, Lewis, & Thornhill, 2007)

Scoping has been done to enable the study to deliver a viable result. This has been done in discussion with the employer and the supervisor to ensure that focus will be kept throughout the thesis. Time and geography restrictions have ensured that focus has been towards the areas of most interest. The scoping has ensured that the study's purpose and research questions have been well defined and that focus has been kept throughout theory, empirical study, analysing and formulation of conclusions and recommendations.

2.2.3 Theoretical Framework

Multiple frameworks for creating business strategies for various purposes exist. However, to the authors' best knowledge no general holistic framework has been developed for the sole purpose of identifying technological shifts. The study proposes a framework developed to identify potential technological shifts and the factors indicating potential technological shifts.

Current frameworks, not solely designed to identify technological shifts has been deconstructed in order to identify appropriate building blocks and aspects that maps out indications of technological shifts. Framework for multiple purposes have been used and deconstructed. This has provided a holistic base where several aspects have been considered and evaluated regarding their interaction and correlation with technological shifts.

Additionally, multiple exclusively sources and frameworks have been used to minimize the dependence on single frameworks and sources and authors individual opinions. The framework has been limited to consider external market factors and their individual interaction and correlation with technological shifts. Thus, an internal company analysis has not been conducted. This, as potential technological shift initially can be identified in external factors.

The theoretical framework is developed with the intention to identify and examine potential technological shifts in general. Thus, the framework is not limited or developed solely for the industry in which the employer acts. Thus, the framework is intended to work equally well and deliver equal good result in different industries and situations.

2.2.4 Case study

The framework will be verified on a case study. In order to validate the framework it is of high importance that the used empirical data is relevant, significant for the study's purpose and reliable. (Kumar, 2000) Both primary and secondary data has been used throughout the case study. The data was gathered from both primary and secondary sources. The data was roughly sorted into the two segments of interest genset and off-road. Furthermore, primary data was processed with the intention to get comparable data from different sources and regions, thus the data should answer to the same questions but represent different sources and regions so that the data over one specific area of interest could be compared and analysed between different regions and sources.

2.2.4.1 Survey

In a survey all questions are standardised for all respondents, this puts demands on that the questions must be clear and leave little space for own interpretations. Furthermore, the selected population the survey is intended to examine should be representative of the entire population of interest and not limited to one or few subgroups. Several alternatives as mail, Internet, telephone and interview surveys exist for reaching out to the selected population. (Eriksson & Wiedersheim, 2008)

The survey used in this thesis was conducted by e-mail dispatch of a structured predetermined fixed questionnaire including both qualitative and quantitative questions. This, as the survey was intended to reach out to a large population and provide clear result that is comparable between actors within the population. The survey was intended to map the customers' needs and technological requirement as well as identify trends and aspects influencing and affecting the customers. The survey included open qualitative questions where the participants could express their individual opinion regarding the question in matter. Furthermore, the survey included a quantitative part were the participants expressed their needs and market views in a more quantitative way, thus providing comparable quantitative market data.

The survey included questions from all four parts of the proposed framework, thus questions about technology, customer and market, environmental aspects and competition aspects.

The survey was sent out by e-mail dispatch to regional offices within the company enrolled in diesel engine sales in relevant regions for this thesis, including Europe, America and Asia-Pacific. The regional offices where responsible for forwarding the survey to sub offices within the region, as well as compiling the data from their specific region. By this, the survey ended up at relevant persons, possessing extensive knowledge about the individual regions and sub-regions. Appendix 2.2 specifies all regional offices within Europe, America and Asia-Pacific. Results were obtained from 11 out of 12 regional offices in Europe, 3 out of 3 regional offices in America and 10 out of 18 regional offices in Asia. As the regional offices were responsible for the contact with the sub offices within the region, no data exist on the number of sub offices who participated in the survey in each region.

The participants were given a time period of 3 weeks to complete the survey, to ensure that sufficient time existed to deliver high quality results. Reminders where sent out twice, to ensure a high response frequency. The template used for the survey is attached in appendix 2.1. The answers were received by written answers, those answers where then compared within the regions of Europe, North America and Asia to identify common denominators and processed to see if a unanimous answer to the entire region could be derived. All data was processed in a excel database enabling easy access and comparison between the data.

2.2.4.2 Interview

The choice of utilizing interviews should carefully be pondered, as the outcome of interviews depends on the method used. An interview can be open or gradually move toward being completely structured. Open interviews allow the interviewees to freely answer questions without any requirement to stay within specified limits. The interviewer directs a structured interview and the interviewee can only respond according to specific responses. When choosing interview technique, the degree of prior knowledge of the population should be taken into consideration, as well as the interview method that suits the issue, the purpose and the study group best. (Lantz, 2007)

Interviews were conducted both by phone and in person, with internal employees at the company as well as external actors as customers and competitors. In persons interviews were favourable where the opportunity to a closer interaction with the interviewee existed, however geographical obstacles forced some interviews to be conducted by phone e.g. with actors from North American. The interviews were documented by the interviewer, and in the cases when both authors were involved in the interview, one had responsibility for conducting the interview and one for the documentation.

The interviews followed a semi-structured approach with both structured and open nature. This allowed the interviewees to freely express their opinion about the questions in matter. However, the interviewer ensured that the interview followed a scheme that the relevant questions were answered, although the relative question order varied form interview to interview. The intention was to allow freedom to the interviewees so that the answer were of relevant and good quality, but still keep a structure so that all interviews generated answer to the same questions, and that the independent answers were comparable. The template used for the interviews is attached in appendix 2.2. The interviews were not solely limited to the questions included in the interview template as discussions sometimes involved other areas relevant to the purpose and the specific region in matter.

In total 21 interviews have been conducted with to the company both internal and external professionals possessing special knowledge in areas of interest. All professional with whom interviews have been conducted are found in appendix 2.4.

2.2.4.3 Secondary data

Secondary data has been gathered and used in all four areas of the proposed framework, thus in technology, customer and market, competition and environmental aspects. For instance, secondary data as reports, documents, journals and patent information has been gathered and used as technological data to examine and map technological trends and developments. Moreover, secondary data has been used to map customers and the market. For instance, existing surveys and data compilations have been used for identification of the market size and its development as well as trends and aspects influencing the market. Data regarding customers have been gathered form secondary sources as compilations, external surveys and websites. Secondary data has further been used to identify environmental aspects influencing the market as well as the competition.

Secondary data constitutes for a large part of the used empirical data in this thesis, as the intention is in not to focus on gathering as much primary data as possible covering all areas of interest, but rather to utilize and compile already existing data from multiple existing external sources as databases and industry reports, etc. Primary data will be complementing specific areas of interest and areas lacking sufficient data to build an adequate analysis.

2.2.5 Analysis

The analysis has been based on the theoretical framework and the empirical data gathered in the frame of this thesis. The analysis has followed the structure of the proposed framework and was strictly focused on analysing the empirical data based on the theory. Thus, own thoughts and discussions were left out and were instead addressed in the discussion and the conclusion.

To concretize, the theoretical framework was first of all utilised as guidance when collecting the empirical data. Thus, the gathering of data relevant to the analysis could be assured. This also enabled that the empirical result chapter could be structured more or less as the theoretical framework. By doing so, the analysing process was simplified, as it was rather uncomplicated to link empirical data with relevant theory, and the quality of the analysis was likely enhanced as the structure assured that the analysis was kept focused and relevant. Furthermore, the analysis is structured as the theoretical framework and, to some extent, the empirical result, which is believed to help the reader to follow the reasoning in the thesis.

Apart from following the structure of the theoretical framework, each section of the analysis was further divided into the different regions relevant for this study, Europe, North America and Asia. Furthermore similarities in needs and trends as well as differences between regions are identified and analysed.

2.2.6 Conclusion

A conclusion shall include final key take-outs that can be drawn from the work conducted and summarize the entire work that has been conducted. (Eriksson & Wiedersheim, 2008) The conclusion was developed progressively as the work proceeded, however final conclusion was not developed until all relevant aspects had been included and finalized. The conclusion is based both on theory, empirical data and analyses and well as own input, findings and insights that has been developed during the work.

2.3 Quality & Criticism

In any conducted study it is vital to be aware of the quality of the study so that the obtained result can be put in context to the quality of the study. To ensure the quality of the research made within the frames of this thesis, and that the results are reasonable and obtained through adequate methods there are some important aspects to consider. A credible study and ultimately a credible result should contain research of both high validity and reliability. (Eriksson & Wiedersheim, 2008) Furthermore, a study of this character should have an independent approach. Finally, the authors have utilized multiple sources as it further strengthens the quality as it provides independency (Yin, 2003).

2.3.1 Validity

Validity is a measurement of the ability of research methods to measure what the method is intended to measure (Lekvall & Wahlbin, 2001). Validity is highly important to this study as the result is intended to be used as a base for facilitating decision-making regarding how to approach potential technological shifts. Thus, it is of highest importance that the method used surely identifies the aspects they are intended to do. To ensure a high validity both interviews and surveys have been utilized to gather data. Here, both qualitative and quantitative methods have been used to provide both in depth understanding on important areas and to generate a more holistic view of the sources. Further, the interviews allowed the authors to introduce the topic and its intention so that the interviewee had an understanding for the study and the data gathered in the interviews. The interviews further allowed the authors to ask clarifying question both during the interviews and by contacting the interviewee at a later point in time.

The validity of used research methods is strengthened if people highly experienced in the industry actively partakes in the development of interview and survey materials and consider the material to be relevant regarding the subject in matter. (Bryman & Bell, 2011) Consequently, the authors have before the interviews and surveys discussed the utilized methods and utilized materials with the employer to strengthen the validity of the research. This by ensuring that the research methods and material utilized in the interviews and survey provides the data and result needed for the study. Furthermore, literature has been reviewed to further guarantee that the utilised methods ensure to provide the data sought after.

It should be added that an aspect potentially questioning the validity is the fact that data gathered in the interviews represent the sole individual sources and is, hence, no general statements, findings or conclusions should be drawn for the whole population and thus, this aspect should be considered. (Bryman & Bell, 2011)

2.3.2 Reliability

Reliability refers to a method's ability to be conducted in a reliable way. (Davidsson & Patel, 2003) Thus, that the utilized methods will provide the same results from independent repeated interviews. To ensure this, methods must exclude external affects that can affect the interview and be careful and precise in the documentation of the collected data. (Yin, 2003) To ensure a high reliability the authors have before conducting interviews and surveys introduced the subject and the objective of the research to provide a better understanding of why the research is conducted. Further, the survey included a section defining all concepts used, this to ensure that the interviewees had a sufficient understanding and homogenous interpretation of the used concepts.

A template have been utilized during the interviews to ensure a high reliability and that the interview is documented in a detailed and efficient way. The template was developed in collaboration with the employer and was tested before usage. Furthermore, the interviews followed a semi-structured approach to allow the interviewees freedom to express their standpoint and experiences and at the same time follow a general scheme to gather and document all relevant data.

It could be argued that some topics and data of interest during the interviews are of strategic importance for the individual actor the interviewees represent, thus represent confidential information. This might have the affect that interviewees have avoided to provide sought after data. Furthermore, although the authors had the intention to interview interviewees in the same position at different actors, there is an uncertainty that the interviewees have different perceptions regarding certain issues and questions.

2.3.3 Criticism of Resources

As described in *section 2.2.4* the case study included both primary data sources, as interviews and survey, and secondary sources. It can be questioned whether the interviewees expressed the views of the actor they represent or their own standpoints and experiences. Further, it could be argued that it is hard to secure the quality of the survey, as the authors of the thesis do not supervise the answering procedure.

Finally, secondary data is always hard to validate, as no insight exists on how the data was gathered. The author have to their best ability tried to verify used secondary data against other sources, both primary and secondary to verify the data and ensure its quality.

3 Literature study

The following chapter presents the literature study that has been conducted in the frame of this thesis. The literature study will provide theory to enable the authors to answer the purpose of this thesis. The literature study starts with defining the framework components, which incorporates what a theoretical framework identifying technological shifts and facilitates the decision-making on how to approach technological shifts should include. Secondly, the actual framework components are put together and a framework is proposed. Finally, framework utilization present literature on how to utilize the proposed framework and what insights the framework could generate.

When conducting an analysis with the intention to support future strategic decisions it is vital to have a well-defined structure, both to generate a result of high quality but also to focus efforts on vital aspects of the analysis. Utilizing a framework, from which the analysis is conducted, offer the possibility to conduct the analysis by a structured approach and focus on vital aspects generating a result of high quality. (Grant, 2008)

When utilizing and structuring analyses based on a predetermined framework, it is vital that the framework is universal and thus includes several aspects to ensure that a holistic analysis considering several aspects is conducted. Moreover, including several aspects is important as to minimize the importance individual aspects have on the generated result. This as individual aspects can be not completely independent, as they have been designed for a specific purpose. (Grant, 2008)

Following the above reasoning, the analytical process will follow the defined structure in figure 3, starting in the proposed framework (originated from the identified framework components) where empirical data is analysed using the framework. Secondly, analysis regarding framework utilization will be conducted to analyse how to utilize the data generated from the framework, and thus facilitate decision-making. The decision-making can be facilitated directly with data from the framework or indirect through identifying trends, threats, opportunities and strategic uncertainties, and further by conducting a scenario analysis (see figure 3). (Aaker & McLoughlin, 2010)

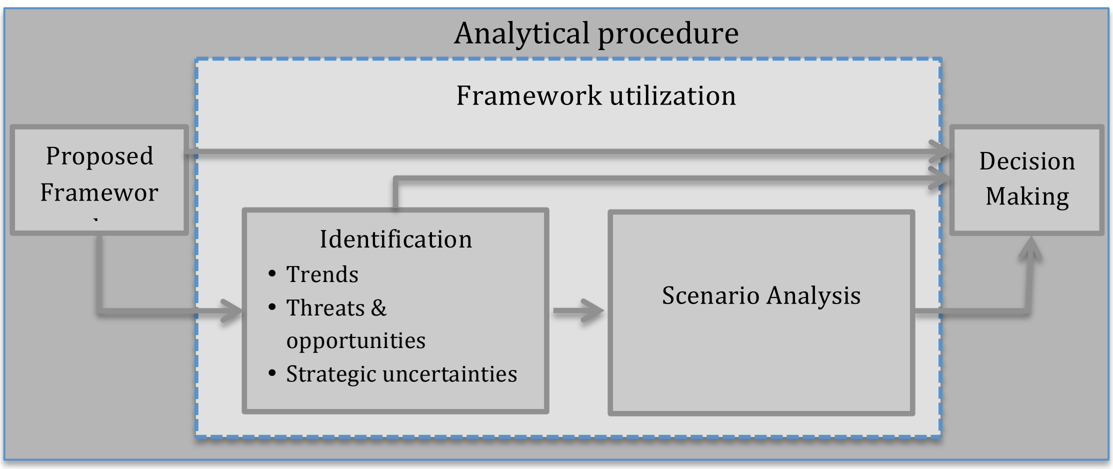


Figure 3 Analytical procedure

Identification including trends, e.g. increased competition or macro trends like increased environmental concerns, result in possible threats or opportunities and, thus, are important to identify and map. Uncertainties whether certain trends, threats or opportunities will occur or come through also need to be evaluated. Thus, strategic uncertainties influences strategic decisions. For example, an uncertainty about the future potential of a market will affect the strategic decision if a company should invest in that market. Hence, knowing the answers to strategic uncertainties is essential when planning strategic decisions. (Aaker & McLoughlin, 2010)

The information acquired in the identification phase could either be used directly for decision-making or be further analysed through a scenario analysis. The scenario analysis could be applied to test different scenarios depending on the extent of an identified trend or on the consequences of different outputs from strategic uncertainties. Depending on the level of strategic uncertainties focus could address different information-need areas where uncertainties could be reduced by acquiring more information. (Aaker & McLoughlin, 2010)

3.1 Framework Components

Theoretical frameworks are favourable for several reasons, as they guides your research by identifying the concepts that describes the area of interest, directs the operational concepts, identifies statistical relationships and provides direction for further data analysis, thus what data and concepts that should be used for further analysis. However, the first step is to clarify and define the components forming the framework. (Shortridge-Baggett, 2010)

The framework components will belong to one of the following four areas; technology, customer and market, competition and environmental aspects

3.1.1 Technology

By assessing the historical technological development insights about future technological shift can be obtained (Schumpeter, 1919), moreover by assessing the current technology and the technological development, trends and opportunities insights about future technological shift can be obtained (Grant, 2008). The four analytical methods of s-curve, life-cycle, patent information and dominant design can be used for this purpose.

3.1.1.1 S-curve

A S-curve maps the performance of a technology over time. They illustrate the stages of introduction, growth, maturity and decline of a technology. (Mullins, Walker, Boyd, & Larréché, 2005) (Shilling, 2010)In an early stage, the technological performance is low and large resources, as time and money, need to be spent on the technology while small performance improvement are reached (Shilling, 2010). Over time the knowledge about the technology accumulates and the performance progress becomes more rapid (Mullins, Walker, Boyd, & Larréché, 2005). When the major technological obstacles are overcome and a satisfying adoption level is reached the performance increase in a fast pace and the growth stage has been reached. In this phase small investment of resources will result in large performance increases. Over time the technological performance decreases and the technology reaches a maturity phase. Finally, the technology performance starts to decline as it reaches its physical limits. Pushing the technological performance further becomes increasingly difficult and resource demanding. Thus, investments in alternative technologies become more attractive as they offer better output for invested resources. This indicates a shift towards a new technology creating a new s-curve, shifted to the right of the original one, with a higher performance limit, offering better output on invested resources (see figure4). (Shilling, 2010)

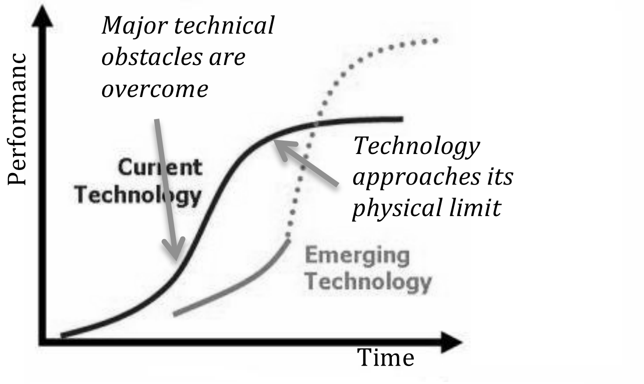


Figure 4 S-curve illustration

Several authors argue that S-curves can be used as a perceptive tool for predicting the future development of a technology, thus predict when the technology will reach its limit and when a technological shift will occur to a new technology offering better performance. Industry actors can use data from own investments and own technological performance or corresponding data from the overall industry in order to map a technological S-curve. (Shilling, 2010; Innovationzen, 2013)

Although a new technology offers a significant improvement over an existing technology, it is not obvious that the users will switch to the new technology. The answer may lie in the complexity of the knowledge underlying the new technology and the resources needed for making the new technology useful for a specific actor and its circumstances. (Tushman & Anderson, 2004) Furthermore, it is not likely that the true limits of a technology are known or can be predicted, as different actors consider the technological limits to occur at different phases. Finally, unexpected changes in the technology, market or other events may impact the development of a given technology and create a different development then the one illustrated by the S-curve. (Shilling, 2010)

3.1.1.2 Life-cycle

Life cycles illustrate the development of an industry or technology experience during its lifespan. The development starts of in an introduction phase and then undergoes a life cycle of growth, maturity and finally reaches a declining stage. (Granstrand, 2010)

The introduction phase is characterised by great uncertainties as the technology is new, unknown and not widely spread on the market, thus the adoption level is low. As the adoption level grows and more users are embracing the new technology the introduction level exceeds into a growth stage characterised by a steadily growing customer base as the technology spreads on the market.

As the technology develops and more customers embrace the new technology the development reaches the maturity stage, here the technology is well developed and initial uncertainties are overcome. Moreover the technology is well established on the market and has an existing customer base. Finally, the development slows off and reaches a final stage of decline. The technology is now considered old and the customer base start to shrink as other more attractive alternatives entice the customers. (Granstrand, 2010)

3.1.1.3 Patent information

In order to receive a patent, inventors must disclose information about their invention in exchange for patents rights. This information shall be comprehensive and include enough information so that skilled persons could reproduce the invention separately. This information covers; patent documentation, auxiliary documents, proprietary information, licensing information and patent maintenance information and is referred to as patent information. (Granstrand, 2010)

Patent information can be used as a management tool as it provides a unique source of technical information. The information is collected, screened, published and presented according to internationally agreed standards. This distinguishes patent information as more qualitative information than other technical information carriers as publications, people or products and processes, which puts no or little demands on the information's quality (Granstrand, 2010).

Patent information possesses significant technological information and offers benefits due to its extensive time and technology coverage and its detailed information. Furthermore it is easily accessible and the quality of the patent documents is standardized. Patent information can indicate: (Granstrand, 2010)

- Actors and competitors technological profile, indicating what technologies and fields that are in focus
- Technological breakthroughs, trends and forecasts (both market specific and actors specific)
- Actors R&D and technological investment strategies

As patent information is a carrier of technology information is can be utilized to identify technology developments and, thus be used to identify technological shifts. Although patent information possesses extensive information it should be considered as complementary information and should not alone be used for decision-making (Granstrand, 2010).

3.1.1.4 Dominant Design

A fundamental aspect to consider when industries, markets or new technologies emerge is the aspect of dominant design, which refers to a single product, technology or process that dominates the market. A dominant design is a "de facto standard" meaning that while it may not be officially enforced, the design had become the standard for the industry or market. (Shilling, 2010)

The time prior to the dominant design is set is referred to as an era of ferment where it is unclear of which technology that will become a dominant design (Tushman & Anderson, 2004). The era of ferment is characterized of market and technology uncertainties and can be seen upon as a time period where market, technology and the industry are negotiating between each other. At some point in time during the introduction or growth phase of an industry the objectives of these aspects will be compromised in to an official or unofficial agreement and a dominant design will be set.

Having one uniform dominating design offers multiple benefits over several independent competing technologies as: (Shilling, 2010; Suárez & Utterback, 2007)

- Absorptive capacity, refers to that one dominating design facilitates one organisations ability to recognize and utilize knowledge

- Network externalities, refers to that the value of a design increases with the number of users of the same design.
- Large installed base, refers to that customers choose a specific design due to that the specific design has an existing installed customer base
- Complementary goods, refers to that additional or complementary goods or services enhances the value of a specific design
- Less risk, refers to that the risk decreases as one design reveals as dominating, this decreases the extensive technology and market uncertainty that occurs when several designs are available
- Production of scale, a uniform dominating design offers scalability and cheaper manufacturing cost as the manufacturing can be focused on one design

The fact that a dominating design will be established creates a "winner takes it all" situation. Where one design will if not completely dominate, at least by large majority become the largest dominating design. Choosing the wrong technology can lead to ruinous consequences, as another dominating technology will be the one used and requested. At the point in time of technological shift the uncertainties regarding dominant designs are even greater as uncertainties exist not only between different new technologies but also between the new technologies and the predecessors as well as uncertainties regarding when in time that technological shift will take place. (Shilling, 2010)

3.1.2 Market and Customer

By evaluating customer and markets and understanding the customer segments, customer needs and drivers, market size, market growth, market trends and the market attractiveness insight about customers and markets future development can be obtained and put in relation to how it will impact a future technological shift. (Aaker & McLoughlin, 2010)

3.1.2.1 Customer Segments

Segmentation is according to Aaker and McLoughlin (2010, p. 26) defined as "the identification of customer groups that responds differently from other groups to competitive offerings". An understanding of different customer needs in different segments is of significant importance when structuring a strategic investment decision in order to create a sustainable competitive advantage (Aaker & McLoughlin, 2010). In order to successfully identify main segments, customers must be evaluated based on specific variables. These variables defining the segments may differ from case to case but can mainly be divided into two groups; customer characteristics and product-related approaches. Customer characteristics are variables not related to the specific products but merely variables focused on demographics, such as geographic classification, or organisation characteristics like type of organisation and the size of a company. Product-related approaches are variables related to a specific product. Examples of product-related variables are benefits from using a product, buying incentives influencing a specific customer segment or customer's price sensitivity. (Aaker & McLoughlin, 2010)

3.1.2.2 Customer Needs and Drivers

Customers' needs and drivers are important to identify as to understand motivations driving their buying decision. (Aaker & McLoughlin, 2010) Aspects to consider are why a customer use a product, what objectives a customer has and what, according to the customers defines a good products. (Szymanski & Henard, 2001) These aspects should be assessed on their importance and what impacts they will exert on the customers. (Aaker & McLoughlin, 2010)

Another key aspect that potentially can differentiate a business is to identify unmet needs. Unmet needs can be defined as needs that existing products do not fulfil and therefore could entail a business opportunity. Hence, there is a possibility of increasing market (Wilkinson, 1995) shares or even creating new markets. However, unmet needs can entail threats for companies competing in a market because there is a possibility for competitors to benefit from the opportunity as well, and, thus create a competitive advantage. Customers may not be aware of their unmet needs, hence it is important for a company to reveal those needs by for example developing and offering new technologies. (Aaker & McLoughlin, 2010)

3.1.2.3 Market Size

Assessing the size of a market is a basic initial factor in a market analysis and plays a fundamental role when evaluating the potential and future development of a market. (Aaker & McLoughlin, 2010)

The market size should cover current production and sales, as well as historical market data. Although, this data can be difficult to obtain for the entire market, it is useful and can be used to evaluate the future development of the market. To achieve this it is favourable to use multiple sources. Government and trade association's data should be combined with financial data from major players and customer surveys. (Internet Center for Management and Business Administration, 2013)

3.1.2.4 Market Growth

Aspects to consider when assessing the market growth and deriving future sales should origin from the current market and be based on current sales data but also include new customers or segments and the possibility for existing customers to purchase larger quantities. Moreover, as future shifts in customer needs, drivers, trends and forces driving changes and dynamics of a market can affect the development they may serve as an important complement to forecasting based on current sales. Due to great uncertainties concerning future growth rates and the importance of an accurate forecast, predictions of future market size is a key strategic uncertainty. (Aaker & McLoughlin, 2010)

Additionally, one important aspect in a growth prospect analysis is to determine the industry's position from a life-cycle perspective, described in *section 3.1.1.2*. Some key indicators, determining the life-cycle position of a market and thus, the potential for growth, are price pressure, substitute products, saturation of the market and the lack of growth sources. (Aaker & McLoughlin, 2010)

3.1.2.5 Market Trend

Market trends influence and affect the current market as well as the future development and are therefore important to identify and evaluate regarding how and if they accelerate a potential technological shifts. (Aaker & McLoughlin, 2010)

3.1.2.6 Market Attractiveness

Information about a market's attractiveness carries extensive information about the current market as well as indication on the future development. Thus information about market attractiveness can be utilized to identify and evaluate potential future technological shifts. When assessing market factors as threats of new entrants, bargain power of customers, bargain power of suppliers, industry rivalry and the threat of substitutes are important to examine. (Aaker & McLoughlin, 2010) These factors are further described and illustrated by Michael Porter in his Five Forces model, see figure 5 (Grant, 2008).

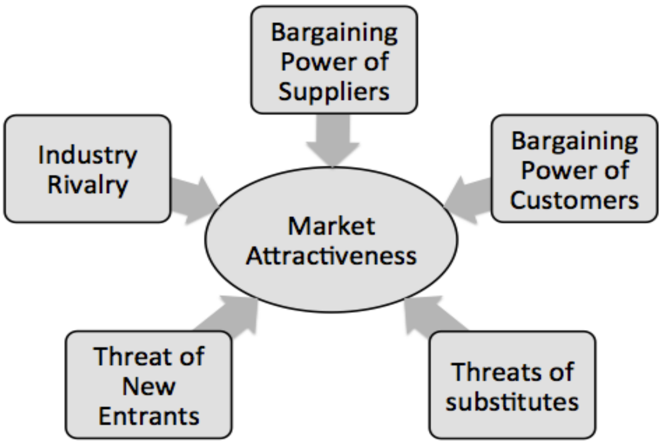


Figure 5 Market attractiveness factors

Industry rivalry refers to the competition among companies within an industry. In order to determine the level of industry rivalry some aspects of the competition and the competitors need to be analysed. First of all, the concentration of the competition should be examined, which basically means finding out the number of competitors as well as their size. Other aspects to consider are the diversity of competitors and the differentiation of their products. (Granstrand, 2010)

If customers have the power to force suppliers to lower prices or change their products the attractiveness of an industry may be affected. Thus, bargain power of customers is an import aspect to consider. The same goes for bargain power of suppliers, which is equally important to consider and evaluate. Mainly two factors influence the bargain power: buyer's price sensitivity and relative bargain power. If customers are sensitive to variations in price of a product they will stop purchasing a product or change to a competitor or substituting product in the case of an increased price. The relative bargain power refers to the balance of power between a buyer and a supplier. The size and the number of buyers in relation to a supplier determine what impact a loss of a buyer will have on the supplier. The extent of how informed a buyer is about a supplier will also affect the bargain power. Furthermore a buyer's ability to integrate vertically, thus eliminating the role of a supplier, can also affect the balance of power. (Aaker & McLoughlin, 2010; Granstrand, 2010)

An important aspect greatly affecting a firm's possibilities to price a product higher than the price on a market of perfect competition is threats of new entrants. Thus, barriers to entry will affect the attractiveness of an industry and hence, are important to analyse. Some examples of barriers to entry are capital requirements, economies of scale resulting in low production cost for large established firms and the access to distribution channels. +Other aspects could be product differentiation resulting in customer's brand loyalty and external factors such as governmental and legal barriers. (Granstrand, 2010)

Finally, analyse regarding threat of substitutes should be conducted. The attractiveness of an industry is dependent on whether or not a substituting product is available or not. If substituting products are available and easily accessed, the risk of customers switching to a substitute is high if the product is not to the customers' satisfaction. (Grant, 2008)

3.1.3 Competition

In order to stay competitive and succeed in an industry it is vital to understand the dynamics of the competitive environment. This is not only to map competition and understand the competitors but also to unveil strategic opportunities in order to achieve and sustain a competitive advantage. (Brummer, Badenhorst, & Neuland, 2006) It is not uncommon that small, emerging firms, with the help of new technology, can seize large market shares and profits, often unanticipated by industry incumbents. Hence, a comprehensive and continuous competition analysis is also a tool for identifying potential market trends indicating potential technological shifts. (Aaker & McLoughlin, 2010)

With these aspects in mind, the purpose of the competition analysis is to create insight of the competitive environment, which should influence the decision-making and provide indication of potential technological shift. Competitors' weaknesses and strengths should be analysed as well as potential threats and opportunities. However, from a technological shift perspective, one of the most important aspects of the competition analysis is to unveil strategic uncertainties created by emerging or incumbent competitors utilizing a new technology. (Aaker & McLoughlin, 2010)

There are two main steps in a competition analysis. The first step is the identification and grouping of competitors. Both current and potential future competitors should be identified and grouped in strategic groups based on their characteristics, strategies and competencies. The second step is to evaluate the competition in order to expose potential opportunities and threats. (Granstrand, 2010)

3.1.3.1 Identifying Competition

The identification of current, direct competitors is straightforward. It could be conducted from a customer-based view, where the choices customers make serve as the base for the identification of competitors. Another method is to use a product-use approach where products with similar use are identified. (Aaker & McLoughlin, 2010)

Indirect competitors and new potential competitors are harder to identify but nevertheless important to consider. As customers' incentives and priorities may change, indirect competition offering substituting products could become direct competitors. Potential competitors could be companies possessing a new technology, companies engaging in a product or market expansion or companies engaging in backward or forward integration. As for indirect competitors, emerging competition can entail great threats to incumbent firms and are, hence, essential to consider. (Aaker & McLoughlin, 2010)

Analysing a large number of competitors is resource demanding and might not be feasible, thus reducing the number by creating strategic groups is a suitable approach. A strategic group should contain competitors sharing similar business strategies. The competitors should have similar characteristics in terms of size, image and positioning and also have comparable assets and capabilities. Even though generalising the competition could result in a loss of insights and content, strategic groups will assist in obtaining an extensive view of the competition where several aspects could be considered. As a result a comprehensive understanding of the competition could be obtained, which will contribute to a substantial support in future decision-making. (Granstrand, 2010)

3.1.3.2 Evaluating Competition

Evaluating competitors are done to create an understanding of the competition by evaluating vital aspects to reveal potential opportunities and threats as well as identifying strategic uncertainties, which should be further monitored and analysed. (Aaker & McLoughlin, 2010)

Aspects to consider when evaluating competitors is first of all economical factors such as size, growth and profitability, which will provide information of the industry in general and the specific competition in particular. Qualitative aspects to consider are positioning strategy, current and past business strategies and the competition's objectives. This is of vital importance because it could reveal incentives and the competition's willingness to invest. Thus, it will serve as an indicator of the competition's belief in a market and potentially predict strategic changes. (Granstrand, 2010)

Potentially the most important aspect to evaluate is the assessment of the competition's strengths and weaknesses. This will create insight into competitors potential to achieve strategic goals as well as reveal opportunities and threats. A weakness among customers can entail an opportunity to develop a successful business strategy. At the same time a competitor's strength could entail a threat that needs to be neutralised. (Aaker & McLoughlin, 2010) Strengths and weaknesses are based on competitors' assets and capabilities or the absence of them. Thus, the assets and capabilities, which are relevant and important for the industry needs to be identified. Hence, assets and capabilities that have contributed to historical success within the industry and components in the value chain that facilitate a competitive advantage should be identified. Furthermore, the driving forces behind customers' buying decisions are needs and motivations. Thus such aspects can be utilised to identify assets and capabilities that contributes to a sustainable competitive advantage and, hence, entails strengths if a company possess them and weaknesses if a company lacks them. (Granstrand, 2010)

3.1.4 Environmental Aspects

Direct and indirect effects on an industry due to external, environmental trends can change the premises of a market and, hence, such trends are important to identify and monitor. (Grant, 2008) In contrast to market trends, environmental trends are not directly related to a specific industry but are more of macro trends potentially affecting several industries and markets. (Aaker & McLoughlin, 2010)

3.1.4.1 Governmental Factors

Governmental factors have the potential to entail strategic opportunities or threats to an industry. These factors are often derived from consumers influencing politicians into creating a political trend. Such trends have the potential to influence both regulations as well as grants. One of the most topical trends influencing political decision-making in most industries is the increasing environmental friendly awareness. This trend has influenced governments for example to put regulations on emissions. (Tushman & Anderson, 2004)

While regulatory constraints is a common way to regulate manufacturing or using of certain products another common political action is to use subsidies. Subsidising products is an effective method to support a certain production and by subsidising an incumbent product a government may have the potential to hinder a technological shift because it creates incentives to not change in to producing a new product. (Aaker & McLoughlin, 2010)

3.1.4.2 External Trends

External trends are referring to trends such as general consumer trends or new changeable technologies, which are not directly related to a specific industry but still may affect strategies within that industry. The severity and the level of opportunities or threats an external trend will have on an industry differ, however a general consequence is that it challenges incumbent firms and may make way for new entrants. (Aaker & McLoughlin, 2010)

It could be argued that it is a straightforward process to identify new trends, however it is harder to identify a potential disruptive technology. (Aaker & McLoughlin, 2010) This is especially true in an era of ferment lacking a dominant design, as described in *section 3.1.1.4*. Furthermore, it is hard to evaluate the impact trends will have on the market and on the incumbent technology. New technologies do not necessarily push out incumbent technologies but can instead create new markets, leaving room for the incumbents. Furthermore, it could be argued that the shift from an old technology to a new usually takes longer time than what is generally predicted, leaving room for adaptation and change among incumbent firms. (Aaker & McLoughlin, 2010)

3.2 Proposed Framework

The following framework (see figure 6) has derived from the framework components identified and described in the literature study (section 3.1). The framework consists of four major blocks, technology, customer and market, competition and environmental aspects. The four blocks are further divided in vital subareas that that can be used for identification of technological shift as well as in the development of a suitable business strategy for facing the potential technological shift. The sub areas do not strive to cover the entire block they represent, but merely the aspects that can be used as indicators for potential technological shifts and as building blocks for developing a suitable business strategy for facing potential technological shifts.

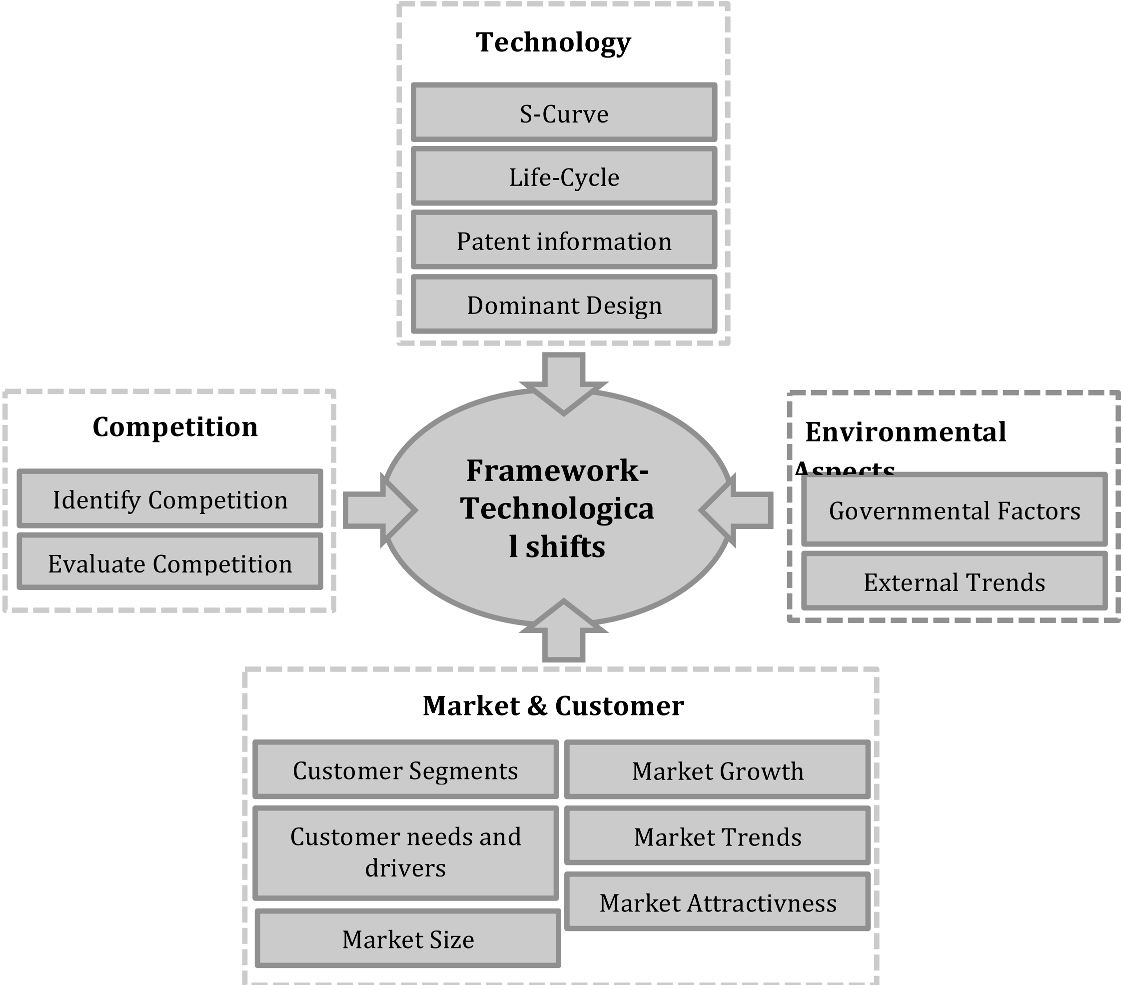


Figure 6 Proposed framework

The proposed framework is developed with the intention to be suitable for a diverse range of industries. The empirical study and the analysis will follow the structure of the proposed framework, thus treating technology, customer and market, competition and environmental aspects. Furthermore, as the case study already includes predetermined customer segments from the employer, the work conducted in this thesis will exclude the framework component of customer segment.

3.3 Framework Utilization

The developed framework proposed in *section 3.2* shall be utilized for conducting the analysis. However, the proposed framework is developed with the aim of supporting the purpose of this thesis, thus identifying technological shifts and facilitating decision-making on how to approach these potential technological shifts. To fully serve this purpose it is vital to understand how to use the data the framework generates and how to transfer that data into a decision basis for decision-making. Thus, to understand the framework utilization phase in figure 7.

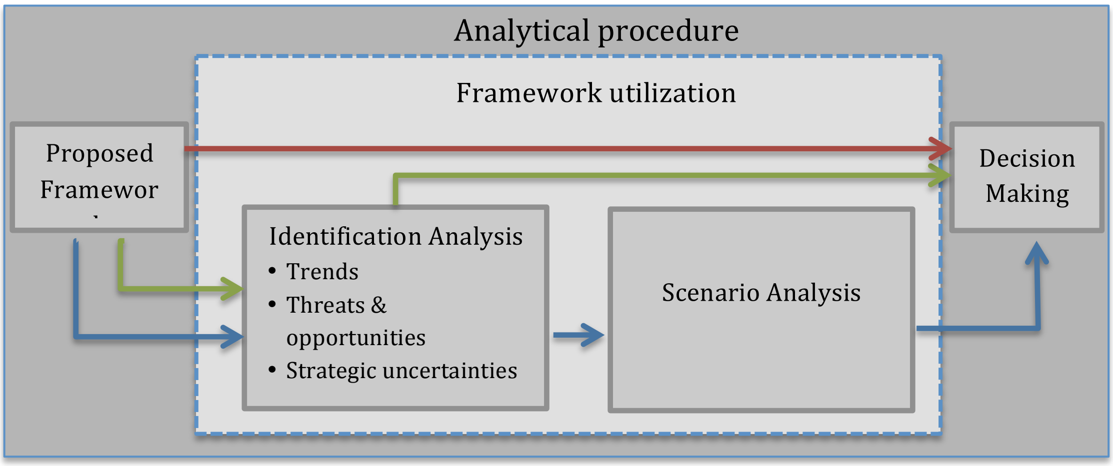


Figure 7 Analytical procedures of framework utilization

The analysis results in data generated from the proposed framework. If applicable, the data could directly be used as a basis for decision-making. Thus, the data generated from the framework will go directly to the decision-making phase and be utilized as a basis for decision-making. The red pathway in figure 7 illustrates this framework utilization process.

3.3.1 Identification Analysis

If the data generated through analysis using the framework not directly can be utilized as a base for decision-making, the data should preferable go through an identification phase. (Aaker & McLoughlin, 2010) The aim of the identification phase is to identify trends within the empirical data. Furthermore threats and opportunities could potentially be derived partly directly from the empirical data and partly from the trends. Finally, a number of strategic uncertainties could possibly be identified from the threats and opportunities as well as from the trends. Strategic uncertainties are defined as uncertainties with the potential to influence and shape the future for an industry. (Aaker & McLoughlin, 2010)

In order to create a relevant base for decision-making the strategic uncertainties need to be identified, grouped and assessed (Wilkinson, 1995). After identifying and grouping uncertainties in groups containing uncertainties, sharing characteristics and potential consequences, an impact analysis can be used to assess and analyse those uncertainties. In the impact analysis the uncertainties are assessed based on essentially two aspects (Aaker & McLoughlin, 2010):

- The impact of the uncertainty, where the extent of related trends should be analysed as well as the importance of the affected business.
- The immediacy of the uncertainty, where the probability of that an uncertainty actually will occur is assessed as well as the time frame of an uncertainty, i.e. when the affect of an uncertainty is expected to appear.

After strategic uncertainties are assessed, they need to be managed. Depending on the impact and the immediacy of the uncertainties different approaches and measures should be taken (see figure 8). (Aaker & McLoughlin, 2010)

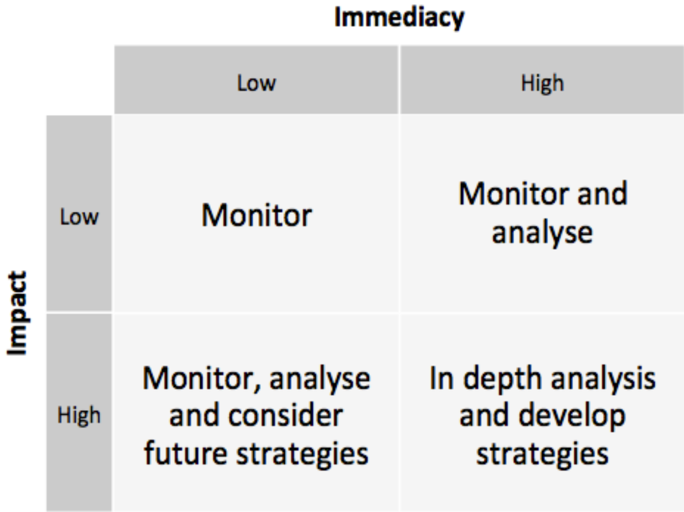


Figure 8 Structure for management of strategic uncertainties (Aaker & McLoughlin, 2010)

If the immediacy and the impact of an uncertainty are assessed to be low, it is sufficient to only monitor the future development of the uncertainty. If the impact is thought to be low but the immediacy is high an analysis of the uncertainty may be suitable. In contrary if the impact is considered to be high and the immediacy low, in addition to monitoring and analysing the uncertainty, future strategies may be considered and prepared. If both the impact and the immediacy are assessed to be high future strategies should be developed and carefully analysed. (Aaker & McLoughlin, 2010)

After managing the strategic uncertainties the data could be used as a base for decision-making. The green pathway in figure 7 identifies this process. (Aaker & McLoughlin, 2010) However, the data could be further processed by tools for mapping and assessing consequences of the impact of strategic uncertainties, which could be conducted by scenario analysis, further explained in *section 3.3.2.* (Wilkinson, 1995)

3.3.2 Scenario Analysis

If the data generated from the identification phase not directly can be utilized as a base for decision-making, the strategic uncertainties can be processed utilizing scenario analysis in order to deliver valuable output that could be used as a basis for the decision-making. The blue pathway in figure 7 illustrates this process. (Aaker & McLoughlin, 2010)

Scenario analysis can further assess different impact levels of the strategic uncertainties and, thus, reduce those uncertainties (Aaker & McLoughlin, 2010). Furthermore, scenario analysis is a model, which can assist in determining which strategy that will be most suitable in a range of different future scenarios i.e. which strategy that adequately will manage uncertainties of the future (Börjesson, 2012). However, scenario analysis is mainly a method for mapping and assessing forces that influence and push uncertainties of the future in diverse directions. Thus, the scenario analysis is a suitable tool for illustrating different scenarios, which should be monitored, analysed and considered when developing future strategies. (Wilkinson, 1995)

The first step of the scenario analysis is to identify main driving forces, influencing the future. The driving forces in the scenario analysis are derived from the strategic uncertainties (Aaker & McLoughlin, 2010), and may entail economical, social, technological or political trends or more commonly a combination of those trends. In order to create a perspicuous and applicable scenario analysis the strategic uncertainties should be reduced to two or three main driving forces with the highest potential impact, that possibly will outline the future. (Wilkinson, 1995) The most critical uncertainties should be inserted in a matrix where they are stretched to their extremes, thus resulting in a number of scenarios, as illustrated in figure 9 (Börjesson, 2012).

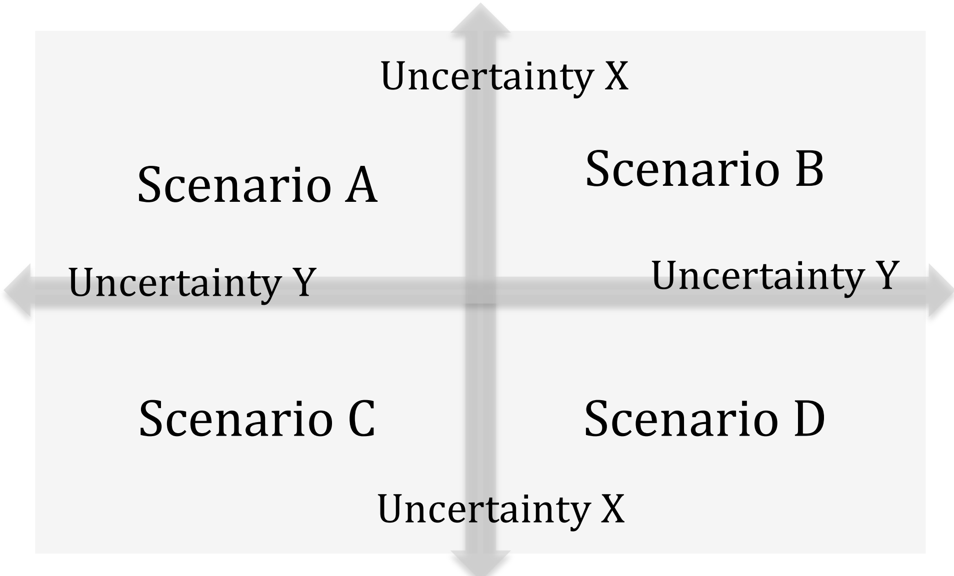


Figure 9 Scenario analysis structure (Wilkinson, 1995)

The goal of scenario analysis is not to identify four different scenarios but to identify four corners of the future, thus four extreme scenarios. In reality the true future is a combination of the different scenarios. Thus, the purpose of the scenario analysis is to understand the future consequences of the strategic uncertainties, enabling the development of a suitable and applicable base for decision-making. (Wilkinson, 1995)

In order to create a relevant and focused scenario analysis and eventually conduct a high quality analysis of empirical findings, which support future strategic decisions, it is necessary to follow a well-defined analytical structure (Grant, 2008). Thus, utilizing the proposed framework, illustrated in figure 6 may enable a holistic analysis, including multiple aspects, where the importance of individual aspects is minimized. The framework comprises of four building blocks of technology, customer and market, competition and environmental aspects, which allows individual analysis of each area as well as a coherent analysis between the four areas.

Furthermore the analytical procedure illustrated in figure 7, provides the opportunity to either support direct decisions derived from the four framework building blocks, technology, customer and market, competition and environmental aspects, or to further analysis these blocks by identifying trends and strategic uncertainties. This analytical procedure enables an opportunity to deeply analyse empirical findings to create a high quality support for strategic decision-making.

4 Empirical result

Following chapter presents the empirical data, which have been collected and utilized in this thesis. The empirical data supports the case study of the gas engine market. First, empirical data will be presented on the areas of technology, followed by data over customer and market, competition and environmental aspects. Data in these four areas will to the extent possible follow the individual structure in these four areas as indicated in the proposed framework in section 3.2.

4.1 Technology

This section includes empirical data related to different gas technologies and engine technologies.

4.1.1 Gas Technology

Today there are two broad classes of gas fuels, natural gas and artificial gas. This classification is not based on their chemical composition, but rather on their individual source and their individual manufacturing processes, thus, those found naturally through natural extraction, and those manufactured from artificial materials. (U.S. Department of Energy, 2013)

All gases can be stored in different forms (chemical phases) as Compressed Natural Gas (CNG) or Liquefied Natural Gas (LNG), which enables easier handling, transportation as well as more energy per volume. CNG is produced by compressing the original gas to approximately 1 percentages of the original volume of the gas at atmosphere pressure. The gas is then stored in containers under a pressure of 200-240 bars. LNG is produced by compressing the original gas to approximately 0,1 percentages of the original volume of the gas at atmosphere pressure, which forces the gas to undergo a phase shift, turning the gas into liquid. LNG offers a benefit over CNG as it delivers 2,4 times more energy by volume, extending the range and reducing refuelling frequency alternatively enabling smaller tanks for storing LNG. (BG Group, 2013) However, LNG puts demands on the storage environment. The fact that LNG is stored as a liquid means that it needs to be stored in conditions that will preserve the liquid phase. This demands that the storage temperature needs to be kept low (around -160 Degrees Celsius). If the environment in which the LNG is stored does not conserve LNG in a liquid phase, it will vaporise into the gas phase inside of the tank. As gas has a larger volume than LNG the pressure increases as more LNG vaporise, the increasing pressure will force gas to slip out of the tank. This is a much unwanted effect as it leads to loss of fuel and raw untreated gas that slip out. Raw untreated natural gas a greenhouse gas effect 20 times higher than carbon dioxide. (Najjaar, 2009)

Today CNG is a more used fuel technology compared to LNG, as CNG has historically been the favourable and mainly used gas. (U.S. Department of Energy, 2013; Natural Gas Europe, 2013) However, the patent activity is both more intense and grows faster within the field of LNG (see figure 10).

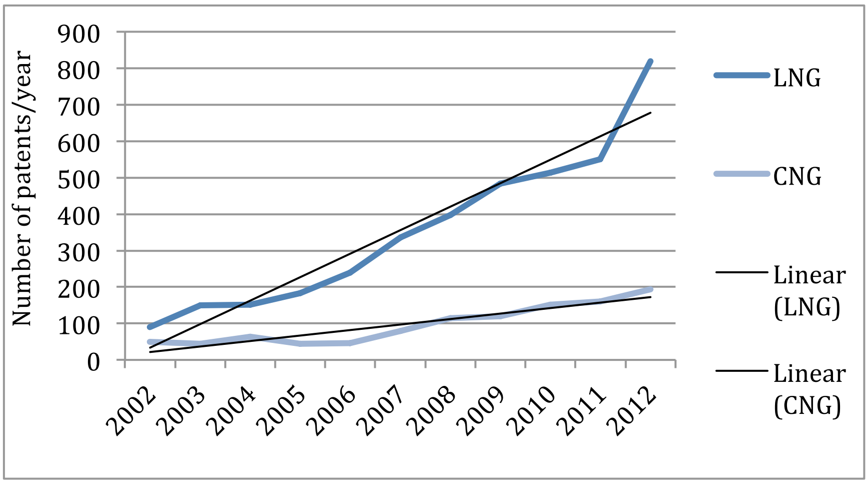


Figure 10 Patent activity within LNG and CNG technologies (Thomson Innovation, 2013)

The quality of the gas differs greatly depending on its origin. Small changes in the quality and the composition of the gas greatly affect its performance and limits the usage to engines modified for that specific gas type. Today, gas engines are usually modified for the specific gas available in the local region. This leads to increased modification costs and limitation of suitable gas fuels. (Advanced Engineering Manager in Engine Industry, 2013) The gas quality is generally defined by the methane number, wobbeindex and gas composition, although other aspects and substances affect the quality of the gas to some degree. The methane number provides an index over the knocking tendency (further described in *section 4.1.2.1*), which greatly affects the efficiency of an engine. The wobbeindex is an index over the energy content of the natural gas, which indicates how much energy the gas contains. The wobbeindex greatly affects the effect of an engine. Gases having the same wobbeindex are held to be interchangeable. (Wikipedia, 2013b; Clarke Energy, 2013a)

4.1.1.1 Natural gases

Natural gas is a broad classification including all gases that are found through natural extraction, this includes mainly hydrocarbons, but also additional gas substances as carbon dioxide, hydrogen, nitrogen, sulphide hydrogen, helium and argon. All natural gases will remain in their gas phase and not condense into liquids at 20°C and atmosphere pressure. (Natgas, 2013) Hydrocarbons are a fossil fuel formed from the remains of prehistoric organic features, as plants and animals. (Energy4me, 2013)

Natural gas includes four hydrocarbons substances, Methane, Ethane, Propane and Butane (see figure 11), all with four or less carbon molecules. Hydrocarbon with more carbon molecules are liquefied at 20°C and atmosphere pressure and is not considered as natural gases, but may exist in gaseous phase in the reservoirs before they are extracted. Methane constitutes for around 80 percentages of all natural gas extracted globally. Further, natural gas is one of the cleanest burning fuels and if burned, the cleanest fossil fuel, after incinerated producing primarily carbon dioxide, water vapour, and small amounts of nitrogen oxides. (Advanced Engineering Manager in Engine Industry, 2013)

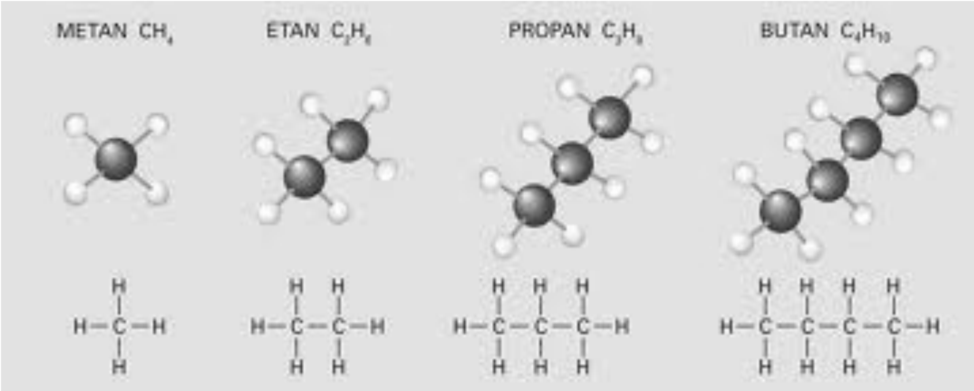


Figure 11 Chemical compositions of natural gas hydrocarbons (Gyldendal, 2013)

Natural gas containing more than 95 percentages of Methane are referred to as dry or lean gas, while natural gas containing less than 95 percentages methane and more than 5 percentages of other hydrocarbon molecules containing more carbons are referred to as rich or wet gas. (Advanced Engineering Manager in Engine Industry, 2013)

Of the four natural gas hydrocarbons, Propane and Butane have the highest energy coefficient (94 MJ/m3 equivalent to 26.1kWh/m3), while Methane and Ethane have a lower energy coefficient (38 MJ/m3 equivalent to 10.6 kWh/m3). This leads to that Methane or Ethane cannot be substitutes for Propane or Butane and vice versa when different energy content of the substances puts different demands on the burning procedure. However, in order to be able to use the same burner for all four substances and get similar combustion characteristics, Propane and Butane can be mixed with air to produce Synthetic Natural Gas (SNG) that possess similar characteristics as Methane and Ethane, and thus, can act as a substitute.

Today natural gas is extracted worldwide (see figure 12). USA and Russia dominated the extraction with volumes on ~ 650 billion cubic meters and ~ 610 billion cubic meters (see appendix 3.1), which constitutes for roughly 40 percentages of the natural gas today extracted globally. (Gaz Prom, 2013; U.S Energy Information Administration, 2013a) For more information about the single largest natural gas producers and consumers see appendix 3.1.

Figure 12 Global natural gas extraction (Wikipedia, 2013a)

Europe & Eurasia together with North America are the two continents with the highest production of natural gas, although the production has been relatively flat over the last ten years. Middle East and Asia Pacific has shown the greatest growth regarding natural gas production during the time period between 2001 and 2011 (see figure 13). Furthermore, Europe & Eurasia together with North America are the two largest consumers of natural gas. Middle East and Asia Pacific had the greatest growth of natural gas consumption during the time period between 2001 and 2011 (see figure 14). (British Petroleum, 2012)

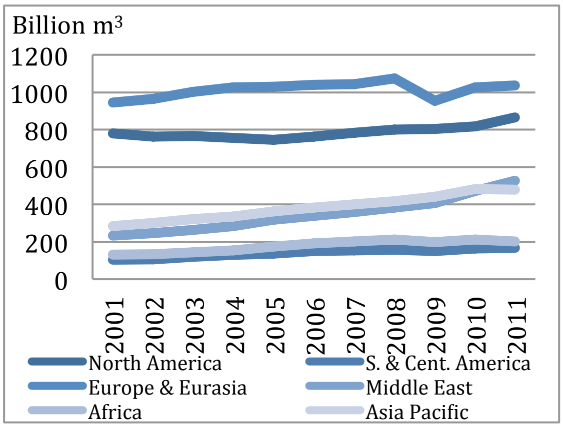


Figure 13 Global gas production (British Petroleum, 2012)

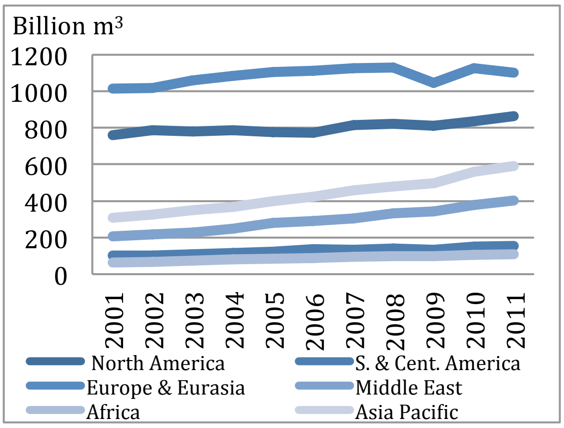


Figure 14 Global gas consumption (British Petroleum, 2012)

Today very large reservoirs have been detected where natural gas has been proven. Figure 15 identifies the amount of gas identified in proven reservoirs globally. These proven regional reservoirs will cover future gas consumption for 75 years within Europe & Eurasia, 15 years in America and 35 years in Asia (see appendix 3.2).

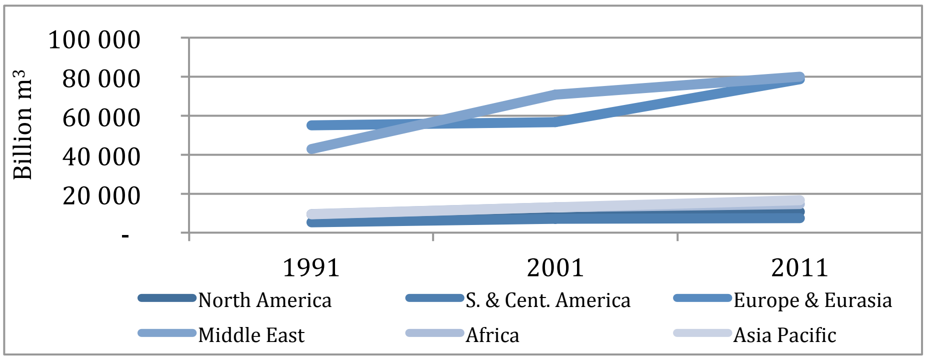


Figure 15 Proven gas reservoirs (British Petroleum, 2012)

4.1.1.2 Artificial gases

Artificial, or manufactured gases are those that are manufactured and assembled by hand. Artificial gases include e.g. biogas, coal gas, water gas, wood gas and compressed or uncompressed hydrogen. Artificial gases can be produced to meet different requirements regarding composition, methane number and wobbeindex. This makes artificial gases diversified and suitable as fuel. Artificial gases as biogas can be produced from multiple materials. Furthermore, artificial gases can be produced of disposals from treatments plants, dumps and agriculture, which ensure efficient handling of the disposal. Additionally biogas is one of the most produced artificial gases (see figure 16 for biogas production globally) (British Petroleum, 2012).

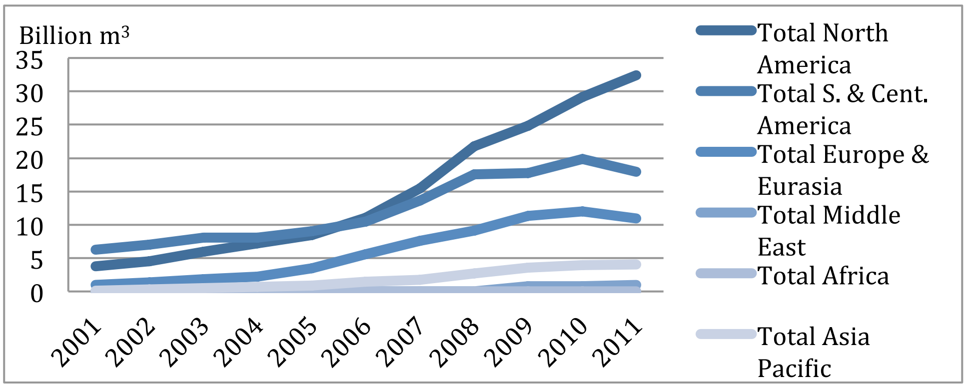


Figure 16 Global Biogas production

4.1.2 Engine technology

The following section describes three types of gas engines, which all are based on conventional technologies of combustion engines and compression ignition engines, but have different specifications and qualifications. Furthermore, the different engine types are compared between each other.

4.1.2.1 Spark Ignition Engines

Spark Ignition Natural Gas (SING) engines use the same technology and principals as petrol combustion engines (Power Eng, 2013). Gas is mixed with air and injected in to a combustion chamber where a piston compresses the mixture. A spark plug ignites the gas and the piston is pressed away by the unleashed energy (see figure 17) (Frost & Sullivan, 2013). Dependent on the quality of the gas and the methane number there is a risk of knocking or pre-ignition of the fuel, implicating that the gas or a portion of the gas will ignite before the piston is fully compressed. Hence, creating a knock, which will damage the engine (Eere Energy, 2013). Due to this complication and in order to prevent knocking, SING engines need to be calibrated to ignite earlier than an engine running on diesel, thus resulting in a lower compression. Consequently the SING engine has a lower torque in relation to a diesel engine and subsequently the SING engine is less energy efficient. (Eere Energy, 2013)

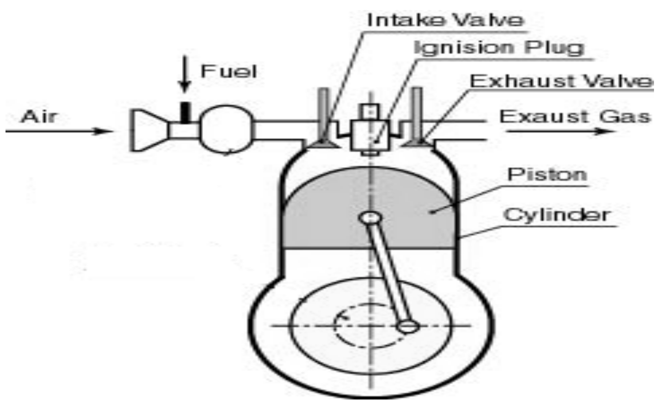


Figure 17 SING engine (Nmri, 2013; Wikipedia, 2013a)

A knock sensor, using a microphone to detect knocking and control the ignition, is essential in order to increase the engine efficiency. By integrating a knock sensor the engine gets less sensitive to fuel with various methane numbers, thus the performance of the engine increases. (Clarke Energy, 2013b)

As a SING engine is based on the same technology as the petrol combustion engine, except from adding a knock sensor and modification to the injection system, the same engine can be used. A SING engine can run on both CNG and LNG and the engine is significantly quieter than a diesel engine (Eere Energy, 2013). An engine running on gas releases, in theory, less Green House Gases than a diesel engine. However, due to methane slip in todays SING engines, where unburned methane is released freely into the air, the level of GHG reduction is uncertain. (Advanced Engineering Manager in Engine Industry, 2013)

4.1.2.2 Dual Fuel Engines

A Dual-fuel engine is based on a diesel compression ignition engine, with a SING engine gas injection technology. Gas is injected in to the combustion chamber, the movement of the piston creates compression and the diesel is injected (Frost & Sullivan, 2013). The diesel self-ignites due to heat and the high pressure, and as a result the diesel ignites the gas (see figure 18). As the gas is compressed by the piston there is a risk of knocking, however, this can to some extent be controlled by increasing the diesel proportion in the mixture or by throttling the amount of air in the gas-air mixture. (Advanced Engineering Manager in Engine Industry, 2013)

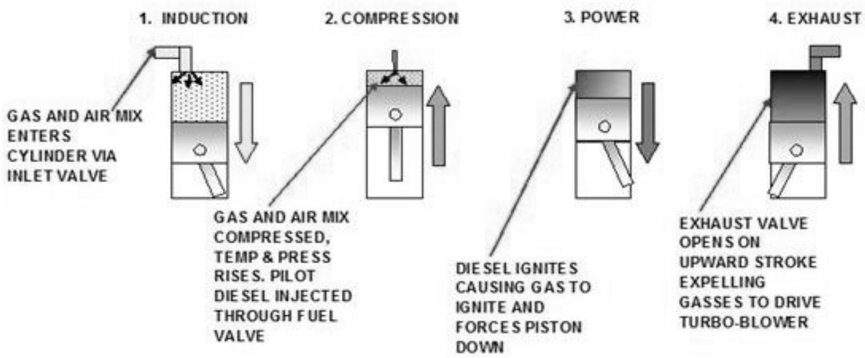


Figure 18 Dual Fuel (DF) engine (Bright Hub, 2013)

Because of similarities in technology between the Dual-fuel engine and a traditional compression-ignition engine the Dual-fuel engine can, except from being run on a mix of gas and diesel, if necessary operate solely on diesel (Bright Hub, 2013). The proportion of gas in relation to diesel is called the Diesel Substitution Factor (DSF). For example an engine being run on 70 % gas and 30 % diesel has DSF number 70 (Clean Air Power, 2013). Except from the availability of the different fuel types the DSF is dependent on driving patterns. Diesel ignites at a significantly lower temperature than natural gas and consequently a certain engine temperature is required in order to substitute diesel with natural gas. As a result the DSF is low in the beginning of a driving cycle, when the engine is cold and a larger proportion of diesel is required, and the DSF may increase after some time when the heat in the engine has increased. Therefore, it is possible to achieve a higher DSF in a long haul truck where the required engine temperature is sustained during most of the driving cycle, than it is in a forklift with more of a stop and go pattern, short driving distances and long idling phases. (Advanced Engineering Manager in Engine Industry, 2013)

Furthermore, Dual-fuel engines have problems with methane slip, limiting the GHG reduction. In fact, due to low engine temperature in the Dual-fuel engine the risk of not igniting all of the gas is higher than in a SING engine, thus resulting in a higher methane slip. Further, a Dual-fuel engine requires an after treatment system in order to meet emission standards. The Dual-fuel engine also requires an extra tank for diesel, as well as a tank for diesel exhaust fluids (DEF) used in the after treatment. (Frost & Sullivan, 2013)

The Dual-fuel engine has the ability to keep the low fuel consumption and torque performance of a diesel engine, while substituting some or most of the diesel fuel with natural gas (Clean Air Power, 2013). Dual-fuel engines can also relatively easy be retrofitted onto a diesel engine by adding the extra required systems and modifying the diesel injection signals. (Clean Air Power, 2013) (Hardstaff Group, 2013)

4.1.2.3 High Pressure Direct Injection Engine

High Pressure Direct Injection (HPDI) engines derive from the compression ignition engine (Low Carbon Fuels, 2013). In the HPDI engine a small diesel injection is sprayed in to the combustion chamber and gets ignited by heat compression prior to the gas injection (see figure 19) (Westport, 2013c). Thus, the gas is injected into the flames and as a consequence the combustion process is easy to control, methane slip is reduced and methane number variations are practically irrelevant (HHP Summit, 2013).

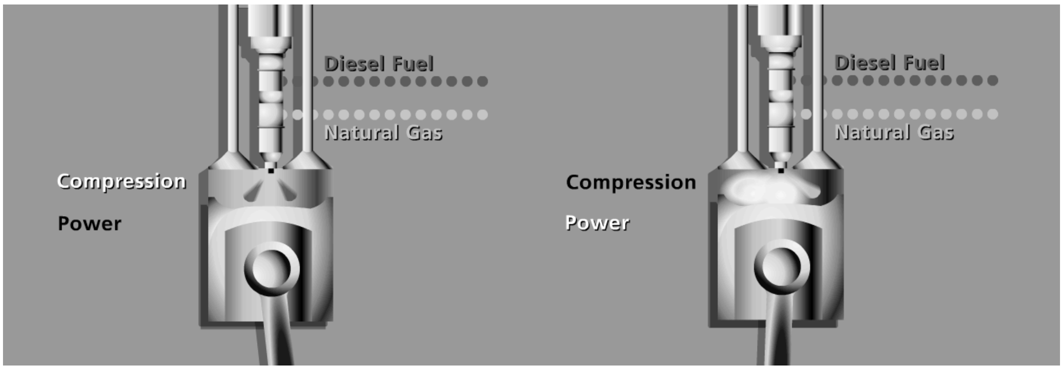


Figure 19 Illustration of the compression stage and the power stage in a HPDI Engine (Westport, 2013b)

The wobbeindex is the key fuel parameter for HPDI engines and if it is not controlled, deviations in torque and power output can occur. However, if variations in wobbeindex are foreseen a control system can adapt to it by adjusting the amount and/or the timing of the gas injection. The torque and the performance of a HPDI engine are equal to a diesel engine and the DSF is over 90 % during all driving conditions. However, due to constraints in the fuel injector, which only can inject a small amount of diesel, the HPDI engine cannot run solely on diesel. (Frost & Sullivan, 2013)

The HPDI injector requires gas with a pressure of 300 bars and as a consequence a special fuel pump for LNG is needed. A regular CNG tank usually holds 240 bars when full, hence a special booster pump is required in order to boost the pressure to a constant of 300 bars. Such a pump is not considered to be commercially feasible, because it would add substantial extra weight, space and cost. (Advanced Engineering Manager in Engine Industry, 2013)

4.1.2.4 Comparison Between the Engine Types

The SING engine offers a relatively lighter weight compared to Dual-fuel and HPDI engines. However, it does not have the same torque and efficiency as a Dual-fuel or a HPDI engines, and consequently a larger SING engine is required to deliver the same performance. Furthermore, SING engines require only one fuel type, and do not require a complex after treatment system. (Frost & Sullivan, 2013)

Dual-fuel engines have approximately equal torque and power to a diesel engine and only slightly lower efficiency. However the Dual-fuel engine is sensitive to variations in the methane number, it has a relatively high methane slip and comparatively low DSF percentage. (Frost & Sullivan, 2013)

HPDI engines' performance and efficiency are equal to a diesel engine, it has a high DSF percentage in comparison to the Dual-fuel engine and methane slip is limited (Westport, 2013d). However, the HDPI technology is more costly than the other two engine alternatives and as it only can operate on LNG it is dependent on a well-functioning LNG infrastructure. (Frost & Sullivan, 2013)

Figure 20 present relevant aspects for the different engine technologies SING, Dual-fuel and HPDI by using a traditional diesel engine as a reference.

Aspects	Spark Ignited (SING)	Dual Fuel	HPDI
Torque	~ 80 % of Diesel	Equal to Diesel	Equal to Diesel
Efficiency	~ 85 % of Diesel	~ 95 % of Diesel	Equal to Diesel
Diesel Substitution Factor	100%	0 % - 90 %	> 90 %
Fuel	Gas(CNG & LNG)	Gas (CNG & LNG), Diesel	Gas (LNG)
GHG Reduction (compared to diesel)	Uncertain (due to Methane Slip)	Uncertain (due to Methane Slip)	aprox 25 %
Robustness (Methane Number variation)	Possible Robust	Sensitive	Robust
Relative price	Low	Medium	High

Figure 20 Gas engine comparison (Advanced Engineering Manager in Engine Industry, 2013; Frost & Sullivan, 2013)

4.2 Market and Customer

The global market for gas engines within the genset and off road segments can be calculated from the production of gas engines for these segments over the last years. The total production within these two segments has been relatively constant over the time period 2008-2013, with a total yearly production off approximately 20 000 units covering all (se figure 21). Where gensets constitutes for the largest part of the production (approximately 15 000 units). (Power System Research, 2013)

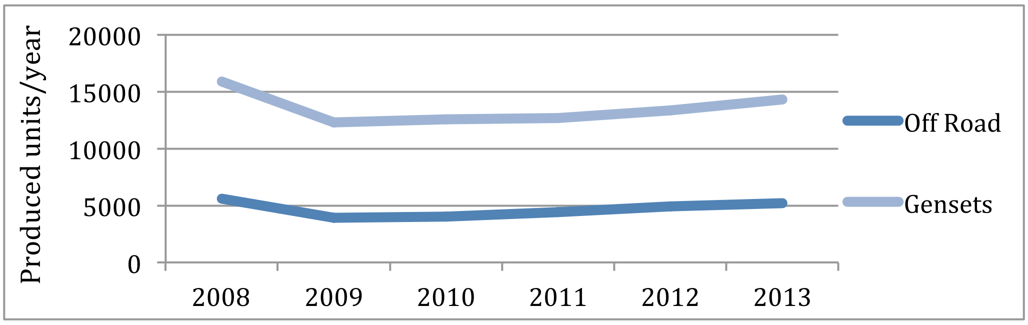


Figure 21 Natural gas engine production (see appendix 1 for definitions of Off-Road and Genset) (Frost & Sullivan, 2012a; Power System Research, 2013)

The global market for diesel engines, which is a direct competing substitute to gas engines, is larger compared to the gas engines market, with an annual production of around 2 million units produced each year in the off road and genset segment (se figure 22). This indicates that the number of engines produced for the same or similar applications, but powered by different fuels is large. (Power System Research, 2013)

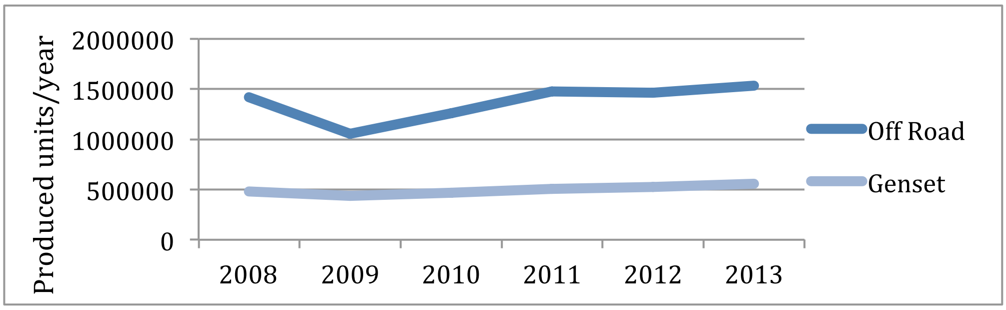


Figure 22 Diesel engine production (see appendix 1 for definitions of Off-Road and Genset) (Frost & Sullivan, 2012a; Power System Research, 2013)

The relation between produced engines powered by natural gas and diesel is presented in firure 23. As seen, diesel constitutes for approximatly 97% of the produced engines within the generator segment and 99% within the off-road segment. (Power System Research, 2013)

		2008	2009	2010	2011	2012	2013
Genset	Gas	3,20 %	2,74 %	2,63 %	2,43 %	2,49 %	2,56 %
	Diesel	96,80 %	97,26 %	97,3 %	97,57 %	97,51 %	97,51 %
Off Road	Gas	0,40 %	0,37 %	0,32 %	0,30 %	0,33 %	0,34 %
	Diesel	99,60 %	99,63 %	99,6 %	99,0 %	99,67 %	99,66 %

Figure 23 Market distribution between gas and diesel engines within the Genset and Off-Road segments (Frost & Sullivan, 2012a)

4.2.1 Genset

The following section present data over gensets used in various areas as industrial, institutional, commercial and the residential sectors (se appendix 1 for definitions).

4.2.1.1 Customer Needs and Drivers

Today customers choose gas gensets for different purposes as their incentives and motivations differs from each other. One common reason for choosing gas gensets is the concern over climate changes and to use an environmental friendly alternative. Furthermore, customers' needs varies between different geographical regions and application areas, this as the customers do not have any uniform request on gas generators. (Survey, 2013)

Generators are primary used for one of the following three applications: (Frost & Sullivan, 2012a)

1. Standby Power, gensets are used as an alternative back-up power source when primary power sources are disconnected or out of function
2. Primary Power, gensets are used as a primary power source
3. Peak Shaving, gensets are used as power supply only for supplying power to cover demand over peak time periods

Figure 24 identifies the global distribution between application areas for gas gensets.

	Global	Europe	America	Asia	China
Standby Power	64%	15%	80%	25%	80%
Primary Power	30%	80%	12%	70%	15%
Peak Shaving	6%	5%	8%	5%	5%

Figure 24 Global application areas for gas genset 2010 (Frost & Sullivan, 2012a)

Globally, gas gensets are used primary as standby power sources. The instability in the current power infrastructure throughout the world, including advanced economies as the US and Europe as well as developing economies is a strong driver for usage of standby power gensets. Primarily, blackouts occur due to capacity overload or external events, such as crisis or environmental effects, as storms, earthquakes, etc. Moreover, the increased environmental concern and the need to meet emission targets are strong drivers for gas gensets. (Frost & Sullivan, 2012a)

Today, diesel gensets are still generally globally favourable over gas gensets due to that they meet the most important customer needs of lower cost and the ability to generate a high power capacity. Furthermore many customers view gas generators as an expensive form of power generation. Additionally, diesel gensets are more suitable for on site power generation and as standby power sources, which constitutes for the largest part of the genset sales. The customers are highly price sensitive and when seeking alternatives to diesel gensets they requests the same performance to an equally low price. (Frost & Sullivan, 2012a; Customer Interview, 2013; Survey, 2013)

Compared to diesel, gas gensets are significant more expensive and in order to justify the higher price they should be used in continuous applications. (Frost & Sullivan, 2010)

Europe
Europe has generally a positive perception of gas as an engine fuel. It is expected that the gas genset market growth will improve the gas engine technology and consequently the usage of gas gensets both as primary power sources and as standby power sources will increase. Currently, gas gensets are primarily used as primary power sources in Europe mainly due to high power stability in the current power infrastructure primarily in Western Europe. Thus, there is a low need for backup power sources. The European demand is primarily driven by increased power demand in Europe and mainly in Eastern Europe, regulations and support for green energy, EU subsidies and directives for large combustion plants to meet new emission standards by January 2016. (Frost & Sullivan, 2010; Customer Interview, 2013; Survey, 2013) Figure 25 visualizes a schematic representation of the customer needs in Europe. The aspects are evaluated on a scale from 0-5 where 0 indicated no customer need and 5 indicates a very high customer need.

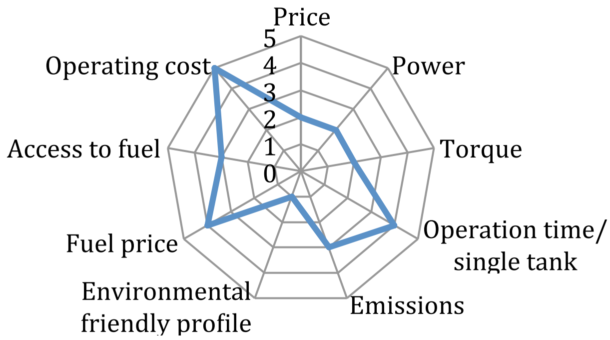


Figure 25 Schematic representation of genset customers Europe (Customer Interview, 2013; Interview, 2013)

America
Gas gensets are mostly used as standby power sources in America (especially spark ignited natural gas gensets), due to frequent blackouts from disasters and capacity overload. Recently, several severe natural disasters have further increased this usage of gas gensets as standby power supply. The instability in the current power infrastructure drives sales of smaller gensets (0-60 kW) for back-up power generation for residential and smaller commercial application, while larger gensets (>300 kW) is sold as back-up power generation to industrial and larger commercial applications. (Frost & Sullivan, 2012a)

The American market is driven by increased power demand, the low natural gas price, the current power infrastructure unreliability and increasing shale gas production (Frost & Sullivan, 2012a).

Asia
In Asia the usage of gas gensets varies. China uses gas gensets primary as standby power sources to cover power demands due to instability in the current power infrastructure and to supply power during natural disasters. However, the need for gas gensets as primary power sources in industries as oil fields, mining and construction sites will increase in the near future. In the rest of Asia, power gensets are used as a primary power source due to lack of enough power supply. (Frost & Sullivan, 2012a; Survey, 2013)

The Chinese government is driving the market and promoting the usage of clean energies as natural gas by adjusting the structure of energy resources, offering and providing subsidises on 0.04 USD per kWh electricity generated using green sources. (Frost & Sullivan, 2012a)

4.2.1.2 Market Size

The global genset market had a market value of 3 459 mUSD in 2012. Figure 26 shows the global geographical distribution of the market value.

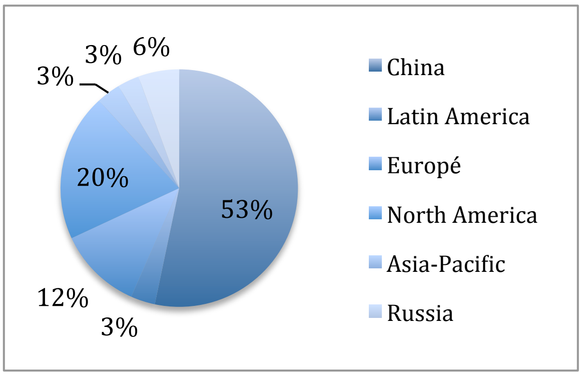


Figure 26 Global market value 2012 (Frost & Sullivan, 2012a)

The global genset market varies between different application areas and power classes according to figure 27 and 28. Generally, the industry sector is the largest areas suitable for generators, which is seen in its relatively large market percentages. (Frost & Sullivan, 2012a)

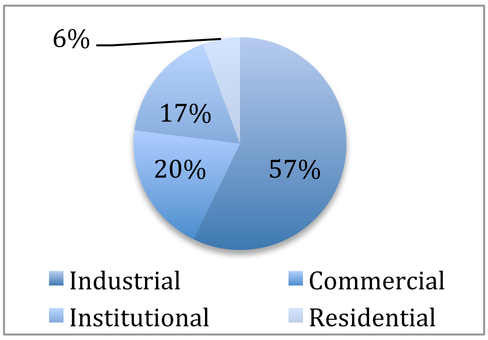


Figure 27 Global market value distribution between application areas in 2010 (Frost & Sullivan, 2012a)

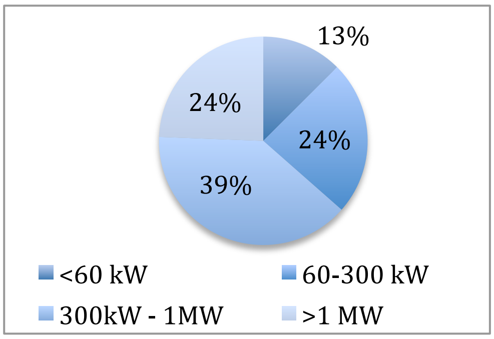


Figure 28 Global market value distribution between engine power 2010 (Frost & Sullivan, 2012a)

Europe

The European gas genset market had a value of 415 mUSD in 2012 and Germany is the single larges market (see figure 29 for geographical distribution between countries in the region). Gensets are mostly used as primary power sources in Easter Europe, as this region lacks sufficient supply of electricity, and as standby power sources in Western Europe (Customer Interview, 2013). Gensets are primarily used in the industrial segment (se figure 30). Furthermore, 57.6 % of the European market value in 2010 origins from the 300kW -1MW range of gas gensets (see figure 31). (Frost & Sullivan, 2010; Survey, 2013) Gas gensets are utilized more as a primary power source in the industrial segment compared to the commercial, institutional and residential, in which gas gensets mostly functions as a standby power source. (Frost & Sullivan, 2012a)

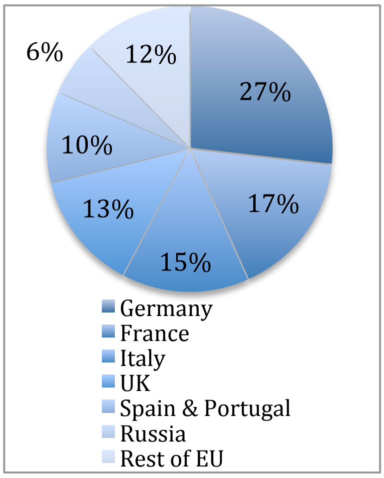


Figure 29 European market value distribution by region (Frost & Sullivan, 2012a)

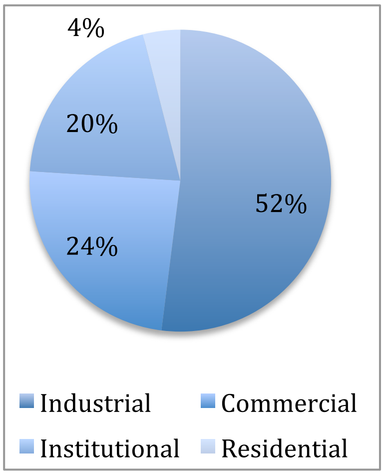


Figure 30 European market value distribution by application area 2010 (Frost & Sullivan, 2010)

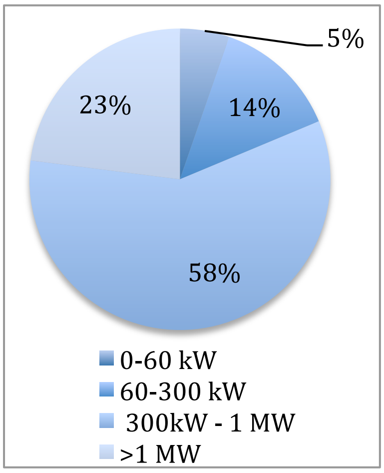


Figure 31 European market value distribution by engine power 2010 (Frost & Sullivan, 2010)

In Spain and Italy, between 500-700 gas gensets are sold per year and in each country, the volume goes up and down according to the price of gas and governmental subsidies. The power is mainly from 400kW to 4.500kW. Furthermore, the higher volume is concentrated between 1000 and 2000kW. (Customer Interview, 2013; Survey, 2013)

America

The American market had a value of 692 mUSD in 2012 (Frost & Sullivan, 2012a). American actors have generally a positive view on gas gensets as fracking has driven down the cost of supply (Customer Interview, 2013; Survey, 2013). In North America gas gensets are mainly used as standby power sources (see figure 24) by for instance hospitals and data centres, to support the instability in the current power infrastructure. (Customer Interview, 2013). Furthermore, the American market for gas gensets is dominated by the industry segment and low power gas gensets (see figure 32 and 33). (Frost & Sullivan, 2012a) Additionally, Dual-fuel has made great progress as a requested product, as the price of natural gas remains relatively low (Customer Interview, 2013).

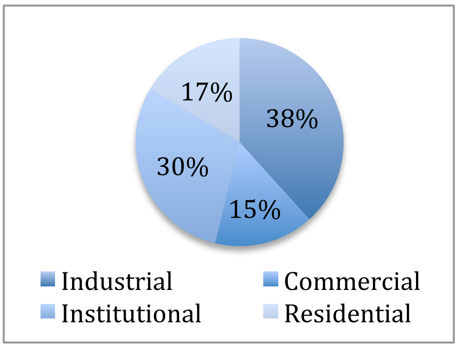


Figure 32 American market value distribution by application area 2010 (Frost & Sullivan, 2012a)

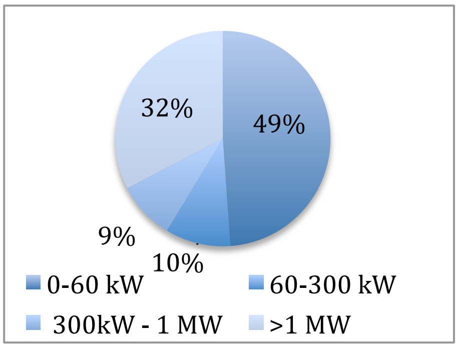


Figure 33 American market value distribution by engine power 2010 (Frost & Sullivan, 2012a)

Asia

The Asian market excluding China had a value of 114 mUSD in 2012 (Frost & Sullivan, 2012a). The current market is dominated by diesel gensets due to the inadequate gas supply and high initial cost for gas gensets (Survey, 2013). Gas gensets are mostly used as primary power sources in Asia due to lack of access to electricity in Asia (se figure 24). Furthermore, industrial is the larges application segment and the gensets with an engine power over 1 MW dominates the market (se figure 34 and 35). (Frost & Sullivan, 2012a)

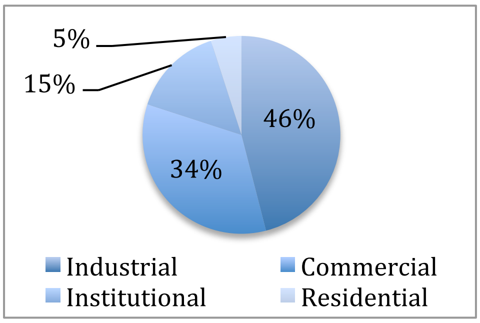


Figure 34 Asian market value distribution by application area 2010 (Frost & Sullivan, 2012a)

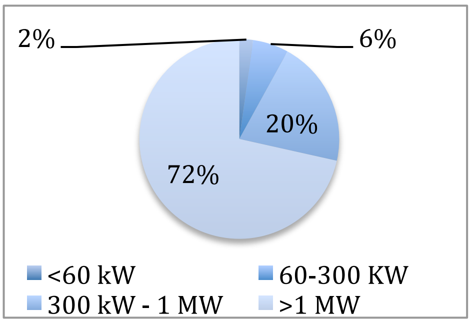


Figure 35 Asian market value distribution by engine power 2010 (Frost & Sullivan, 2012a)

The Chinese gas genset market had a value of 1862 mUSD in 2012 and the gas gensets are usually used as standby power sources (se figure 24) to cover blackouts due to instability in the current power supply infrastructure. (Frost & Sullivan, 2012a) (Survey, 2013) China dominates the Asian market completely as both the largest and the fastest growing individual market. The Chinese market revenue is dominated by the industry segment and by the 300kW – 1MW genset power range (see figure 36 and 37). (Frost & Sullivan, 2012a)

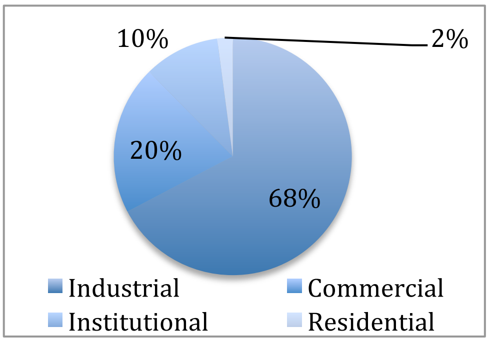


Figure 36 Chinese market value distribution by application area 2010 (Frost & Sullivan, 2012a)

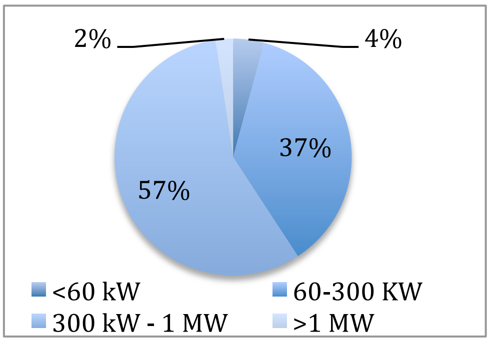
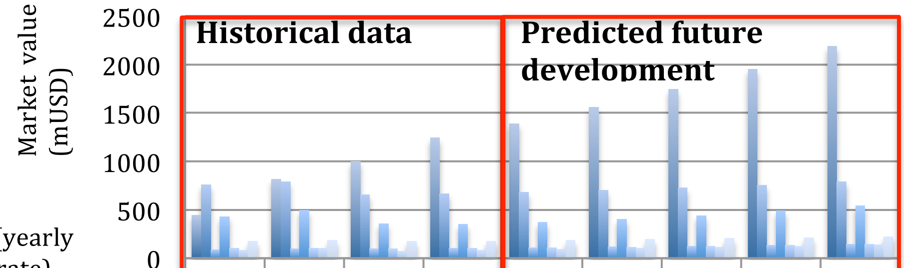


Figure 37 Chinese market value distribution by engine power 2010 (Frost & Sullivan, 2012a)

4.2.1.3 Market Growth

The global gas genset market is in an early stage of high growth with multiple business opportunities available around the world. Increased exploration of gas worldwide and the price of natural gas are expected to drive the market and the implementation of gas gensets. (Survey, 2013) The global market is predicted to reach a value of 4 174 mUSD in 2015 with varying growth rates in different regions (see figure 38) (Frost & Sullivan, 2012a).



Region (yearly growth rate)	2007	2008	2009	2010	2011	2012	2013	2014	2015
China (12,0%)	446	816	1000	1242	1391	1558	1745	1954	2188
North America (1,9%)	758	792	658	665	682	703	726	754	792
Latin America (4,91%)	89	100	98	103	109	116	124	134	145
Europe (4,6%)	430	495	358	353	372	400	440	490	540
Asia-Pacific (4,4%)	105	103	98	101	107	114	122	132	145
Russia (6,8%)	85	102	70	80	92	103	114	126	140
Rest Of World (3,0%)	173	186	173	177	186	195	205	213	224

Figure 38 Global gas genset market forecast (Frost & Sullivan, 2012a)

Furthermore, some small but growing markets as the Indian, Middle East and the African market, have very low short term potential due to the lack of infrastructural support, unavailability of natural gas, poor economy and lack of environmental awareness (Frost & Sullivan, 2012a)

Europa

The European market for gas gensets is a relatively stable market, as it has benefited from a favourable political environment. (Frost & Sullivan, 2013) The European gas genset market's high dependency of Russia and the relatively high cost of gas applications have recently slowed down the growth rate. Eastern Europe is expected to grow approximately with 5-8 % and Russia with 11-12 %. Furthermore, Western Europe including countries as UK, France, Germany, Italy will remain their overall dominant position within Europe. (Customer Interview, 2013; Frost & Sullivan, 2010)

The growth will mostly derive from growth in the larger generator segments (see figure 39). The above 1MW range will be the fastest growing generator segment in Europe with a growth rate of 6,2 % per year until 2020, followed by the 300 kW – 1 MW range with a growth rate on 5,8 % per year during the same period. (Frost & Sullivan, 2010)

Generator Market Europe	
Power Range	**Yearly Growth (2010-2020)**
<60kW	-0,4%
60-300 kW	1,5%
300kW-1MW	5,8%
>1MW	6,2%

Figure 39 Predicted growth rate European genset market (Frost & Sullivan, 2012a)

The standby market is expected to grow in Easter Europe, due to instability in current power infrastructure in this region. Moreover, with the increased usage of renewable power sources in Europe the need for peak shaving application as gas generators is predicted to grow significantly. (Customer Interview, 2013; Frost & Sullivan, 2012a)

America

The North American market experienced a slowdown during 2008-2010, mainly to the financial crisis. The market is expected to recover from this slowdown over the time period between 2012-2017 (see figure 40) (Frost & Sullivan, 2012a). The growth will mainly origin from engines with smaller power capacity (see figure 40 for forecast over market value and appendix 4.3 for forecast over sold gensets). Furthermore, due to legal and governmental regulations (see *section 4.4.1*) the landfill and mining sector are expected to have a significant future growth exceeding the overall American growth during 2010-2015. (Customer Interview, 2013; Survey, 2013; Frost & Sullivan, 2012a)

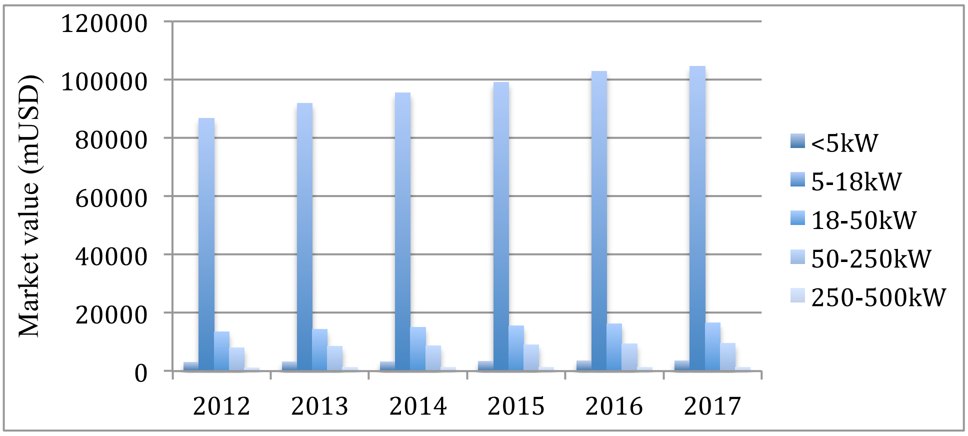
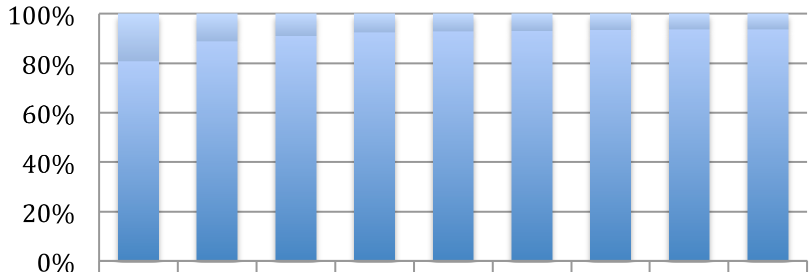


Figure 40 Predicted market value growth per engine power for American genset market (Frost & Sullivan, 2012a)

Lastly, the increased energy demand and stricter emission regulations tend to drive the American market towards using large-scale gas gensets as a primary power source. (Customer Interview, 2013)

Asia

As the Asian market is totally dominated by China, its growth will align with China's growth, which is already in a fast stage of development, with a forecasted growth on approximately 12 % per year over the next years (see figure 41). This is partly due to the Government's strong and supportive policy for natural gas gensets, but also because of the increased need for standby solutions, due to instability in the current power infrastructure. (Survey, 2013) (Frost & Sullivan, 2012a)



	2007	2008	2009	2010	2011	2012	2013	2014	2015
Asia-Pacific (4,4%)	105	103	98	101	107	114	122	132	145
China (12,0%)	446	816	1000	1242	1391	1558	1745	1954	2188

Figure 41 Asian market and growth distribution (Frost & Sullivan, 2012a; Power System Research, 2013) (Survey, 2013)

4.2.1.4 Market Trends

Increased power demand. Today, there is a growing need of power supply to provide energy to the globally increasing demand, especially from the fast growing economies and developing countries around the world as East Europe and Russia. (Survey, 2013) (Frost & Sullivan, 2012a) This together with a growing population which can reach 9,1 billion people by 2050 puts focus on increasing the power supply to meet the increased need. (United Nation, 2013) The increasing electricity demand drives the genset market both in Europe, America and Asia as well as the rest of the world. This as gensets are considered as an immediate quick short-term solution to the increasing power need. (Customer Interview, 2013; Frost & Sullivan, 2012a)

Too high oil dependency. The effect of the oil dependency on the European economy is, according to the EU, too large to neglect. A strategy for the transport sector to gradually replace oil with alternative fuels and build up the necessary infrastructure could bring savings on the oil import bill of € 4.2 billion per year in 2020, increasing to € 9.3 billion per year in 2030, and another € 1 billion per year from dampening of price hikes. (European Commission, 2013a)

Support to the market development of alternative fuels and investment in their infrastructure in Europe will boost growth and a wide range of jobs in the EU. Research convened by the European Climate Foundation conclude that 'greening' cars could generate about 700,000 additional jobs by 2025. Vigorous actions of the EU as a first-mover on innovative alternative fuel solutions (for instance on batteries and powertrains) will also create new market opportunities for European industry and boost Europe's competitiveness on the emerging global market. (European Commission, 2013a)

Increased price gap. The fuel price on diesel and gasoline is volatile (see appendix 4.2) and compared to gas high (U.S Energy Information Administration, 2013b). A low gas price could potentially shift the market from diesel to natural gas, as low price on gas drives the sales of gensets, both as standby, primary and peak shaving power sources. The gas price has varied under the last 10 years (see appendix 4.2), especially in USA. However, as seen in figure 42 the difference between gas and diesel and gasoline is expected to grow in North America until year 2050. (Frost & Sullivan, 2010)

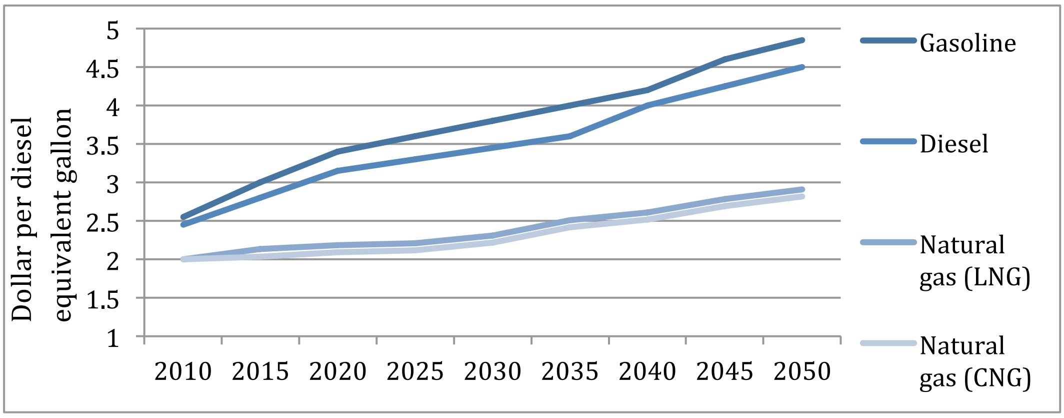


Figure 42 Fuel price difference in North American (National Petroleum Council, 2013)

The American energy revolution. An energy revolution is currently changing the energy demography in USA. This change will over the next decades affect multiple industries. The energy revolution is mainly driven by the increased production natural gas. As the price on the energy equivalent on natural gas is drastically lower than gasoline and diesel many actors may switch the cheaper energy fuel. (Survey, 2013) Furthermore, this regards especially USA as their gas price is relatively low compared to Europe and Japan (se appendix 4.3). (Frost & Sullivan, 2012a)

Increased technological performance. Aspects including safety, automation, engine compactness and remote monitoring are steadily improved and makes the gas technology a more attractive alternative. (Survey, 2013) (Frost & Sullivan, 2012a)

Increased biogas usage. In Europe the biogas usage increases rapidly as many new projects include biogas installations. These projects are partly driven by economic aspects, but mainly by subsidies, as gas is seen as an environmentally friendlier alternative than diesel and gasoline. This trend applies for the entire European landscape, as members of EU are forced to meet certain environmental targets. (Customer Interview, 2013) (Frost & Sullivan, 2013)

The gas focus in Asia has in recent years increased substantially making it a fast growing and highly interesting market, this as a direct effect of the lack of major oil discoveries in the region. (PWC, 2013) The Chinese Government promotes usage of clean energy, such as gas by providing a 0.04 USD discount per kWh electricity generated by clean energy sources. (Frost & Sullivan, 2012a)

Increasing demand for rental gensets, as difficulties exist to justify the high investment cost for some actors. (Frost & Sullivan, 2010; Frost & Sullivan, 2012a)

4.2.1.5 Market Attractiveness

Due to the increased industry consolidation, the global but mainly the European market will likely be dominated by top three participants. A few competitors dominate the market by possessing around 65% of the total market share.

Competitive factors customer mostly value are cost, engine emissions, engine performance and support. (Survey, 2013; Customer Interview, 2013) Currently, the supply of gas gensets is limited, due to few alternatives and the general industry consolidation. Moreover, gas gensets represent a relatively new technology to the one currently used. The gas generators are expected to have a replacement rate on 8-15 years. (Frost & Sullivan, 2012a)

Gas gensets are costly compared diesel gensets and can cost as much as 250 000 UDS compared to 120 000 UDS for a diesel genset. (Survey, 2013; Customer Interview, 2013)

4.2.2 Off-Road

The following section presents data over off-road engines (see appendix 1 for definition) used in various areas as industrial, institutional, commercial and the residential sectors (se appendix 1 definitions).

4.2.2.1 Customer Needs and Drivers

Today customers choose gas off-road engines for different purposes as their incentives and motivations differ from each other. Furthermore, the customers' needs varies between different geographical regions and application areas, this as the customer do not have any uniform request on gas off-road engines. (Survey, 2013; Customer Interview, 2013)

As for today, gas technologies has not been widely applied in the off road segment. The development is expected to increase gradually as actors introduce more gas driven vehicles. (Frost & Sullivan, 2012b) Furthermore, diesel engines are still generally favourable over gas engines as they meet the most important customer needs of lower cost and the ability to generate a high power capacity. Many customers view gas alternatives as an expensive and inefficient alternative. (Survey, 2013) Additionally, diesel is globally viewed as more accessible, and thus is more suitable as engine fuel for geographical areas where no sufficient supply of gas exist. (Frost & Sullivan, 2012a)

Diesel engines are almost exclusively the only option available on the market for off road vehicles as diesel engines holds approximately 99 % of the total market (Power System Research, 2013).

However, one segment, showing increased demand for gas of-road engines due to increased population and governments incentives to address food security concerns around the world is the agricultural industry, which shows development towards more large scale farms, thus more off road vehicles are being used in this segment. (Frost & Sullivan, 2012b)

Europa
In Europe the general perception of gas engines for off road vehicles is very positive, this as a large part of the European market value clean, environmental friendly solutions. However, the fact that natural gas is still a fossil fuel, producing unwanted waste gases, and that it is not accessible everywhere is to some extent drawbacks. Together with that gas engines do not offer the same performance as diesel and that it puts demands on more storage space still prevents the market to seriously challenge the diesel sector. (Survey, 2013; Customer Interview, 2013)

America
The general perception of off road gas engines in America and primarily in North America is positive. Furthermore, Dual-fuel has made great progress as a requested product as the price of natural gas remains relatively low. However, many actors wish to use the natural gas supply right out of the ground, which is a significant problem as raw untreated gas is not an ideally fuel and

invokes serious environmental implications when slugging (dirty/wet gas). Furthermore the methane content of untreated gas is varying outside of the engine parameters. (Survey, 2013; Customer Interview, 2013; Frost & Sullivan, 2012a)

Asia

The customers in Asia requests cheap, accessible and energy efficient fuel solutions, which gas in comparison to diesel currently cannot offer. However, new favourable governmental policies together with an increased gas infrastructure development have had a large positive impact on the new off road engine market in China. (Frost & Sullivan, 2012b)

4.2.2.2 Market Size

In 2012 a total of approximately 1,5 million off-road vehicles was produced globally. Around 99% of these vehicles were diesels driven while only 0,33 % were gas driven (Power System Research, 2013).

Europe

The gas off-road market is driven by governmental subsidies in many European countries, such as Italy and Spain. (Survey, 2013; Customer Interview, 2013) In the construction segment, Europe has traditionally three large markets, Germany, UK, and France, and within the European construction segment mini excavators is the most sold unit. Figure 43 illustrates the size and distribution between gas engines and engines fuelled by other fuels on the European construction market. (Frost & Sullivan, 2013)

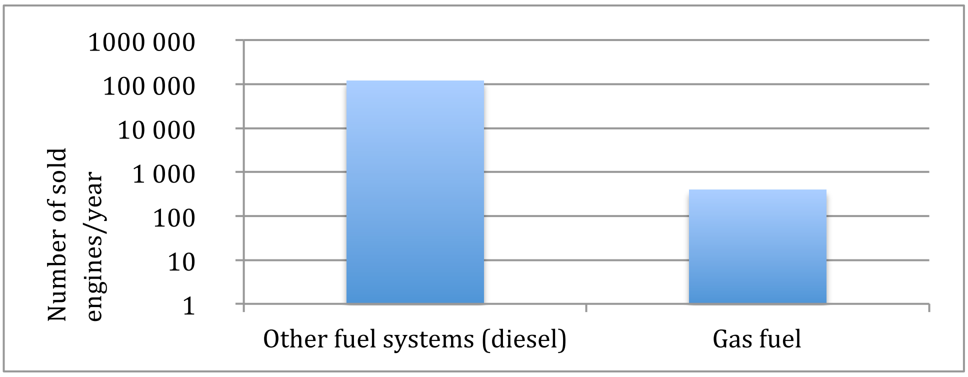


Figure 43 European construction vehicle market distribution 2012 (Frost & Sullivan, 2013)

Asia

The Asian market is largely dominated by China, which is by far the largest market. The Chinese market consisted of approximately 1200 gas driven vehicles 2010. Currently, diesel is and will over the nearest future remain the dominant fuel for the off-road segment. Approximately 98 % of the off road vehicles in Asia and China is being powered by diesel, which made the size of off road diesel engine market to approximately 1 200 000 in 2010, (460 000 of these vehicles are in the medium and large size, while remaining are considered as small). (Frost & Sullivan, 2012b)

Gas has not been widely applied in off-road vehicles in Asia or China, however gas fuelled vehicle is expected to increase gradually, as manufacturer as XMCG and CLG have develop competitive bulldozers and XMCG has launched new CNG loaders. The total sales of off-road vehicles in China is expected to reach 1.5 million vehicles in 2017 by growing at 2,7 percentages per year, and the market value will be 61,9 billion US dollar in 2107. Furthermore the distribution of the off road vehicle market in China can be viewed in figure 44. (Frost & Sullivan, 2012b)

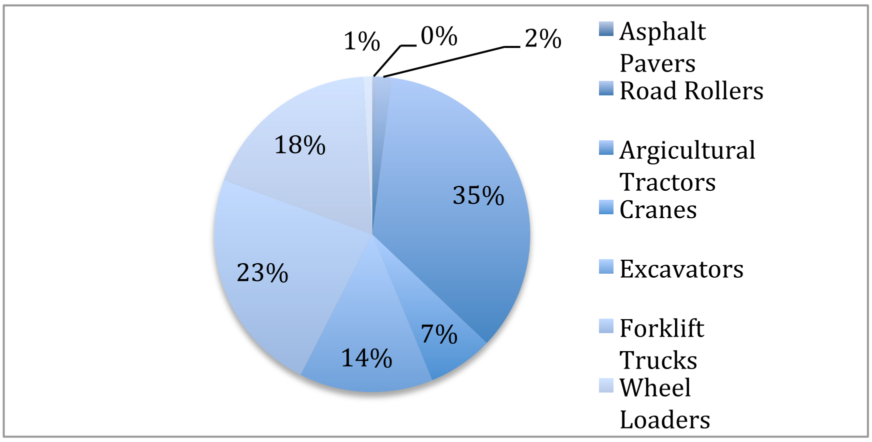


Figure 44 Chinese off-road market distribution by application areas (Frost & Sullivan, 2012b)

The construction industry is the second largest in India and investments in it accounts for about 11.5 percentages of the country's gross domestic production. In 2008, there was a 63.9 percentage increase in the number of mining projects approved in India (269 in 2007 to 441 in 2008), where 90% were surface mining and 10% underground mining projects. Furthermore globalization is likely to take place to make the market for off road vehicles in India increasingly profitable. (Frost & Sullivan, 2009)

4.2.2.3 Market Growth

The global market including all off road vehicles is expected to grow slightly between 2012 and 2014 (around 1-2 % per year) (Power System Research, 2013).

Diesel's market share is expected to decrease in the future, although slightly as there is a wide unfamiliarity and uncertainty towards other available alternatives. (Frost & Sullivan, 2012b; Survey, 2013)

Europe

Compared to the average sales per year during 2000-2010, 2012 has seen an 18% decline in the total sales of off road construction vehicles (Power System Research, 2013; Volvo CE, 2012).

The construction segment has seen a decline in sales from 2008 until 2013 in Europe, mainly due to the financial crisis. The decline in the construction industry especially affected the Irish market and markets in Southern Europe, including countries as Portugal, Italy and Spain. However, the market is expected to grow from 2013 and forward (see figure 45). (Frost & Sullivan, 2013)

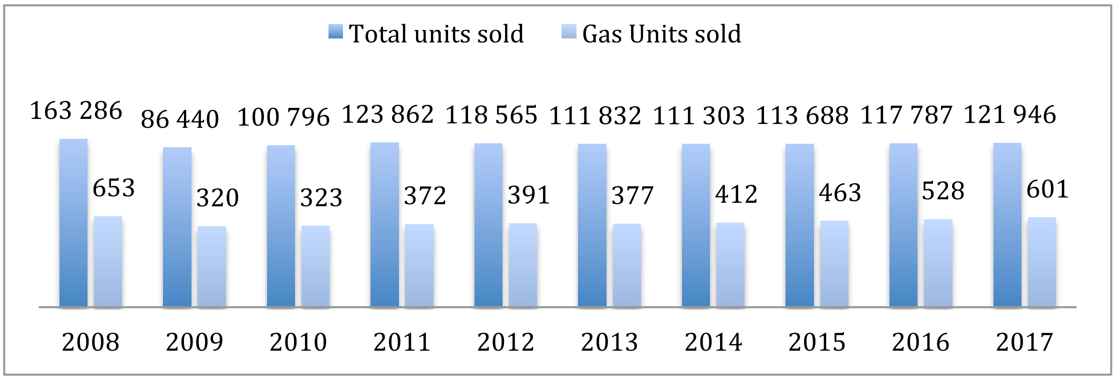
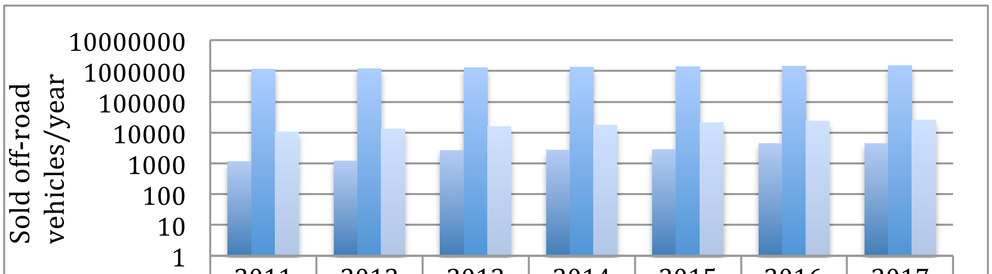


Figure 45 Predicted growth rate on European construction market (Frost & Sullivan, 2013)

Asia

The total off road market in China has under the last few years undergone an extraordinary growth. The market is further expected to grow in the coming years, however in a lover pace. The market for gas fuelled off-road vehicles in Asia and mostly China is also expected to grow significantly until 2017 when the Chinese market is expected to include 4500 gas driven off road vehicles (see figure 46). (Frost & Sullivan, 2012b)

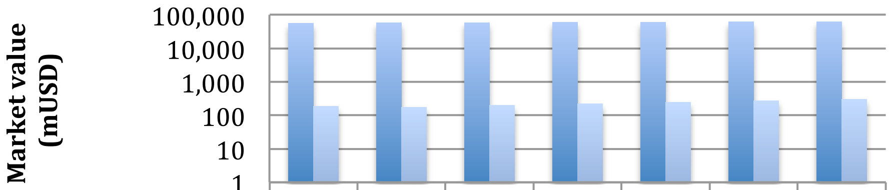


	2011	2012	2013	2014	2015	2016	2017
LNG/CNG	1160	1200	2600	2700	2800	4440	4500
Diesel	1148400	1185600	1281800	1329750	1376200	1451880	1470000
Other	10440	13200	15600	17550	21000	23680	25500

Figure 46 Manufactured off road vehicles in China (Frost & Sullivan, 2012b)

The growth is largest in the off road vehicle segments; road rollers and asphalt pavers. (Frost & Sullivan, 2012b)

The Chinese market value for the off-road segment was 57 307 mUSD in 2012, of this 172 mUSD originated from the gas off-road segment (see figure 47). Moreover, the future development of the off-road market in China is predicted in figure 47.



	2011	2012	2013	2014	2015	2016	2017
Total market value (mUSD)	56,430	57,307	58,197	59,102	60,020	60,953	61,900
Gas market value (mUSD)	186	172	196	219	245	273	305

Figure 47 Forecast Chinese off-road market (Frost & Sullivan, 2012b)

4.2.2.4 Market Trends

Developing markets will open up new opportunities around the world for exporting off road vehicles. These markets will grow at a significant rate and thus, increasing global sales and volumes. (Frost & Sullivan, 2012b; Frost & Sullivan, 2011)

Too high oil dependency. The effect of the oil dependency on the European economy is, according to the EU too large to neglect. A strategy for the transport sector to gradually replace oil with alternative fuels and build up the necessary infrastructure could bring savings on the oil import bill of € 4.2 billion per year in 2020, increasing to € 9.3 billion per year in 2030, and another € 1 billion per year from dampening of price hikes. (European Commission, 2013a; European Commission, 2013b)

Increased fuel price. The fuel price on diesel and gasoline is volatile (see appendix 4.2) and high in comparison with the gas price (U.S Energy Information Administration, 2013b). A low gas price may cause a market shift from diesel to natural gas. As seen in appendix 4.2 the gas price has varied during the last 10 years, especially in USA. However, as seen in figure 42 the difference between gas and diesel and gasoline is expected to grow in USA until year 2050. (Frost & Sullivan, 2010)

The gas focus in Asia has in recent years increased substantially making it a fast growing and highly interesting market, this as a direct affect of the lack of major oil discoveries in the region. (PWC, 2013; Nmri, 2013)

Introduction of favourable government policies in China have had a significant positive impact on the overall off road gas market. The favourable politics will encourage the development of new fuel alternatives to diesel for off road vehicles. Furthermore, the implementation of these policies will help companies to establish new manufacturing plants, integrate advanced technology and launch new investment opportunities. (Frost & Sullivan, 2012b)

4.2.2.5 Market Attractiveness

Currently, the market for gas off-road vehicles is small, still considered to be in its infancy, thus customers have few alternatives to choose between on the market. Competitive actors need to possess a competitive gas technology, which is costly to manufacture. (Frost & Sullivan, 2012b)

As the market develops the industry rivalry increases as more actors identifies the potential of the gas market for off-road vehicles.

4.3 Competition

There are only a limited number of companies in the world offering natural gas engines for off-road and genset markets (Volvo CE, 2012). Historically, for larger vehicles in Europe, only a small number of natural gas engines have been sold. The main technology has been spark ignited gas engines and the usage has primarily been in buses. A dominant actor in this segment has been MAN with approximately 500 engines delivered annually. (Frost & Sullivan, 2013)

However, more and more actors start to develop gas engines although the in a varying degree. Currently around 60 actors are considered as active market competitors on the global gas genset market. They however, have a varying gas focus from unique niched gas specialists to actors only active in the gas industry as a side business to their core business. 2010 the top 6 competitors jointly possessed a 65 % market share. Over the last years several actors have joint the gas generator industry and intensified the competition and decreasing the possession from the top 6 competitors, however to a varying degree. (Frost & Sullivan, 2012a) Moreover, around 50 actors are considered as active market competitors on the global gas off-road market. They however, have a varying gas focus from unique niched gas specialists to actors only active in the gas industry as a side business to their core business. 2010 the top 3 competitors jointly possessed a 33 % market share. Over the last years several actors have joint the gas generator industry and intensified the competition and decreasing the possession from the top 3 competitors. (Customer Interview, 2013; Frost & Sullivan, 2012b)

Westport is one of the global leaders on the natural gas engine market. They manufacture spark ignited and HPDI engines on their own and together with other companies, such as Cummins and Weichai, in joint ventures. As can be seen in figure 48, Westport has rapidly increased their sales during the last year. (Westport, 2013e)

2011	2012	Q1 2013
1771	22025	9845

Figure 48 Westport's gas engine sales (# sold engines) (Westport, 2013e)

Westport considers HPDI to be the preferred natural gas engine technology for larger engines (>300 hp) as there, compared to a diesel engine, is no reduction in compression ratio, affecting the fuel efficiency. In comparison, there is a reduction in compression ratio in the spark-ignited engine, however this technology is less expensive, which could make it more attractive in smaller engine segments. (Cummins Westport, 2003) Furthermore, Westport has begun collaboration with ENN Group. A Chinese company mainly focused on building natural gas fuelling stations. The purpose of the collaboration is to improve and expand the natural gas infrastructure in North America to enable a growing utilization of natural gas engines in, among others, truck, rail, marine and mining applications. (Powertrends, 2013)

As for dual-fuel technology, Clean Air Power, with 300 dual-fuel units sold 2012 (70 units 2011) together with Hardstaff, a company that specialize in converting diesel engines to gas engines, are two of the prime movers. Hardstaff has by the end of 2012 managed to convert approximately 400 diesel engines for trucks into dual-fuel engines. (Volvo CE, 2012) Hardstaff prefers the use of LNG to the use of CNG mainly because of the significantly larger storage capacity in LNG fuel tanks. However, as the infrastructure mainly supports compressed gas they consider CNG to be most commonly used. (Interview, 2013)

As, Westport, Clean Air Power and Hardstaff may be prime movers in developing natural gas engine technology; they are still relatively small actors. However, activities among larger actors can be identified, for example Westport's collaborators Cummins and Caterpillar.

Cummins Westport offers spark-ignited gas engines in the range 150-300 kW, (Westport, 2013a) and they recently announced that the Cummins Westport ISX12 G engine has been certified by the EPA meeting requirements both from the EPA 2013 regulations as well as from the new US greenhouse gas and fuel-efficiency rules. (Diesel Progress, 2013) Cummins Westport recently announced that they will produce larger dual-fuel in the range of 600-2600 kW meeting demands from high horsepower markets. The diesel-gas substitution rate is said to be approximately 50 % with expected figures up to 70 %. It is further stated that "The rapid expansion and abundance of natural gas in many areas of the world has driven a dramatic cost advantage of natural gas over diesel fuel. The ability to substitute diesel fuel with natural gas drives down the total cost of ownership of equipment. For oil and gas customers, the potential for return on investment is great, with the ability to harness natural gas from the wellhead and run in equipment on-site, with low overhead cost." Cummins further argues that for oil and gas industries there will be a return on investment in gas driven pumping applications within six month of operation due to lower fuel costs. (Cummins, 2012)

As for Caterpillar, they consider natural gas engines to be the preferred future fuel in high horsepower engines. Together with Westport, Caterpillar will develop a full range of engines both utilizing dual-fuel and HPDI technology (Westport, 2012; Powertrends, 2013). Caterpillar's strategy director Joel Feucht has stated that Caterpillar will have the "broadest product line in the industry" and that "Mining and rail will use LNG exclusively" (HHP Insight, 2013).

As a continuous supply of gas still is challenging in many areas Caterpillar consider the dual-fuel technology will act as a natural gas confidence builder among industry actors, due to the possibility to use diesel when gas supply is insufficient. However, as the confidence in natural gas grows stronger the HPDI technology will, according to Caterpillar, follow. Caterpillar argues that the market for heavy-duty natural gas engines will double by 2015 and double again by 2020. Furthermore they argue that 25 mine trucks, (each with approximately 2500 kW) using natural gas instead of diesel could save $17 million. Apart from mining and rail, engines used in a variety of applications, such as electric power, machine, industrial, marine and petroleum will be developed and, eventually, sold worldwide. The engine development will start immediately and commercial production is planned to begin in approximately five years. (HHP Insight, 2013)

4.4 Environmental Aspects

The market environment has potential to greatly affect and influence a technological shift and consequently is essential to consider and evaluate (Aaker & McLoughlin, 2010). In relation to a potential technological shift from diesel engines to gas engines, governmental aspects and external trends, such as infrastructure support, plays a part. Thus, these factors need to be considered and assessed. (Frost & Sullivan, 2013)

4.4.1 Governmental factors

In terms of regulations, mobile engines are generally more regulated than stationary engines. Stationary engines are instead indirectly regulated by the emission regulations stated for the factory or the plant where it is placed (Laws and Regulations Analyst in Engine Industry, 2013). As for now there is generally little or no regulations regarding gas engine emission standards. However if the engine is a dual fuel engine, and can work solely on diesel it needs to be certified based on diesel emission standards. (Laws and Regulations Analyst in Engine Industry, 2013)

One important aspect in determining which energy source that will dominate the future is governmental incentives and support. Figure 49 identifies the expected level of governmental support up until 2030 based on interviews with governmental and industry representatives as well as analysts and researchers.

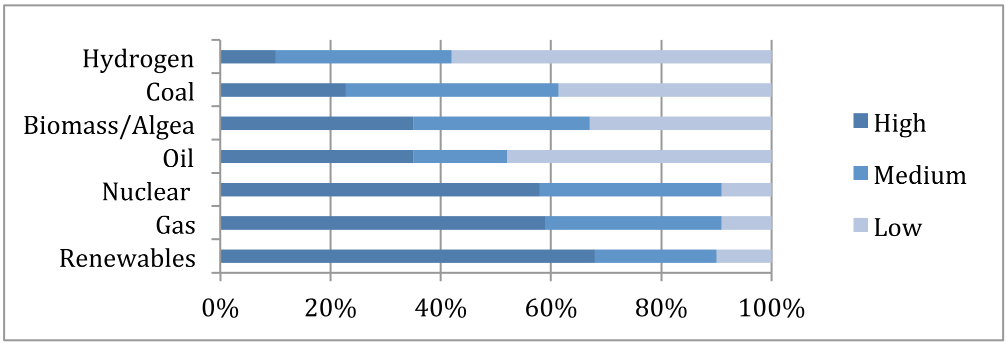


Figure 49 Global governmental support (Frost & Sullivan, 2011)

Europe

Currently, there are no emission standards for gas engines in the off-road segments (Director Environmental Affairs in Engine Industry, 2013). However there is a likelihood of such regulations being included in emission standards for off-road engines possibly already in 2016 as there is an on-going discussion in the EU commission to include new non road gas directives in the next non road emission standards. Furthermore, such regulations are likely to correspond to the emission standards for off-road diesel engines. (Customer Interview, 2013) (Laws and Regulations Manager in Engine Industry, 2013)

Upcoming GHG regulations results in truck fleets seeing CNG/LNG as a long-time solution. Furthermore, the goal of reducing CO2 emission by 20 % in 2020 pressures the European Union in to a focus on alternative fuels (Frost & Sullivan, 2013). Tightening emission norms in general may also benefit the adoption of NG vehicles among fleet owners as NG technology has a cleaner fuel advantage against diesel. Additionally, there are widespread government incentives in Europe towards differentiating the duty of NG and diesel and to lower taxes on NG vehicles (Frost & Sullivan, 2013).

In order to increase the incentives to adopt alternative fuels within the European Union the European Commission has initiated the creation of an EU directive containing fuelling infrastructure guidelines and standards within the Union. The main purpose is to develop a European strategy for adopting alternative fuel in order to substitute oil and reduce GHG emissions. The directive is under formulation, however, a proposed directive is published based on input from stakeholders, both governmental, industrial as well as other interest groups, within the Union. (European Commission, 2013b)

In terms of LNG fuelling stations, the directive declares that all European maritime and inland waterway ports should provide LNG. More specific, at least at the end of 2020 should a core network of ports have LNG fuelling stations. This means that by the end of 2020 publicly accessible refuelling stations for LNG shall be established within distances not exceeding 400 km. Furthermore, the directive declares that an extensive inland infrastructure should be created to support LNG driven heavy duty vehicles, in order to meet emission limits specified in the Euro VI. (European Commission, 2013b)

Additionally, CNG infrastructure should, according to the directive, continue to expand within the European Union to support the use of CNG primarily in passenger vehicles. By the end of 2020 all countries in the European Union should provide CNG fuelling stations within distances of 150 km. (European Commission, 2013b)

There is currently a lack of a coordinated EU policy in terms of specifying gas quality requirements. In 2005 industry associations, governmental and company representatives from Europe put together some guidelines defining for example required Wobbe Index for natural gas in Europe. These guidelines are, however, considered to be to wide-ranging and do not cover all aspects of natural gas quality. (Frost & Sullivan, 2013) As a result guidelines and requirements, similar to the NATGAS Act in the US (which will be further described in the next section), with tighter requirements are demanded from engine manufacturer representatives and is likely to be developed. (Laws and Regulations Manager in Engine Industry, 2013)

America

The US Environmental Protection Agency (EPA) is currently discussing how to certify dual fuel and gas engines. As for now there is no regulations related to emission standards for off-road gas engines. However, when launching a new engine on the US market, in order to avoid future fines and bans, companies tend contact EPA to get the engine certified even though there are no legal requirements. As for stationary engines non certified gas engines can be sold as long as they fulfil the factory's total emission requirements. (Survey, 2013) (Laws and Regulations Manager in Engine Industry, 2013)

There is, in contrary to the rest of the world, a uniform gas quality requirement within the US specifying and regulating the quality of the gas within the country. It is called NATGAS Act and it is developed by the US National Gas Council together with a working group of gas suppliers, users and representatives from the engine manufacturing industry. The NATGAS Act, shown in figure 50 is considered to be specified and narrow enough to more or less eliminate the knocking problem for engines in the US. (Klimstra, 2011)

Index	Maximum Value
Wobbe Index	52,2 MJ/m3
Higher Heating Value	41,0 MJ/m3
C4+ Gases	1,5 mol %
Inert Components	4%

Figure 50 Gas quality specifications in USA (Klimstra, 2011)

Furthermore EPA has specified a required gas quality for testing procedures, as illustrated in figure 51((U.S. Government Printing Office, 2013).

Item	Value
Methane, CH4	Minimum, 0.87 mol/mol
Ethane, C2H6	Maximum, 0.055 mol/mol
Propane, C3H8	Maximum, 0.012 mol/mol
Butane, C4H10	Maximum, 0.0035 mol/mol
Pentane, C5H12	Maximum, 0.0013 mol/mol
C6+	Maximum, 0.001 mol/mol
Oxygen	Maximum, 0.001 mol/mol
Inert gases (sum of CO2 and N2)	Maximum, 0.051 mol/mol

Figure 51 Gas quality for testing procedures in USA (U.S. Government Printing Office, 2013)

Countries in America facing economic growth, such as Brazil and Mexico, tends to subsidies crude oil prices in order to avoid high fuel prices for end customers and thus, stimulate industries within the country. As a result price gap between diesel and gas price decreases and incentives to change to gas fuel may be reduced. (Frost & Sullivan, 2013)

Asia

The countries of Asia tend to follow in the footsteps of Europe and USA in terms of emission standards regulations with some years lag. The exception is Japan where emission standards are comparable to the regulations of Europe and the US. Thus, there are currently no regulations regarding non road gas engines. (Laws and Regulations Manager in Engine Industry, 2013) As for China especially emission standards for off-road diesel engines lag behind North American and European standards. One important factor restraining the implementation of stricter emission standards is the poor diesel quality. However, the next emission standard is expected to be implemented by 2014 or 2015.

As for developing countries in America, countries in Asia facing economic growth, such as India and China, tends to subsidies crude oil prices in order to avoid high fuel prices for end customers and thus, stimulate industries within the country. As a result price gap between diesel and gas price decreases and incentives to change to gas fuel may be reduced. (Frost & Sullivan, 2013)

4.4.2 External trends

There is a rapidly increased supply of NG partly due to large findings and extractions in the US as well as in Australia (Shell, 2011). As a consequence LNG gas supplies destined for the US has been made available for other parts of the world creating an abundant supply. Furthermore, the adoption of gas as an engine fuel is according to Frost & Sullivan (2012a) directly related to the gas availability in a specific geographical region. Figure 52 illustrates the natural gas trade movements (both CNG and LNG) in the world and there is in general a relatively well-developed CNG infrastructure all across the world. However the LNG infrastructure is still insufficient. (Advanced Engineering Manager in Engine Industry, 2013)

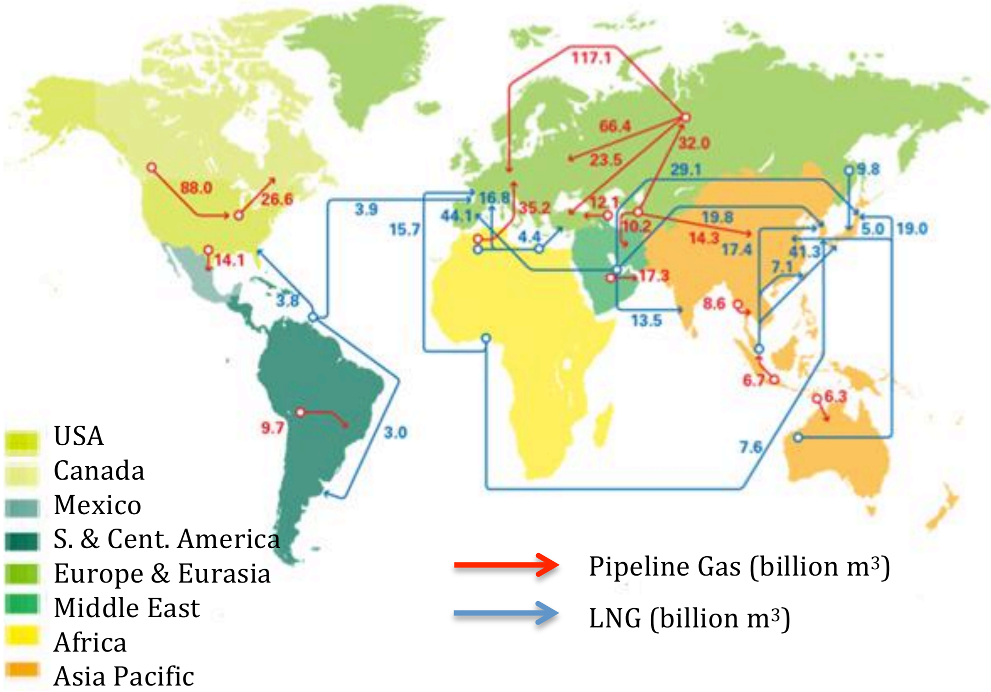


Figure 52 Gas trade movements 2011 (British Petroleum, 2012)

Today most natural gas fuelling stations globally are built for passenger cars, as can be seen in figure 53. Notable is that out of the 1 160 fuelling stations in the US only 58 are LNG stations and in China, 460 out of the total number of 1 400 are LNG stations. The trend, as indicated in figure 54 is that the infrastructure, both for CNG and LNG, is expanding globally (see appendix 5.1 and 5.2 for further information about gas trades). (NGV Communications Group, 2012)

Total number of gas fuelling stations (2011): 18 200	
North America	
US	1160
Latin America	
Brazil	1700
Argentina	1900
Colomiba	600
Europe	
Italy	800
Ukraine	300
Germany	900
Asia-Pacific	
Pakistan	3300
Iran	1600
India	600
China	1400
Thailand	400
Uzbekistan	100
Africa	
Egypt	120

Figure 53 Total number of gas fuelling stations (LNG and CNG) worldwide (NGV Communications Group, 2012)

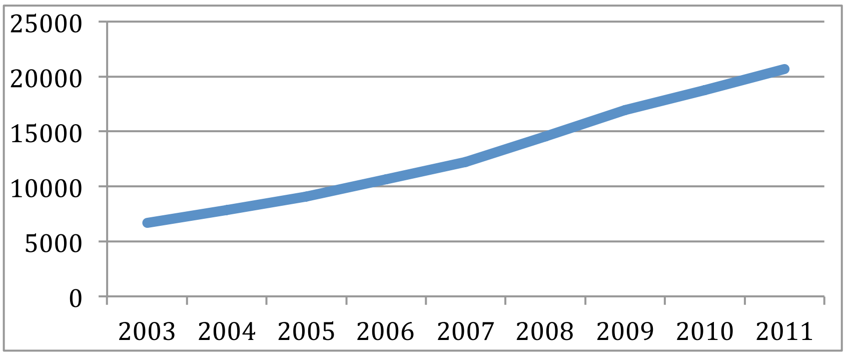


Figure 54 Number of gas fuelling stations worldwide (NGV Communications Group, 2012)

Europe

Currently 44 % of the imported natural gas in to EU comes from Russia. As there is an on-going debate between EU and Russia concerning energy security, EU sees it as essential to reduce Russia's role as the major supplier of natural gas. Thus it is expected that Poland will start a shale gas revolution in Europe. This, in combination with the increasing import of LNG as well as a proposed pipeline from the Caspian Sea, bypassing Russia, have potential to change the landscape of the European gas supply. (Frost & Sullivan, 2010)

The European Union is funding a number of projects with the purpose of extending the LNG infrastructure mainly with the focus on LNG infrastructure for shipping, but also for road traffic, by for example the LNG Blue Corridor project (European Commission, 2013a). The purpose of the LNG Blue Corridor project is to establish at least four pan European routes with LNG filling stations, which would allow long haul traffic vehicles to be run on LNG (NGVA Europe, 2012).

The infrastructure and the number of filling stations differ widely among the countries in Europe as can be seen in figure 55. The prime movers in terms of the adoption of NG as a fuel for trucks are the western countries of Sweden, Germany, Austria, France and Italy, who all have relatively extensive NG fuel infrastructure. (Frost & Sullivan, 2013) According to Frost & Sullivan (2013) the trend towards a widely adopted use of NG vehicles in this region will accelerate, as the infrastructure will meet critical mass. Frost & Sullivan (2013) further argue that countries geographically close to the prime movers has begun to expand their NG fuelling network in order to extend the range of international vehicle fleets as well as supporting the NG adoption for domestic fleets.

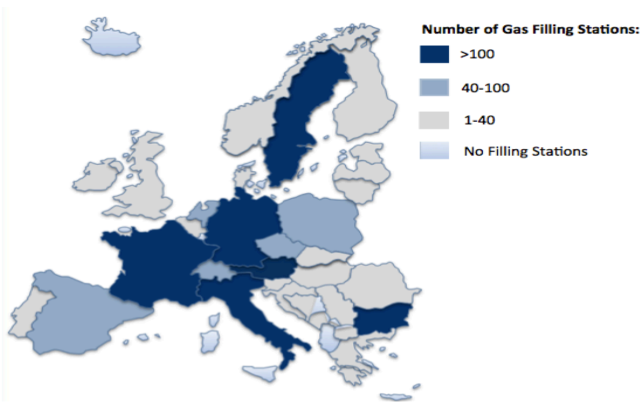


Figure 55 Number of gas fuelling stations worldwide (Frost & Sullivan, 2013)

Due to sulphur emission regulations in the North Sea, the Baltic Sea and the coast along California an increasing number of ships constructed to operate in these areas are LNG driven. As a consequence the demand of LNG within these areas is forecasted to grow substantially. Furthermore all countries in these areas, except Norway, are expected to be importing LNG by 2020, which call for an increased infrastructure, primarily in an expansion of the number of LNG terminals. (Danish Maritime Authority & European Union, 2012)

The LNG infrastructure in Sweden today supports the use of LNG driven trucks in the south, based on a cruising range of 300-350 km (approximately 10 fuelling stations). The infrastructure in the north, where important industries are situated, is, however, still insufficient. (Svenskt Gastekniskt Center AB, 2011)

The lack of a continental NG infrastructure hampers a rapid adoption of NG as a fuel in Europe and as the incentives and the expansion of the infrastructure differ among the European countries the growth is vastly polarized (Frost & Sullivan, 2013). Thus, in order to increase market penetration an Europe-wide coordination is necessary (European Commission, 2013a).

America

There is a global trend in favour for LNG over CNG, however, in the US there is still a focus on and a great belief in CNG as an engine fuel. Globally, North America has one of the largest and most well developed natural gas infrastructure networks. (Alternative Drivelines Planning Manager, 2013)

Comparing natural gas pipeline investments to oil pipeline investments in terms of infrastructure, the natural gas segment was accounted for 65 % of the total revenue in 2011. Furthermore the natural gas pipeline network is forecasted to grow from 13620 miles to 22360 miles until 2017 and as can be seen in figure 56 there is a steady growth within the gas pipeline infrastructure. However, due to the financial crisis, there has been a delay in several infrastructure projects lately. (Frost & Sullivan, 2012a)

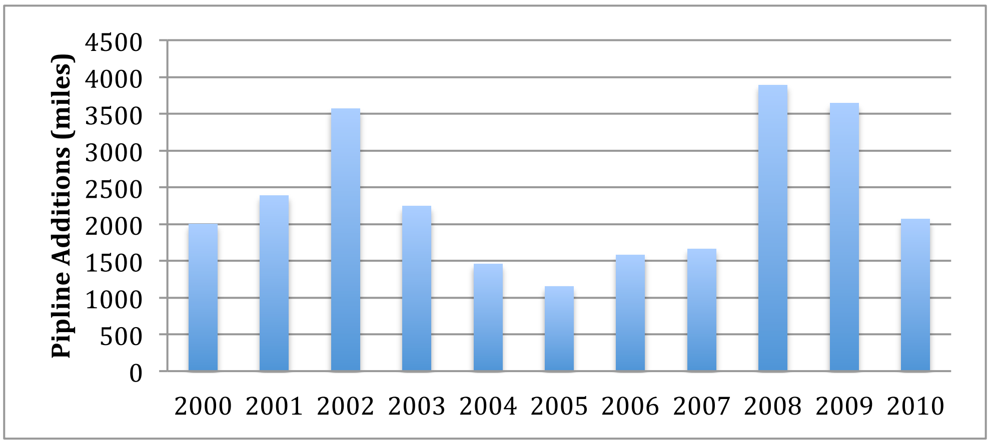


Figure 56 Pipeline additions in USA, year 2000-2010 (Frost & Sullivan, 2012a)

As for now North America has more than 20 LNG facilities and both Canada and the US are likely to become net exporters of LNG (Frost & Sullivan, 2012) and according to Frost & Sullivan a growth in gas demand from the power generation segment is a key factor in the growth of the natural gas infrastructure.

5 Analysis

In the following chapter, the empirical data will be analysed using the proposed framework. The analysis will evaluate technology, customer and market, competition and environmental aspects and assess whether these individual aspects supports or undermines a technological shift.

5.1 Technological

Following section will analyse over the technical aspects presented in the proposed framework.

5.1.1 S-curve

S-curves are used to map technologies' performance over time. The gas engine technology is not a new technology as it utilises the same principals as diesel and petroleum engine technology. However, as the latter two today are the dominating technologies, resources and effort have been focusing on improving those two rather than the gas engine technology. Thus, the performance of the gas engine is still relatively low. This indicates that the gas engine technology is in an early stage of the s-curve development and thus, according to the literature, relatively large amount of resources may have to be spent in order to reach small improvements. Over time the knowledge about the technology is, according to the literature, accumulated and the performance progress becomes more rapid. In the case of gas engine technology, as it shares many characteristics and technical aspects with traditional engines the performance development could potentially utilise that knowledge and hasten the development.

One of the major trends in the genset and off-road segments described in the empirical results is the increasing environmental focus resulting in tightening emission standards. As a consequence substantial resources are required to improve the diesel engine technology in order to meet the emission standards. As a gas engine is an environmental friendly alternative, investments in that technology could be attractive from an emission perspective as it offer better output for the invested resources. From an s-curve perspective this may indicate that the diesel engine is moving towards a decline phase, as it is about to reach its physical limits. According to s-curve theory this will eventually lead to a shift towards a new technology with a development along a new separate s-curve.

The technological shift occurs, according to the literature, when an earlier inferior technology overtakes the current dominating technology and becomes the new dominating technology offering superior performance. Besides environmental and emission aspects, the gas engine technology is arguable still inferior to diesel engine technology and thus, the market may yet not be ready for a technological shift from diesel engine technology to gas engine technology.

5.1.2 Lice-cycle

In relation to S-curves, life-cycle analysis can be used to describe and identify the development of the gas technology market. Today, it could be argued that the gas technology still offers inferior performance over diesel and petroleum engine technology. Moreover, the gas technology field is characterised by a low adoption level and the technology is mostly used in special application areas and is not widely spread on the market. Furthermore, there is a widely spread uncertainty regarding gas and gas technologies as doubts exist over the future development and distribution on the market.

All these aspects are typical characteristics of the introduction phase described in a life-cycle analysis. This means that large uncertainties but also large opportunities exist as the gas technology has the possibility to undergo the development of an entire life-cycle and manifold the market value.

5.1.3 Patent Information

As described in the theoretical framework, patent information could be utilised to identify technological activities and developments and thus, can be seen as complementary information when identifying potential technological shifts. Patent information can assist in identifying technological breakthroughs, however, as described in the empirical results, the gas engine technology derives from classical spark ignited and compression ignition engines and thus, is an old technology. Consequently the patent information may be insufficient when determining which engine technology that will dominate the future.

Even though the patent information is inadequate when comparing different gas engine technologies it may serve as a trend indicator in terms of which gas technology that will be most adopted and utilised in the future. According to the empirical results, CNG is the most widely spread and used gas. However, derived from the patent search, presented in the empirical results, the patent activity is both more intense and grows faster within the field of LNG. Hence, this can be a complementary indication that LNG will be the most used gas in the future.

5.1.4 Dominant Design

A dominant design is according to the literature a design that has become the standard for an industry or a market. The time prior to the dominant design is set is referred to as an era of ferment where it is unclear of which technology that will become the dominant design. This can, in some sense, be related to gas engine technology where three major technology contenders, SING, dual-fuel and HPDI, currently are available, and based on the empirical results there are great uncertainty within the industry related to which technology that will dominate the future and thus be the one to invest in. Additionally one aspect is the uncertainty of which gas "technology", or gas type (LNG or CNG) that will be most widely used. This creates uncertainties on where to focus infrastructure investments but also influences the engine technology because HPDI technology is bound to use LNG.

The era of ferment is described in the literature as characterized by market and technology uncertainty, which, as described above, is relatable to the gas engine market. The literature further argues that the set of a dominating design will create a winner takes it all situation, where one design will if not completely dominate, at least by large majority become the most utilized. Choosing to invest in the "wrong" technology can, thus, result in devastating economical consequences for a company. Based on the empirical findings it can be argued that, as different market segments has different needs and motivations for choosing different engines, not only one engine technology or gas type will be dominant. Because the different technologies has various pros and cons a situation where the different engine technologies will dominate different market segments may be possible.

As shown in *figure 20 in section 4.1.2.4* the SING engine is currently less expensive than the other two engine technologies, which, as the relevant market are viewed upon as price sensitive, speak in favour of that technology. Furthermore it is a lighter engine and it is not dependent on diesel. However, it does not have the same torque and efficiency as a Dual-fuel or a HPDI engine and consequently a larger SING engine is required to get the same performance as the other two engine types. Thus, the advantage of a lighter engine is diminished. The fact that the SING engine only requires one fuel type can in some aspects also be looked upon as a weakness because consequently it can only run on one fuel type and, hence relies on a continuous supply of gas.

With that in mind, one of the biggest advantages of a Dual-fuel engine is that it, in case of a gas shortage, can run solely on diesel. Therefore it can be looked upon as a preferable technology in segments where a continuous supply of gas cannot be ensured. Furthermore some actors emphasise that the Dual-fuel engine could act as a gas engine confidence builder because the choice of running solely on diesel always is present. This could be a significant argument in favour of the Dual-fuel technology since some customers express uncertainty in gas technology and concerns about relaying on gas supply.

As for the HPDI technology it has two major advantages over the other two technologies. It has a performance comparable to the diesel technology and it is has robustness towards variations in gas quality. However, it is the most expensive alternative, it can, as the SING engine, not use diesel fuel as a substitute and it cannot operate on CNG. As there is a great uncertainty related to which fuel type that will be dominating in the future this is a large disadvantage.

As can be derived from the empirical results the global general view is that LNG will be dominating in the future. However, important regions such as the US emphasises a strong belief in CNG. Nevertheless, LNG has great advantages over CNG in terms of storage volume, which, according to the empirical results, is of substantial importance for many customers. Though, for applications that is not run on a regular basis, for example gensets used as standby power sources and possible some mobile off-road vehicles, LNG has a disadvantage because the fuel vaporises and leaks out of the tank.

For the gas engine market the uncertainties are greater than the once related to the era of ferment, as uncertainties exist not only between new technologies but also between the new technologies and the incumbent. As a result there are substantial risks involved for actors involved in gas engine market. As the adoption and the installed base are low, production of scale for manufacturers is limited and uncertainties for customers related to which technology to choose is high.

5.2 Customer and Market

5.2.1 Customer Needs and Drivers

It is according to the literature important to identify what needs and motivations that drive the buying decision. Today, diesel engines are still favourable globally over gas engines due to that they meet the most important customer needs of lower investment costs and have the ability to generate a high power capacity. Furthermore, diesel is globally viewed as more accessible, and thus is more suitable as engine fuel for geographical areas where no sufficient supply of gas exist. However, some geographical regions where gas infrastructure is well developed are expressing great interest in gas. As a consequence there is not a global uniform view on gas engines as a potential technological substitute to diesel engines.

The literature emphasises the importance of considering why a customer use a product and what, according to the customer, defines a good product. It is further argued that these aspects should be assessed based on what impact they will have on differentiating a business and defining the future business strategy. As discussed above for both the genset and the off-road segments, the empirical study shows that cost is one of the most important aspects to consider when buying an engine. While gas engines are more expensive than diesel engines the fuel price becomes an important factor to consider when buying a gas engine.

Many customers' needs differ between the market segments. For example some off-road customers express concerns about the relatively large fuel tanks required when operating on gas. Furthermore, some genset customers view gas engines as an expensive form of generating power. The reason for this could be that they are utilising gensets as standby power with low fuel consumption. As a consequence positive aspect of low gas prices is diminished.

5.2.2 Market Size

The market size of gas engines is, according to the empirical result, marginal in comparison to the diesel engine's market size. The proportions of the genset market constituted by gas engines are slightly bigger than the proportions for gas engines within the off-road segments. While these proportions speak in favour of diesel engines the reason for them is that the technological shift has not occurred. Furthermore, future changes in market drivers and trends have potential to marginalise the importance of today's market size when analysing a potential technological shifts.

5.2.3 Market Growth

The market shares of gas engines in the genset and the off-road segment has according to the empirical data, besides a downturn due to the financial crisis, neither increased nor decreased over the past five years. Although, this can, according to the literature, be used as an indication that future sales proportion will stay unchanged, there are great uncertainties concerning growth rates and the accuracy of such forecasts. Hence, an identification of forces driving changes and dynamics of a market is therefore a suitable starting point when determining the market growth rate as well as an important complement to forecasting based on today's sales. As for the genset market there is a general indication that the accessibility of gas will be a key driver to the adoption and hence, the growth rate. Thus, the increased exploration of gas worldwide could indicate a growth in the gas genset market.

There is a general concern in the European gas genset market related to the high dependency of Russian gas, which has slowed down the growth rate. However governmental incentives towards decreasing Russian gas dependency may reduce such concerns and potentially increase the growth rate. As stated in the empirical findings this growth will mostly derive from the larger genset segment due to that the main application area for gensets in Europe is as a primary source where larger genset are preferable.

As for America the tightening emission standards will likely speak in favour of gas over diesel. Furthermore the empirical findings indicate that that the American genset market is on the verge to recover from the financial crisis. As the gas exploration rapidly increases in North America gensets for the mining industry are likely to encounter a rapid growth rate mainly due to the on site gas availability. Additionally a general increasing energy demand and stricter emission regulation tends to speak in favour of gas over diesel and drive the North American market towards using large-scale gas gensets as a primary power source.

The Chinese market is expected to face the highest market growth in the world and the largest underlying factors explaining this is a rapidly increased energy demand, an on-going change in governmental policy support from diesel towards gas as well as an increased need for standby solutions due to the instability in the current power infrastructure.

As for the off-road segment the future growth rate for gas applications is expected to be slow for the next couple of years. This is mainly due to a general unfamiliarity and uncertainty towards gas engines and gas as an engine fuel. Furthermore, the off-road segment is more dependent on well-developed fuel infrastructure than stationary gensets and as gas infrastructure still is insufficiently developed globally a major technological shift in the industry is uncertain. An additional note is that, as the total Chinese off-road market has during the last few years undergone an extraordinary growth and is expected to continue to grow the gas engine segment of that market is expected to follow.

This section has illustrated the underlying factors of market growth, however it does not account for future changes in market drivers and trends. Such changes have potential to marginalise the importance of today's market growth factors when analysing a potential technological shifts. Hence, prediction of future market size is a key strategic uncertainty.

5.2.4 Market Trends

Market trends can, according to the literature, have great impact on current and future profitability and are, therefore, important to identify and evaluate. Based on the empirical findings many trends indicating growing markets for genset and off-road applications in general and for gas as an engine fuel in those applications in particular can be identified.

First of all the global trend of increased power demand may indicate a market growth for gas gensets, however it is not a direct indication of a technological shift from diesel to gas. Nevertheless, as fuel demand increases concerns related to the oil dependency may speak in favour of gas.

Other identified trends are directly related to the potential technological shift. The exploration of shale gas has enabled a huge supply of gas globally. The increasing focus on environmental friendly options has resulted in a governmental shift in legal support from diesel to more environmental friendly fuels. Furthermore, the technological performance of gas engines are closing in on that of diesel engines and as the price gap between diesel and gas is predicted to continue to increase, more and more speaks in favour of a technological shift.

5.2.5 Market Attractiveness

Industry rivalry

There are only a limited number of companies in the world offering natural gas engines for off-road and genset markets, implying a relative low industry rivalry. However, as more actors sees the potential of the gas engine market, an increasing number of engine manufactures are starting to offer gas engines and thus, is intensifying the rivalry.

Customers' and suppliers' bargain power

The relative bargain power of gas engine customers is currently considered to be limited due to few available alternatives. However, as operating costs is an important customer need, they can be viewed upon as price sensitive and as diesel engines is an equivalent, if not superior, alternative the bargain power in the sense that customers can choose between gas and diesel engines is high.

It can be argued that the suppliers' bargain power is low as the gas technology is largely based on the diesel technology and here are the customers large and represent a large customer. Moreover, it could be added that suppliers should be keen on establishing relationship with gas engine manufacturers as if the gas technology market develop it will possess a large and significant market for the suppliers.

Threats of Substitutes
The profitability of an industry is dependent on whether or not a substituting product is available. In this case, diesel engines serve as substantial substitute to gas engines. The role of diesel engines as a substitute may diminish if a technological shift takes place and the performance of gas engines becomes superior to the diesel engine performance. However, for now the threats of substitutes is considered to be high.

Threats of New Entrants
Capital requirements and technological advanced products are two examples of barriers to entry, which are relatable to the gas engine market. Thus it may be difficult for new actors to enter the market. However, large actors on the diesel engine market potentially possess the required resources as well as similar technological knowledge, which may indicate that the barriers to entry for such actors are low. As a consequence the threats of new entrants can be upon as medium.

Market Attractiveness Conclusion
Reviewing the market attractiveness analysis it seems like the market attractiveness is relatively low. Mainly because of the high threat of customers choosing diesel engines over gas engines. It is also likely that if the profitability increases on the gas engine market actors currently active on the diesel engine market will develop gas engines and as a consequence the rivalry intensity will increase.

However, this analysis is based on a situation prior to a technological shift from diesel engines to gas engines. Should such a shift occur it is probable that the level of threats will change. If gas engines become significantly superior to diesel engines, the threats of substitutes and as a consequence the bargain power of customers will decrease. Thus, potentially increasing the market attractiveness.

5.3 Competition

The competition analysis should, according to the theoretical framework, aim to identify current and potential competitors and arrange them in strategic groups in order to enable an assessment of the competitors' weakness and strengths. At a later stage this assessment could serve as a base for identifying potential opportunities and threats for the industry.

Currently there are, as described in the empirical results, only a limited number of companies in the world offering natural gas engines for off-road and genset markets. Traditionally the main technology has been spark ignited gas engines and the usage has primarily been in buses. However, many of the new actors on the market are utilizing the dual-fuel technology and a trend towards an increased development of HPDI engines can be identified.

The current and potential competitors can be arranged in to two strategic groups. Prime movers and large actors that derive from the diesel engine industry. In order to create a base for identifying opportunities and threats, these two groups should be analysed based on economical factors as well as on qualitative aspects such as objectives and positioning.

Three examples of prime movers are Westport, Clean Air Power and Hardstaff. They are relatively small actors but have a reasonably high growth rate in sales volume. They are in some sense niched actors. Clean Air Power focuses on a dual-fuel technology while Hardstaff has specialized in converting diesel engines to dual-fuel engines. Westport offers engines utilizing all of the three gas engine technologies, however they are expressing belief and focus in the HPDI technology especially for larger engine applications. A common strategy shared by all these actors is collaboration with larger engine manufacturer.

Derived from the empirical results there is a general strategic uncertainty among the actors in the second strategic group, large diesel engine manufacturers, whether or not they should advance in to the gas engine segment. There is also a lack of gas technology knowledge among these actors in general and even more so an uncertainty in which gas engine technology that will be dominating in the future. However the actors in this group possess large economical muscles and even though they may be late movers and are currently not active on the gas engine market they probably have the potential to move in, as a dominant design is set and the market growth rate starts to increase. Thus, all major players on the diesel engine market should be seen as potential actors for the gas engine market and hence, imply a market threat for all actors currently on that market.

Consequently, on one side the actors in the prime mover group are small and perhaps do not compose a large threat to larger engine manufacturer on their own. Furthermore, on the other side large diesel engine may have the resources needed but currently not the gas engine technology knowledge. However, collaboration and joint ventures combining the specific knowledge from prime movers with the economical muscles as well as a general engine market understanding from large diesel engine manufacturers may have the potential to be a successful method for dominating the market after a potential technological shift.

5.4 Environmental Aspects

According to the literature, direct and indirect effects on an industry due to external, environmental trends can change the premises of a market and, hence, are important to identify and monitor. Derived from the empirical results two important factors have been identified as potentially entailing great influence of whether or not a technological shift from diesel to gas will take place. These two factors are governmental factors and external trends influencing the gas technology development and the gas engine market.

5.4.1 Governmental factors

Governmental factors have the potential to entail strategic opportunities or threats to an industry. As can be derived from the empirical results, the gas engine market is highly dependent of governmental factors directly or indirectly affecting the market.

In terms of regulations, there are no emissions standards regulating the gas off-road or gas genset engine market. However, based on the empirical results, regulations can be expected in the future, at least for the off-road segment and hence, needs to be taken in concern. As a general thumb rule the gas engines emission levels should be able to match the comparable diesel engine. Furthermore, emission regulations for gensets are not expected to be formed, because gensets instead are indirectly regulated by the emission regulations stated for the factory or the plant where it is placed.

One significant concern among actors potentially entering the gas engine market is the varying gas quality between regions that both reduces engine power as well as possess a risk of damaging engines. Initiatives towards forming regulations regarding gas quality are initiated. However, for now, no global gas quality regulations are available. Hence, concerns regarding gas quality are still existent and valid, and may possible hinder a global acceptance and adoption of the new technology.

A EU initiative that potentially will have huge impact on the gas engine market is the EU commission's directive regarding the infrastructure for alternative fuel in Europe. As described in the empirical results, the directive states that an extensive development of the CNG and the LNG infrastructure should be conducted by all member states and be finished by 2020. Nevertheless, this is a directive from the EU and in the end it comes down to initiatives and investments in each member states, which makes the outcome much more uncertain. However, if EU puts pressure on every member state's government, potentially these governments will put pressure on the local industries and thus creating a trend towards an gas infrastructure development.

The literature states that subsidising a product potentially may hinder a technological shift and currently several countries are subsidising the use of diesel. Thus the price gap between diesel and gas is reduced and the arguments for a technological shift is undermined. However, other countries are beginning to subsidise gas and, as described in the empirical results, it is expected that the gas will be far more subsidised in the future in comparison to diesel.

5.4.2 External trends

It is, according to the literature, hard to evaluate the impact trends will have on the market and on an incumbent technology. However, there is a rapidly increased supply of natural gas globally and according to industry experts the adoption of gas as an engine fuel is directly related to the gas availability in a specific geographical region. Industry experts further argue that growth in gas demand from the power generation segment is a key factor in the growth of the natural gas infrastructure.

Derived from the empirical results there is generally a relatively well-developed CNG infrastructure all across the world. Although the actual infrastructural support varies between different countries and to some extent within different regions in some countries. However the LNG infrastructure is still insufficient. Nevertheless, incentives to improve LNG infrastructure has been identified as far more common than incentives towards CNG improvements.

As for Europe and EU the dependency of Russian gas supply drives the development of infrastructure supporting alternative gas import. As emission regulations affecting the shipping industry in parts of Western Europe is being formed an increasing number of ships constructed to operate in these areas are LNG driven. As a consequence the demand of LNG within these areas will potentially grow substantially. Arguably, following the same reasoning as above, other market segments in these regions, such as the material handling applications in harbours, will potentially adopt the gas technology as the supply of gas increases.

North America has, according to the empirical findings, one of the largest and most well developed natural gas infrastructure networks in the world. They have also recently started an extensive shale gas exploration with potential of creating a surplus of natural gas within the region. Again following the above reasoning, in combination with the relatively well-developed natural gas infrastructure, indications point towards an increased adoption of gas engines.

The literature states that the shift from an old technology to a new usually takes longer time than what is generally predicted, leaving room for adaptation and change among incumbent firms. The adoption rate of gas engine technology is low, however the empirical results argue that the trend towards a widely adopted use of natural gas engines will accelerate, as the infrastructure will meet critical mass.

6 Discussion

The following chapter discusses the key aspects of the proposed framework that strongly supports or opposes the specific technological shift in the case study. Furthermore the purpose of the discussion is to consider and answer the research questions of the thesis.

6.1 The Theoretical Framework

Derived from the literature study, no existing framework was found for identifying technological shifts and providing suitable analysing tools to generate data and insight as a decision base for developing strategies for how to approach these shifts.

The proposed theoretical reference framework was created with the sole purpose to act as a base for analysing potential technological shifts. The aim was to create a well-structured framework enabling a structured method for how to approach and conduct analysis regarding potential technological shifts and generate relevant results with high quality, which can serve as a basis for decision-making. The framework was developed with the aim of creating a generalised and universal framework suitable for identifying potential technological shift across multiple industries.

The proposed framework utilises aspects from several external literature sources, mainly with a focus on external analysis. Even though, the frameworks from those sources are extensive, most of them are not comprehensive in terms of identifying and analysing all aspects relevant for supporting decision making in relation to a potential technological shift. Furthermore, in order to create a comprehensive base for decision making in a specific company, great emphasis need to be put on analysing capabilities, strengths and weaknesses in that particular firm. Thus, literature concerning internal analysis needs to be utilised and combined with the framework.

By assessing technological aspects both related to the current technology as well as related to the development of new technologies, it is believed that trends and opportunities can be identified and potentially render insights about future technological developments. Thus, technology aspects such as s-curves and dominant design are believed to be relevant to assess. Moreover, the proposed framework includes the aspect of patent information, which is a carrier of extensive and well-structured technological information. Thus, patent information is highly relevant and suitable to include in a framework for identifying potential technological shifts as it can be used to identify future technological trends and developments. This is to the authors' best knowledge a new aspect compared to available theories and literature on the subject.

Some of the most important aspects when considering a potential technological shift are customer needs, customer drivers and general market trends. By assessing those aspects, relevant information regarding in what direction a market is evolving can be identified. Furthermore, in order to unveil strategic opportunities and threats on markets facing a potential technological shift it is essential to understand and assess competitors' position and development. Thus, analysing activities on the market could potentially assist a company in creating and sustaining a competitive advantage.

Even though above discussed aspects are fundamental in a technological shift analysis, particular environmental aspects have the potential to hinder or rapidly accelerate a technological shift and hence, are crucial to analyse. Even though all aspects are pointing towards a technological shift, a governmental ban or a subsidy could potentially put a hold on the shift. Thus, making an environmental analysis a necessity when creating a supporting framework for assessment of potential technological shifts. It is believed that many frameworks developed prior to this thesis do not emphasize these environmental aspects. The environmental aspects were found highly relevant to the case study as the technological shift from diesel engines to gas engines is largely regulated by external entities.

6.2 Current status of the gas engine market

Although many engine manufacturers and customers have little knowledge about gas engines and gas engine technology, there is a vast amount of secondary data and information available concerning most aspects of the current status of the gas engine market. However, the data origins from multiple mutually exclusive sources and thus, is somewhat hard to make comparable. Although this, the different engine technologies aspects are extensively described online and information related to laws and infrastructure are also relatively easy to obtain. As for competition, actors developing gas engines are generally keen to inform the industry about their initiatives, thus there is a lot of written material related to that aspect. The aspects of customers and market, is a bit more unclear and uncertain. As described customers have generally little knowledge about gas engines and their own needs. There is surprisingly little and often insufficient knowledge and data describing the size of the current gas engine market, which can be argued to origin from the widespread market uncertainty. Consequently some aspects are well described and assessed in previous studies and some are less concerned, however few or possibly no previous study is giving a comprehensive view and status report of the gas engine market.

Today, diesel engines are preferred by the majority of the market and thus, it can be found that a technological shift from diesel engines to gas engines has not yet occurred.

Technology
Today, two main gas technologies are available on the market, spark-ignited engines and dual-fuel engines. Both alternatives have its advantages and disadvantages as described in chapter 4.2.1, however no technology dominates the global market. A third technology, HPDI, is being developed but is currently not widely distributed on the market. Different actors are focusing on different technologies and the perception is that there is a differentiated view from regions and segments related to which technology they prefer and what technology that will dominate the future.

Currently, CNG is the most widespread gas fuel on the market although some actors prefer LNG to CNG. CNG is further favourable due to the fact that CNG is used in other applications, which has stimulated the infrastructure development for CNG.

Customer and Market
As identified in the empirical results, the gas engine market is currently a marginal market in relation to the diesel engine market and there has not been any significant markets grow during the last five years for the gas engine market. This goes for both gas gensets and gas off-road vehicles. It should be added that the diesel market, which is considerably larger, also has experienced non-growth both for gensets and off-road vehicles during the past five past years. The fact that customers today choose diesel engine over gas could be argued to origin from a great uncertainty regarding gas engines and its usage and application areas within the market and

among the customers. Moreover, diesel engines are technically superior and meet the most important customers' needs of low investment cost and a high performance.

As for today there are macro trends, such as an increased environmental awareness, a rapid increase in the power demand worldwide and an increased price gap between the cheaper gas and the more expensive diesel, speaking in favour of gas engines to diesel engines. These trends have the potential to eliminate the value of evaluating historical data when forecasting the future for gas engines.

Competition

Today several actors are present and active within the field of gas gensets and gas off-road engines. However, their individual dedication varies as the gas incentives usually lies separated form the core business and are considered as a separate niche business. The general uncertainty among diesel engine manufacturers concerning the potential of gas engines may derive from an uncertainty regarding customer needs or the technological performance gas engines offer. There is not a well-defined, unison customer need regarding gas engines and, from a customer perspective, which gas technology that is preferable.

It could be argued that the development will be hindered as long as the widespread uncertainty among the actors on the market prevails. This as no actor will take actions and drive the development as uncertainties about e.g. which technology to focus on exist.

Environmental Aspects

Two environmental aspects can be singled out as important factors in influencing a change from diesel to gas, these are infrastructural and governmental support.

First of all, the gas infrastructure varies worldwide, some areas have an extensive infrastructure while some areas lack infrastructure to provide sufficient gas access. Generally, the infrastructure for CNG is, today, more developed than for LNG. It could be argued that the infrastructure support is a vital aspect, as it does not matter how high the belief in gas engines is among customers if they do not have access to gas.

The second aspect that can be singled out is governmental involvement. This aspect can, depending on incentives, either support or undermine the technological shift. Currently several governments are subsidising diesel and thus, the fuel price gap in those regions decreases or gets eliminated. However, the on-going trend for governments and institutions to create incentives for gas engine adoption by supporting gas infrastructure could potentially become a key factor in favour of a technological shift. Moreover, today there is no emission legislations regulating gas engines. Thus, gas engines are allowed any emission level. It could be argued that gas engines will not be favoured due to their environmental friendly technology unless governments put demands on the emission levels for gas engines and strengthen the legislations on diesel engines so that the gas technology could benefit from its lover emission levels.

6.3 The Future for the Gas Engine Market

If there is a lot of data and information available related to most aspects of the current status of the gas engine market, there is generally little information regarding predictions and forecasts about the future development of the market. Some reports and studies are forecasting the future market size based on current sales and market drivers. However, technology predictions such as which gas engine technology that will dominate the market in the future are hard to find. Related to what was previously discussed about the uncertainty among industry actors, there is insufficient information regarding engine manufacturers' strategy concerning how to address and tackle the gas engine technology, indicating that they do not have such strategies. Furthermore, even though there are governmental infrastructure initiatives favouring gas, there is, deriving from available information, uncertainties whether or not actors developing the infrastructure will back up such initiatives.

Technology

Today, diesel engines are superior and outperform gas engines. This regarding both technological performance as high performance capacity and economical aspects as in a low initial investment cost. However, if the inferior gas engine's technical aspects follow an s-curve pattern it can be argued to be in an initial stage both according to s-curve analyses and life-cycle analysis. Thus, the gas engine technology has a high improvement capacity and continuous development will increase the gas engines performance over time. Consequently, a technological shift will potentially occur eventually and gas engines will outperform the diesel engine technology if the gas engine technology continues to improve.

As derived from the analysis it is of great importance for a dominant design to be set to enable a focused technological development. However, for this specific market, it is, as discussed in the analysis, possible that different engine technologies will dominate different market segments. Even though the HPDI technology can be seen as a superior gas technology as it delivers a higher performance compared to the other gas technologies, it has some disadvantages as it relies on a continuous supply of gas, thus making it insufficient on many markets. Therefore, Dual-fuel engines can be viewed as advantageous partly on markets where gas supply is uncertain but also as a confidence builder for the whole industry. Nevertheless, HPDI offers performance capabilities no other gas technology today reaches, and thus if obstacles as continuous access to gas and a higher initial cost can be overcome, HPDI will have every opportunity to become the dominating technology on the market. As Dual-fuel engines are more versatile regarding fuel acceptance it can be used as an initial springboard to attract customers to start using gas engines over diesel engines. This might however lead to that the Dual-fuel technology gains a substantial customer base, which favours the Dual-fuel technology and hence, is blocking the development of the HPDI technology.

An aspect that many potential customers has singled out as a key factor against changing to gas engines is the relatively high investment cost in comparison to diesel. However, as the market of gas engines increases, the investment cost will arguably decrease due to economies of scale and technological development. Nevertheless, as long as there are uncertainties regarding which technology to develop and manufacture, no large market penetration will transpire and economies of scale will be hindered.

In exception of fuel prices, the without a doubt largest advantage of gas engines in comparison with diesel engines is the level of emissions. Gas is more environmental friendly than diesel and this aspect will continue to play an important part in a potential technological shift. However, gas is still a fossil fuel, thus, from a green house gas perspective, there are even more environmental friendly alternatives. These alternatives may not have the same commercialization potential as for today. However, this aspect is implying that gas can be viewed as an interim fuel, between diesel and something else. Hence, there is a key uncertainty and potential threat in knowing the time length of this interim period.

Customer and Market

Forecasting the future growth of the gas engine market by drawing on historical figures may not give an accurate result. As the analysis foretells, future trends and drivers will play a substantially larger part in forming the future, thus the future development will likely not have the same development as the historical development and cannot be forecasted solely based on historical data. As previously stated, the customer needs and drivers differs among segments and the future direction will probably be hard to foresee as long as the market and its customer express this uncertainty. It could be argued that as the industry of gas engines develops and customers' insight into the industry increases, customer needs and requirements regarding gas engines will condense and consolidate and form more uniform requirements. However, as for now, one mutual driver is cost, and more specific investment cost and operational cost.

Depending on the segment and how the product is utilized there is potentially a various focus on either investment cost or operational cost. For genset customers using the genset as a standby power source and thus, not consume large fuel volumes, the investment cost becomes the most relevant aspect. It should be added that one of the largest advantages with gas engines, a relatively cheap fuel, is lost if the engine in not used as primary power source and thus used a lot which implicates consuming a substantial amount of fuel. Moreover, if the trend of an increased fuel price gap will sustain, the role of the investment cost will decrease, as customers will focus more on a relative low operation cost. Furthermore, if the adoption of gas engines increases manufacturers can potentially benefit from economies of scale and thus, the investment cost will decrease.

Finally, the global trend with increased energy demand speaks in favor of gas engines as they will offer a today unutilized power source.

Competition

The lack of knowledge among diesel engine manufacturers together with uncertainties related to customer needs and requirements hinders a focused and dedicated gas engine development. However, there are prime movers on the market with more extensive gas engine technology knowledge. These actors are relatively small in comparison to major diesel engine manufacturers and hence, may not cause a great future market threat. However, these prime movers could be utilised as collaboration partners rather than be viewed as competition.

As there are relatively few actors currently involved in gas engine development and those who are, is focusing on different technologies, it is hard to distinguish signs on an upcoming technological shift any time soon. Nevertheless, an increasing number of major diesel engine manufacturers are adding at least some gas engines to there offer, indicating, if nothing else, a continuous market growth for gas engines. Furthermore, it is likely that a part of the gas market initially will continue to constitute of smaller specialized actors providing special gas engines for unique sub areas of the market. Finally, more actors will potentially enter the gas market as the development proceeds, and can be used as an indication of a growing market.

Environmental Aspects

Although there is currently insufficient infrastructure to enable a global technological shift from diesel to gas, it is possible to identify a lot of incentives and factors in favor of gas infrastructure development in general and LNG infrastructure development in particular.

There is extensive European, as well as global governmental initiatives, towards improving gas infrastructure and standardizing gas quality. The question is however if it will be executed and followed by industry actors, which is essential in order to build up a sufficient gas infrastructure making gas a competitive alternative to diesel. This infrastructure development has already started but is still in its infancy, and thus it could be argued that more efforts and resources should be focused on this area to allow a more rapid development. Furthermore, if the adoption rate of gas engine users does not increase, governmental focus could potentially switch to other alternative fuel sources.

As stated, several countries put subsidies on crude oil, however as the environmental friendly trend continues governments will potentially continue to take actions towards alternatives to diesel either by subsidies or regulations in order to put pressure on the industry. Whether or not gas will be the receiver of those subsidies or if focus will be on greener fuel sources is uncertain. Nevertheless, it could be argued that is it likely that governments will favor the more environmental friendly gas fuel over diesel fuel.

Finally, if and when the gas engine market starts to show some serious growth, it is most likely that gas engines will be covered by emission legislations, which further will direct focus on the environmental friendly gas engines and eventually could increase the acceptance of gas engines as a substitute to diesel engines.

6.4 Decision Making Support

The following section provides a nuanced view on the future, by discussing how to utilize the proposed framework to identify different scenarios relevant when determining whether or not a technological shift will occur. This is of highest importance, as the proposed framework itself does not offer a definite approach on how to utilize the framework and the data generated by the framework. For instance a framework usually offers a structured, but simplified method for collecting and analysing data, moreover as the framework is standardized it might be times when an actor's situation does not fit into the framework as it excludes vital areas relevant for the specific case. Thus, it is vital to understand a framework and the data generated by the framework so that the user is aware of its strengths and weaknesses in order to maximize the output.

6.4.1 Dealing with Strategic Uncertainties

Key aspects and strategic uncertainties can be utilised to determine the potential and the future development of the gas engine technology and the effect it will have on the diesel engine industry. Based on the potential impact and immediacy of the strategic uncertainty a relevant approach can be proposed to deal with the uncertainties. In this case the potential impact is related to the customer adoption rate, i.e. a high number of customers switching from diesel engines to gas engines means a high impact and few customer switching means a low impact. The immediacy is in this case referred to when the shift can be expected, i.e. a high immediacy means that the shift is impending and vice versa.

The aspects and uncertainties in favour of either a high or a low impact and immediacy derives from the analysis and the discussion and are presented below.

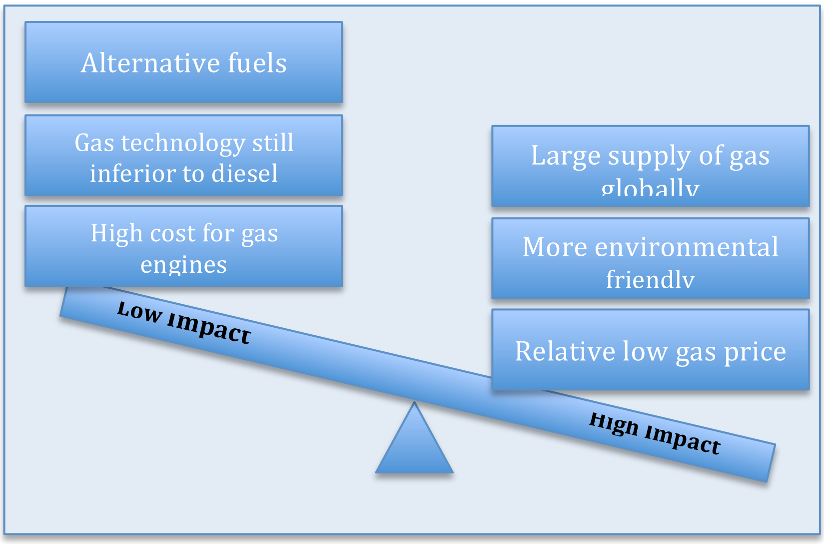


Figure 57 Impact assessment

As discussed above, the high investment cost for gas engines combined with the inferior technological performance and the fact that there are alternative fuels, such as electricity, decreases the potential impact of a technological shift. However, the aspects of inferior engine technology and a relative high cost for gas engines are likely diminish as the gas engine technology continues. Furthermore, the low gas price in relation to the diesel price, the environmental aspect and the large supply of gas globally is thought to be the important aspects in favour of gas engines over diesel engines. Hence, it is implied that the impact will be high, as can be seen in figure 57, and a technological shift is probable.

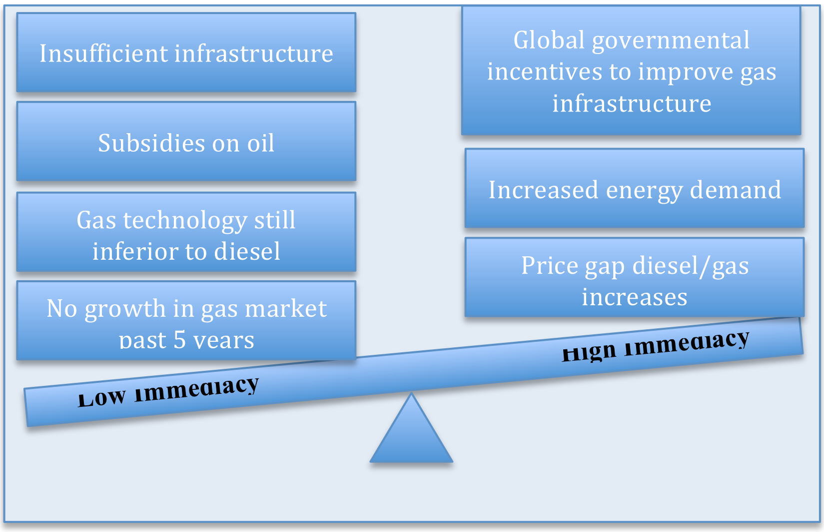


Figure 58 Immediacy assessment

The increasing price gap between diesel and gas, together with the increased global energy demand and governmental incentives towards improving gas infrastructure and standardizing gas quality accelerates a potential shift to gas engines. However, the lack of sufficient infrastructure supporting the gas market, governmental subsidies on oil in specific regions, the low knowledge about gas and gas engines as well as the fact that gas engines offer inferior performance compared to diesel engines and finally the fact that there has not been a significant market growth the past five years are implying that the immediacy is reasonable low, as can be seen in figure 58. Thus, the potential of the gas engine market, based on impact and immediacy is showed in figure 59.

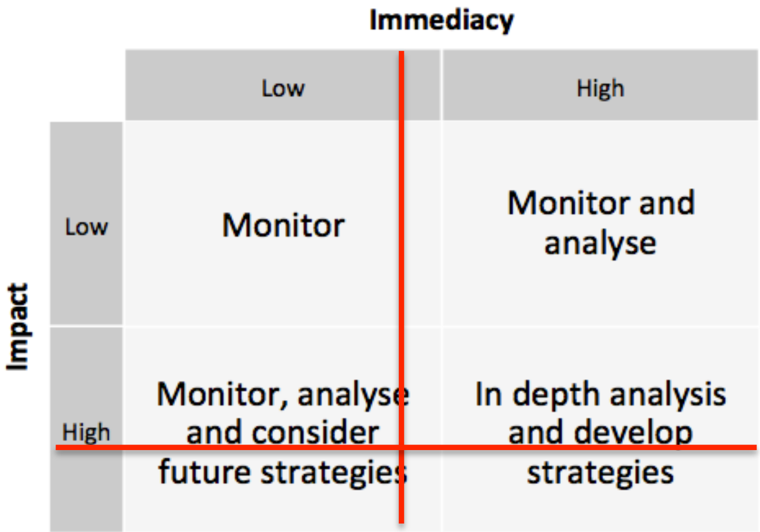


Figure 59 Potential impact and immediacy of potential technological shifts

Figure 59 is indicating that companies in the diesel engine industry should not only monitor and further analyse these strategic uncertainties, but also consider and prepare future strategies. It could be concluded that the gas engine markets for gensets and off-road vehicles today are small and large uncertainties as discussed exist regarding the future development, including aspects as which technology will dominate the market and what the customer need will be in the future. With this in mind, the future development is hard to foresee, and it could be argued that a potential future development and market growth is not impending.

6.4.2 Scenario Analysis

A potential technological shift from diesel to gas would invoke a high impact, as most actors would potentially adopt the new technology as it offers a low priced fuel and a more environmental friendly technology. As the gas technology possess the possibility to highly impact the industry and the market by a potential future technological shift the question mainly comes down to when in time this potential technological shift may occur. This could further be analysed by assessing key strategic uncertainties affecting the immediacy of a potential technological shift.

This uncertainty regarding the immediacy is strongly linked to two key aspects, the price gap between diesel and gas and environmental support, i.e. infrastructure development and governmental support. These aspects could further be analysed in a scenario analysis to strategically determine an appropriate approach.

The scenario analysis in figure 60 serves as guidance in how to act depending on the evolvement of these two key strategic uncertainties.

As indicated in the analysis and the discussion many factors supports both an increased price gap as well as increasing environmental support, consequently indicating and accelerating a potential technological shift from diesel engines to gas engines. This is in many aspects a logical conclusion as many factors speaking against a technological shift are likely to diminish in the future. For example, as the market for gas engines mature and growths investments costs are likely to decrease, for reasons described in the analysis, and the technology will potentially improve, closing that gap to the diesel engine technology. In combination with support from an expanding infrastructure and growing incentives from an increased fuel price, the probability for a technological shift is arguably high.

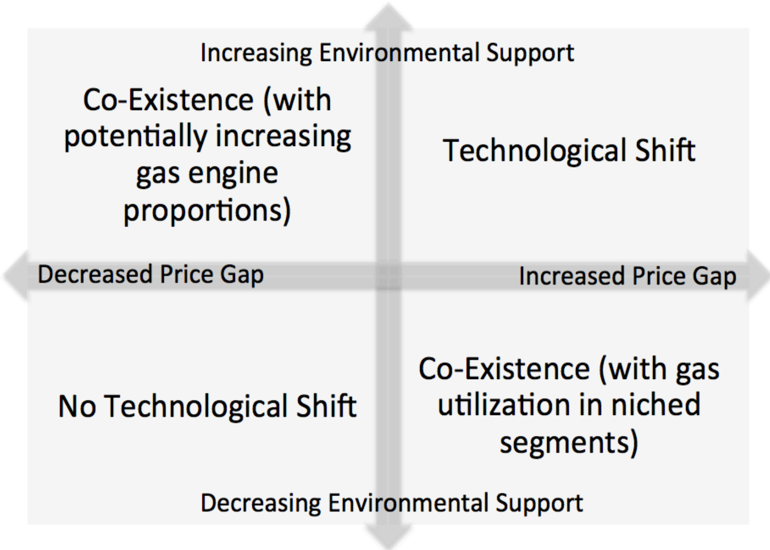


Figure 60 Scenario analysis

However, the time factor, derived from the strategic uncertainty is essential to consider. The growth for the gas engine market until now is more or less non-existing and few aspects indicate that an increased growth pace is impending. Thus, the diesel technology and the gas technology are likely to co-exist for now, with a potential slightly increasing gas engine market proportion. However, considering aspects of dominant design and technology s-curves, once the gas engine technology adoption has reached a critical mass the pace of the market growth will potentially rapidly increase. Consequently it is essential for industry actors not only to closely monitor the development but also to consider and develop future strategies on how to handle the technological shift.

7 Conclusion

The following chapter aims to derive conclusions from the analysis and the discussion in order to fulfil the purpose of this master thesis, "Develop a framework that identifies technological shifts and facilitates decision-making on how to approach these potential shifts. Furthermore, the framework will be utilized on a case study, in order to evaluate the potential technological shift from diesel to gas driven engines."

The analytical framework was created to enable a holistic analysis of potential technological shifts, including multiple aspects, where the importance of individual aspects diminishes. This in order to partly identify technological shifts and partly create a comprehensive base for strategic decision-making on how to approach these technological shifts. Furthermore, it is believed that to be able to conduct a focused analysis, as well as to collect relevant empirical findings, it is necessary to follow a well-defined framework and analytical framework.

The framework was found valuable in identifying potential technological shifts. This as the framework considers multiple aspects derived from the four building blocks of technology, customer and market, competition and environmental aspects. Thus, covering an extensive number of aspects both for analysing the incumbent technology, as well as the potential new technology, resulting in an adequate support when analysing whether or not a technological shift will take place. Furthermore, the comprehensiveness of the framework will make it rather generalizable and thus applicable to numerous different industries. However, as the framework has only been tested on a single case study it could potentially include aspects that are not relevant in other situations, as well as lack aspects that are necessary when studying another industry.

The framework was found to be valuable and relevant when analysing the potential of a technological shift in different industries and eventually in providing support and facilitating decision-making on how to approach these technological shifts. Moreover, it is believed that as the framework entail the possibility to further analyse aspects, by for example identifying strengths and opportunities, assess strategic uncertainties and conduct scenario analyses on important aspects, an in-depth and focused analysis is possible.

Regarding the market, it can be concluded that even though many industry actors express interest in the new gas technology, there has not been a growth in the global gas engine market for the past years. Thus, diesel is still the preferred fuel due to its lover investment cost and higher power capacity and a potential technological shift from diesel to gas engines has not yet occurred.

Although the fact that a technological shift from diesel to gas has not yet occurred, the gas technology has the future potential to overtake diesel and force a technological shift from diesel to gas, due to a lower fuel price, substantially lower emissions and large supply of natural gas. However, historical data over the gas market do not indicate any impending market growth. Moreover, several aspects and strategic uncertainties further hinder a technological shift.

Firstly the gas engine market is largely affected by the widespread uncertainty that exist among both industry actors and customers regarding aspects as which technology to focus on and what gas fuel to power the engines with. This might derive from the fact gas engine technology is a “new” technology, in the sense of few adopters and generally little knowledge about the technology among industry actors.

Secondly, today gas engines possess a relatively inferior technology, offering lower performance compared to diesel engines, and this to a higher initial cost. However, these aspects will potentially diminish as more customers adopt the new technology and increasing resources is focused on gas engine development.

Finally, environmental aspects as the lack of infrastructure supporting access to gas and subsidies on oil are factors that hinder the gas technological development, and thus have the potential to undermine the technological shift. Consequently, even though there are aspects indicating that gas infrastructure will improve and governmental subsidizes will shift focus from oil to gas, it is unclear if and in what pace a technological shift will occur.

As proved, several aspects hinder the technological shift from diesel to gas. However, the diesel technology and the gas technology are likely to co-exist with potentially a marginal increase of the gas engine market. Furthermore, presuming that the influence from negative aspects will decrease and considering aspects of s-curves and dominant design, once the gas engine technology adoption has reached a critical mass the pace of the market growth will potentially increase. Consequently, it is essential for industry actors not only to closely monitor the development but also to consider and develop future strategies on how to handle the technological shift.

Regarding gas technologies, HPDI has the potential to become the largest technology among the gas technologies, as its technological performance is comparable to diesel engines. This is thought to be crucial in order to obtain an extensive customer adoption and offer a competitive engine. However, as there is insufficient gas infrastructure and insecurity and lack of knowledge among engine customers, the Dual-fuel technology with its versatility can act as a confidence builder and consequently is a technology with a lot of initial potential.

Regarding different gas types, CNG is currently the dominating fuel globally. However, LNG has the most potential in the segments of genset and off-road, due to governmental infrastructure initiatives are focusing on the development of LNG infrastructure and higher patent activity indicates a stronger future belief in LNG. LNG further posses a more advanced technology compared to CNG, as its energy density is higher, although LNG puts demands on the storage environment.

Conclusively, even though gas technologies possess a promising future potential a technological shift from diesel to gas will likely not occur in the near future. This as the shift is hindered by both technological, environmental and market aspects. Although, if and when a potential technological shift to gas engines might occur, HPDI combined with Dual-Fuel gas engines together with LNG fuel possess the largest potential.

8 Reflection

The following chapter present reflections from the authors on method, working process, result and conclusion. Furthermore aspects of further research to broaden and strengthen the study are discussed.

The analytical framework was created to enable a holistic analysis of potential technological shifts, including multiple aspects in order to diminish the importance of individual aspects. The comprehensiveness of the framework was thought to contribute to make it rather generalizable and thus, applicable to numerous different industries. Furthermore, the aim was still to sustain a focused analysis, thus only relevant aspects should be included in the framework. The framework has, however, only been applied on a single case study. Thus, it could potentially include aspects that are less important when studying technological shifts in other industries. Furthermore, there is a possibility that the framework is lacking aspects that are important when studying other industries. Consequently, testing and applying the framework on other industries to develop it could be a suitable future research approach.

When structuring the method and the working process for this study it was believed that the majority of the empirical findings would derive from primary data with secondary data as a backup and verification source. It was believed that the extensive survey that was sent out to engine sales offices around the world together with a number of interviews would generate a sufficient amount of data. However, even though the response frequency was rather high, the answers from the survey were not satisfyingly exhaustive and comprehensive and, in fact, many questions were left unanswered. The reason for this is probably the great uncertainty regarding the future of the gas engine market. The same goes for the interviews, where both engine manufacturers and customers expressed uncertainty regarding the potential of the gas engine market.

Consequently, secondary data became a more essential data source than it was intended to in the beginning of the study. There is a vast amount of secondary data and information available mainly concerning most aspects of the current status of the gas engine market. However, the data origins from multiple mutually exclusive sources and thus, is somewhat hard to make comparable. Furthermore, there is generally little information regarding predictions and forecasts about the future development of the market. Some reports and studies are forecasting the future market size based on current sales and market drivers. However, technology predictions such as which gas engine technology that will dominate the market in the future are hard to find.

The uncertainties, both among industry actors as well as in secondary data, regarding the future potential of the gas engine market are logically affecting the depth and the concreteness of the study's conclusions. Thus, it is, crucial for industry actors to closely monitor the development of the gas engine market as well as to consider future strategies. An obvious next step for diesel engine manufacturers is, hence, to conduct an internal analysis where strengths and weaknesses related to gas engines and to changing technology are identified and assessed.

Another further study, that could be beneficial for diesel engine actors, is to study the potential of other alternative fuels. Gas is obviously a more environmental friendly fuel than diesel, but it is still a finite fossil fuel. Thus, there are alternative fuels that are even more environmental friendly. These fuels may not be commercial alternatives as for today, but, as more incentives are focused on environmental friendly fuels, they could potentially become competitive solution in the future. Hence, monitoring these options may prevent an actor from focusing resources on the wrong solution and potentially entail future opportunities that could contribute to a competitive advantage.

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Appendix 1 Definitions

Following chapter defines concepts utilized in this thesis

Genset segment include

- Auxiliary Power Units
- Industrial Generator Sets
- Portable Generator Sets
- Residential Generator Sets
- RV Generator Sets
- Trailer Mounted Generator Sets

Off Road segment include

- Aerial Lifts
- Air Compressors
- Aircraft Support Equipment
- Chippers/Grinders
- Concrete and Industrial Saws
- Cranes
- Crushing and Processing Equipment
- Dumpers/Tenders
- Forklifts
- Gas Compressors
- Hydraulic Power Units
- Irrigation Sets
- Light Plants and Signal Boards
- Bore Drill Rig
- Crawlers
- Excavators
- Finishing Equipment
- Forestry Equipment
- Graders
- Mixers
- Off-Highway Tractors
- Off-Highway Trucks
- Trenchers
- Pavers
- Plate Compactors
- Rollers
- Oil Field Equipment
- Equipment
- Pressure Washers
- Pumps
- Railway Maintenance Equipments
- Rough Terrain Forklifts
- Scrubbers and Sweepers
- Specialty Vehicle and Carts
- Surfacing Equipment
- Terminal Tractors
- Utility Vehicles
- Other Industrial Equipment
- Other Material Handling
- Scrapers
- Skid Steer Loaders
- Tampers/Rammers
- Tractors/Loaders/Backhoes
- Underground Mining Equipment
- Wheel Loaders and Dozers
- Other Construction Equipment

Application segments

Industrial: Comprise factories and manufacturing units such as semiconductors, paper and pulp, food processing units, construction, marine, chemicals, petrochemicals, rubber, metals, and mining.

Commercial: Comprises high-rise buildings, restaurants, resorts, offices, shopping malls, the telecoms industry, IT companies, data centres, small enterprise and commercial warehouses

Institutional: Comprises hospitals, schools, universities, rural communities, government buildings, utilities, airports railways and various other power capacities

Residential: Comprises smaller end-user groups, which vary from apartment complexes to condominiums

Appendix 2 Empirical data templates

Following appendix includes templates used for primary empirical data collection through surveys and interviews.

2.1 Survey template

Gas Engine Survey

This survey aims to map future potential of the gas engine market (the gas engine market is defined as *the entire premium market where the Company is active*), as well as how external factors may impact the given market. Please, answer the questions as thoroughly as possible. Explanatory information to the questions is found in the comment field in each cell with a question.

Please send it in before **xxxx-xx-xx**

)efinitions	
:ngine Technologies	
park- nited	Spark-ignited gas engines use the same technology and principals as a petrol combustion engine. Gas is mixed with air and injected in to the combustion chamber, where a spark plug is used to ignite the gas.
)ual-fuel	Dual-fuel engines are basically a diesel compression ignition engine with gas injection technology. Diesel self-ignites due to pressure and heat, and as a result the diesel ignites the gas. A dual-fuel engine can run solely on diesel.
IPDI	Like the Dual-fuel engine, the HPDI (high pressure direct injection) engine is based on the compression ignition engine technology. However, in the HPDI engine a small diesel injection is sprayed in to the combustion chamber and gets ignited by heat compression prior to the gas injection. Thus, the gas is injected in to the flames and as a consequence the combustion process is easy to control, methane slip is reduced and methane number variations are practically irrelevant. A HPDI engine cannot run solely on diesel.
;as Quality Index	
Iethane ımber	The Methane Number of a gas provides an indication of the knock tendency of a fuel? It is a product of the different constituent gases within the natural gas, particularly the proportions of methane, ethane, propane and butane. Methane, which has a high knock resistance, is given an index value of 100. Hydrogen, which burns quickly relative to methane, has a low knock resistance and is given the index value of 0. If a gas mixture has a methane number of 80, its knock resistance is equivalent to that of a gas comprised of 80% methane and 20% hydrogen. There are gas constituents which have a higher methane number than 100 therefore it is also possible for a gas composite to have a higher methane number than 100. Biogas often has a methane number in excess of 100.
Vobbe dex	The Wobbe Index [MJ/m^3] is a measure of the interchangeability of gases when they are used as a fuel. It compares the energy output of different gases during combustion. The Wobbe index is essential for analyzing the impact of a fuel changeover and is also a common specification of appliances that use gas, and of devices that transport gas.

ntroductive questions	**Answers**
Please state your name and region	

/hat is the general perception of gas as an engine fuel in the region (e.g. positive and negative spects and perceptions of gas as engine fuel)	
What are the current uses of gas driven engines (i.e. in what applications and segments in the egion are gas engines used today)	
What gas type and quality does the customer have access to in the country? (Natural gas, Bio- as, etc. Gas quality aspects to consider are; gas composition, Methane Number, Wobbe Index and the gas quality and type differ across the region)	
What external drivers /factors may affect the development of the gas driven engine market (e.g. ncreased oil price may lead to increased incentives to use gas driven engines etc.)	
Identify main competitors to the Company in the gas engine market	
How does the infrastructure support access to gas for the customer? (How does the nfrastructure support Liquefied Natural Gas (LNG) and Compressed Natural Gas (CNG), and how xtensive is the infrastructure?)	

Market size

ower kW r VA rp]	**Volume** ***Gas driven engines (Total volume on the market (i.e. NOT only the Company's volume) specified in sold units)***																				**Volume** ***Diesel driven engines (NOT only the Company's volume) specified in sold units***				
	Genset				Stationary VE				Material Handling				Mining				Construction				Genset	Stationary VE	Material Handling	Mining	Construction
	Spark-ignited		Dual-Fuel		Spark-ignited		Dual-Fuel		Spark-ignited		Dual-Fuel		Spark-ignited		Dual-Fuel		Spark-ignited		Dual-Fuel						
	2015	2020	2015	2020	2015	2020	2015	2020	2015	2020	2015	2020	2015	2020	2015	2020	2015	2020	2015	2020	2015	2015	2015	2015	2015
- 75																									
6 - 50																									
51 - 50																									
51- 50																									
750																									

dditional questions	Answers
he Dual-fuel technology is a broad segment including many technologies (e.g. Traditional dual- uel, HPDI, etc.). What is the general perception of Dual-fuel technologies in the region, can any rends towards a specific technology be identified?	
/hat market drivers influence the adaption of different dual-fuel technologies (e.g. drivers ffecting the adaption of traditional dual-fuel vs HPDI)?	

Additional questions

Power kW or kVA prp]	Price (*engine*) in USD			Price (*fuel*) in USD		External factors								
	Diesel driven engines	Gas driven engines		Gas	Diesel	Current emission requirement	Future emission requirement		Identified market trends	Customer incentives for choosing gas fuelled engines	Diesel Substitution Factor			
		Spark-ignited	Dual-fuel				When	Legal requirements			Genset	Material Handling	Mining	Construction
- 75														
6 - 250														
51 - 50														
51 - 50														
750														

2.2 Survey participants (regional offices)

America

USA	Vice President Industrial Sales
Americas (general)	Manager Industrial Sales
Caribbean	Vice President Industrial Sales

Asia & Pacific

Asia (Generally)	Business Development Manager
China	VP Sales & Marketing
Indonesia & Myanmar	Executive VP
Japan	Manager
India	Vice President
Asia (Generally)	Product Manager
Dubai	
Middle East	Area Sales Manager
Indonesia & Myanmar	Deputy Head SE Asia
Pacific	Area Sales Manager
South Africa	General Manager
Pacific	General Manager
Russia	Director
Middle East	Importer Business Manager
Asia (Generally)	Area Sales Manager
Asia (Generally)	Manager Technical Service
Asia (Generally)	Key Account Business Manager
United Arab Emirates	Area Sales Manager

Europe

Spain	Sales Manager
Portugal	Sales Manager
Poland	Business Controller
France	Business Manager
Nordic Region	Sales Manager
Baltic Region	Sales Manager
Belgium	Sales Manager
Holland	Sales Manager
Luxemburg	Sales Manager
Italy	Industrial OEM Sales Manager
Germany	Head of Industrial Engines
East Europe	Sales Manager

2.3 Interview template

Interview template Gas Engines

Please state your:

Name:

Position:

Company:

General Questions

- What is your general perception of gas engines and gas as an engine fuel (i.e. positive and negative perceptions and aspects of gas engines)?
- What external drivers/factors may affect the development of the gas driven engine market (e.g. increased oil price may lead to increased incentives to use gas driven engines etc.)?

Technology Questions

- What are the pros and cons of the dual fuel engine in general and Clean Air Power's dual fuel engine in particular in comparison with:
  - Diesel engines
  - Other gas engine technologies (spark-ignited, HPDI)
- Can you identify any trends regarding engine technologies (in the segments; mining, construction, material handling vehicles or generators)?
- In what segment (mining, construction, material handling, generators) do gas engines have the most potential (and why)? How large is this potential? (Number of sold units per year and region)

Infrastructure Questions

- From your point of view, how does today's infrastructure support the access to gas?
  - How does the infrastructure support the access to Liquefied Natural Gas (LNG)
  - How does the infrastructure support the access to Compressed Natural Gas (CNG)

What drivers may affect the buying decision (Grade each aspect with 1-5 (with 5 being very important))?

- Engine price
- Engine power
- Torque
- Operation time/single tank
- Engine emissions
- Environmental friendly profile
- Fuel price
- Access to fuel
- Other drivers?

2.4 Interview participants

Advanced Engineering Manager in Engine Industry	The Company
Alternative Drivelines Planning Manager	The Company
Director Environmental Affairs	The Company
Laws and Regulations Analyst	The Company
Laws and Regulations Manager	The Company
Application Engineer	The Company
Business Development Manager	The Company
Product Manager	The Company
VP Industrial Sales	The Company
Manager Industrial Sales	The Company
Marketing and Sales Manager	The Company
Business Development Director	The Company
Sales Manager	The Company
Industrial OEM Sales Manager	The Company
Product Manager	ComAp
Product Manager	ComAp
General Manager	Cargotec
General Manager	Hardstaff
General Manager	AGCO corp.
Plant Manager	Genpower
Technical Director	Clean Airpower

Appendix 3 Technology

Following appendix includes information about gas technological aspects related to the thesis

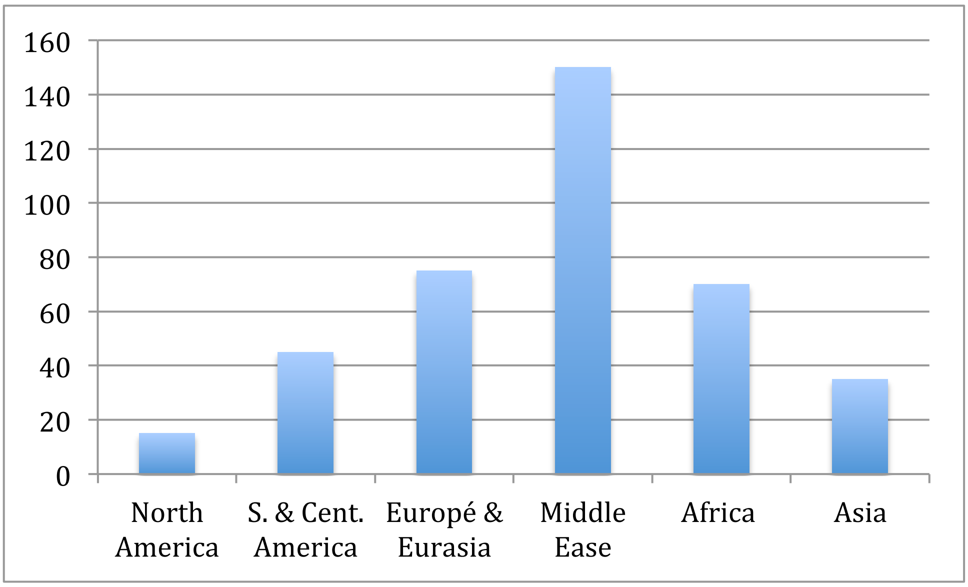
3.1 Largest globally gas producers and consumers (British Petroleum, 2012)

Country	Gas Production, Billion m^3
US	**651,3**
Russia	**607,0**
Canada	**160,5**
Iran	**151,8**
Qatar	**146,8**
China	**102,5**
Norway	**101,4**
Saudi Arabia	**99,2**
Algeria	**78,0**
Indonesia	**75,6**

Country	Gas Consumption Billion m^3
US	**690,1**
Russia	**424,6**
Iran	**153,3**
China	**130,7**
Japan	**105,5**
Canada	**104,8**
Saudi Arabia	**99,2**
United Kingdom	**80,2**
Germany	**72,5**
Italy	**71,3**

3.2 Years of future gas consumption covered by proven reservoirs (British Petroleum, 2012)

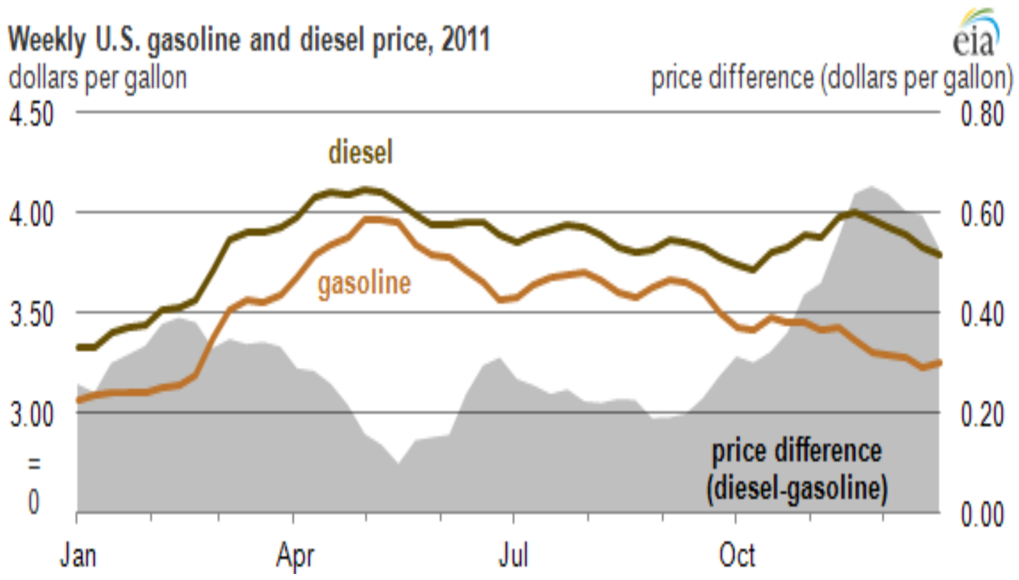
Assumption: Gas consumption will stay the same as today over the time period



Appendix 4 Market and Customer

Following appendix includes information about the market and customers related to the thesis

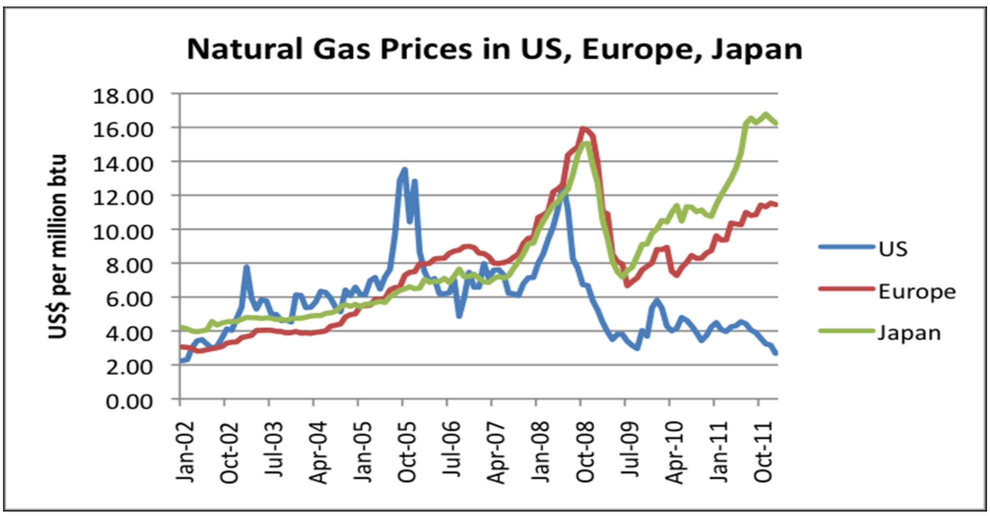
4.1 Fuel price comparison in USA (U.S Energy Information Administration, 2013b)



4.2 Natural gas price in US, Europe and Japan (British Petroleum, 2012)

Natural gas is highly conditioned by pipeline infrastructure and divided along regional markets. Therefore, natural gas spot price is volatile and greatly influenced by seasonal changes, and local market conditions regarding demand, production and distribution. (Frost & Sullivan, 2009)

4.2 Natural gas price in US, Europe and Japan (British Petroleum, 2012)



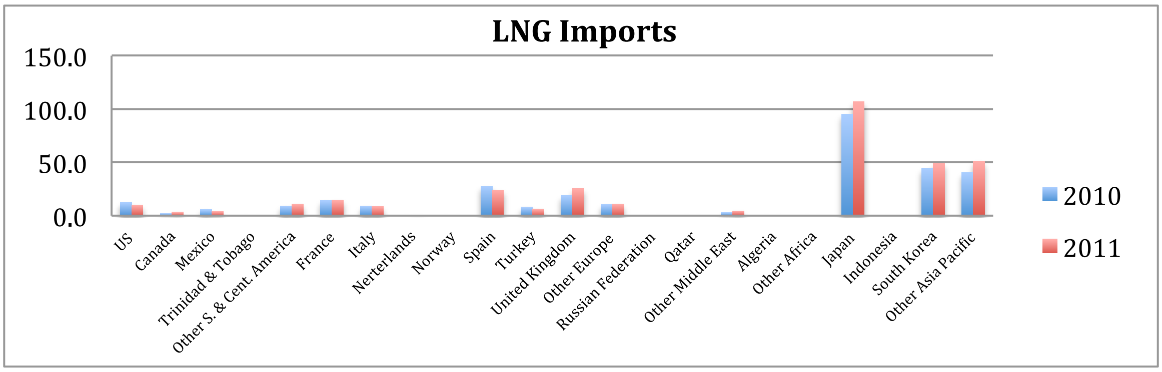
4.3 Forecast over number of sold gensets per engine power on the North America market (Zirnhelt, 2013)

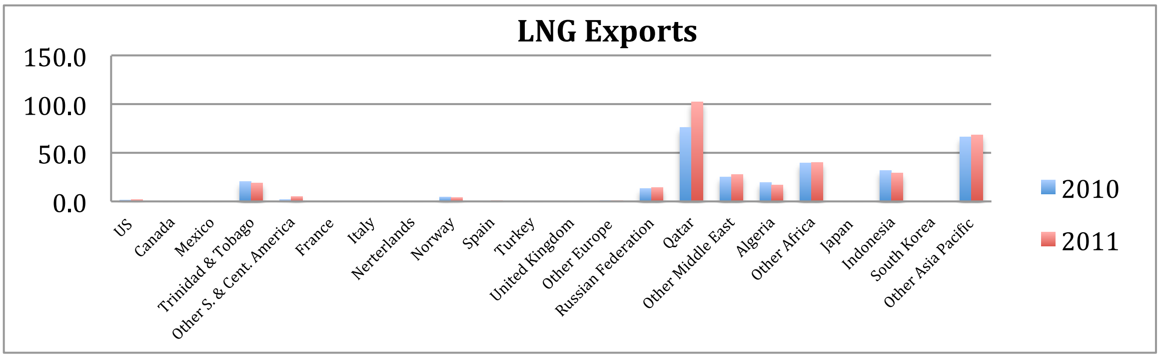
Assumption: The distribution between gas and diesel fuels will remain the same in the different engine power classes)

Engine Power	2013	2014	2015	2016	2017
< 5kW	3175	3285	3398	3513	3556
5-18kW	91942	95478	99120	102882	104654
18-50kW	14411	14992	15604	16241	16578
50-250kW	8486	8761	9066	9388	9530
250-500kW	1242	1279	1322	1368	1387

Appendix 5 Environmental Aspects

5.1 LNG imports and exports (British Petroleum, 2012)





5.2 LNG imports and exports by pipeline (British Petroleum, 2012)