RESILIENT SUSTAINABLE AUTOMOTIVE STRATEGY
Six Month Report

Executive Summary

This report covers the first six months of the doctoral project. The goal of the project is to support Ford in developing of resilient strategies, to address the transition to sustainable transport in the 2015-2050 timeframe. It concerns the incorporation of sustainability concerns within Ford's toolsets, to consider of a wider range of issues, and enhance Ford's ability to assess and select technologies or products to address these issues.

This report includes an overview of the industry and its challenges, an initial look at sustainability tools already used within Ford, and a first look at relevant strategy and innovation theory. A group of potential stakeholders has been identified and there are two main objectives identified for the research project so far:

- Support the analysis of longer term future scenarios
- Propose supplementary metrics and methods for evaluating new technologies, products, and services for sustainability

Various megatrends in the business environment have been emerging over the last few months- globalisation, urbanisation, lifestyle aspirations and resource constraints - all of which further contribute to unsustainable levels of global consumption and demonstrate the need for sustainability to be included in any business analysis. In addition the industry suffers from structural problems which make it unprofitable for most vehicle companies. Combined with overcapacity and economic volatility this provides a further driver for the need to develop organisational resilience.

One sustainable design tool was identified already within use at Ford, the Product Sustainability Index, which may provide a basis for further work. It is discussed against the background of Life Cycle approaches as used in the industry, and upon which it is based.

The final section of the report contains a plan for future work in three main areas: further boundary setting; searching for supporting data on the industry, Ford, and possible methods and metrics; checking assertions in the literature about strategy change and disruptive innovation. Further leads are identified in future business strategies and consumer behaviours, but will be investigated at some later time.

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# Table of Contents

Table of Figures ........................................................................................................... i
Glossary of Terms ......................................................................................................... ii

1 Introduction ................................................................................................................. 1
   1.1 Organisational Context ....................................................................................... 1
   1.2 Strategy Planning Process .................................................................................. 2

2 Economic and Environmental Context of the Research ............................................. 7
   2.1 The Automotive Industry- an Overview .............................................................. 8
   2.2 The Importance of CO₂ Regulation to the Industry ............................................ 10
   2.3 CO₂ Reduction Strategies .................................................................................. 12
   2.4 The Rebound Effect and Price Signals ................................................................ 13
   2.5 Balancing CO₂ and Other Emissions ................................................................. 14
   2.6 The Problem of Design Eco-Inefficiency ............................................................ 15
   2.7 Business Issues- Lock-in and Disruptive Technologies ....................................... 17
   2.8 Shrinking and Changing Markets ..................................................................... 21
   2.8.1 Interaction With the Consumer ..................................................................... 23
   2.9 Cultural Change ................................................................................................ 27

3 Defining the Ford Project Objectives ........................................................................... 29
   3.1 The Project Goal- Enhanced Resilience ............................................................... 29
   3.2 Objective 1 – Support Analysis of Future Scenarios .......................................... 31
   3.3 Objective 2 – Establish Assessment Methods and Metrics .................................. 33

4 Sustainability Tools and Metrics in the Automotive Industry ................................... 34
   4.1 The Ford Product Sustainability Index (PSI) ....................................................... 36
   4.2 Other Sustainability Metrics at Ford Motor Company ........................................ 40
   4.3 Resilience and Other Metrics .......................................................................... 41
   4.4 Strategy, Risk and Sustainability ...................................................................... 45
   4.5 Supporting Decision-Making ............................................................................ 46
   4.5.1 Integrating the Results into the Company ....................................................... 46

5 Summary and Future Work ......................................................................................... 46
   5.1 Future Work Plan .............................................................................................. 47
   5.1.1 Establish Project Boundaries ........................................................................ 47
   5.1.2 Find Supporting Data About the Industry ..................................................... 48
   5.1.3 Find Supporting Data About Possible Solutions ............................................ 49
   5.1.4 Find Out More About Strategic Change and Disruption Theories ................ 50
   5.1.5 Routes to the Future ..................................................................................... 51

References ..................................................................................................................... 53

# Table of Figures

Figure 1 - Simplified process view of initial project scope .............................................. 3
Figure 2 - Organogram showing Ford project stakeholders .......................................... 4
Figure 3 - Strategy process loop .................................................................................. 5
Figure 4 - Overlapping Ford processes ....................................................................... 7
Figure 5 - A sketch of the dynamic process of the adoption of clean technologies ....... 25
Figure 6 - Ford EngD Project Objectives and Context (Skipp, 2011) ......................... 31
Figure 7 - Example output from Ford PSI tool for 2009 Fiesta .................................... 39
Figure 8 - Future research overview.......................................................................... 52
## Glossary of Terms

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACEA</td>
<td>European Automobile Manufacturer's Association</td>
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<tr>
<td>AFV</td>
<td>Alternatively Fuelled Vehicle (covers electric, hybrid and non diesel/gasoline powertrains)</td>
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<td>BEV</td>
<td>Battery Electric Vehicle</td>
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<tr>
<td>CES</td>
<td>Centre for Environmental Strategy (University of Surrey)</td>
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<td>COO</td>
<td>Cost of Ownership</td>
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<td>EC</td>
<td>European Commission</td>
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<td>EPSRC</td>
<td>Engineering and Physical Sciences Research Council</td>
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<td>ETS</td>
<td>Emissions Trading Scheme</td>
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<td>EU</td>
<td>European Union</td>
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<td>EV</td>
<td>Electric Vehicle</td>
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<td>FoB</td>
<td>Ford of Britain</td>
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<td>FoE</td>
<td>Ford of Europe</td>
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<td>GHGs</td>
<td>Greenhouse Gases</td>
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<td>GPDS</td>
<td>Global Product Development System (Ford)</td>
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<td>GTDS</td>
<td>Global Technology Development System (Ford)</td>
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<td>GUC</td>
<td>Government and Universities Collaboration (Ford)</td>
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<tr>
<td>HEV</td>
<td>Hybrid Electric Vehicle</td>
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<tr>
<td>ICE</td>
<td>Internal Combustion Engine</td>
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<tr>
<td>IPCC</td>
<td>International Panel on Climate Change (UN)</td>
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<td>LCA</td>
<td>Life Cycle Analysis</td>
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<td>LCC</td>
<td>Life Cycle Costing</td>
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<td>LowCVP</td>
<td>Low Carbon Vehicle Project</td>
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<tr>
<td>LDV</td>
<td>Light Duty Vehicle (car or light truck)</td>
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<tr>
<td>LEV</td>
<td>Low Emissions Vehicle</td>
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<tr>
<td>OEM</td>
<td>Original Equipment Manufacturer (usually a maker of LDVs)</td>
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<tr>
<td>PHEV</td>
<td>Plug-in Hybrid Electric Vehicle</td>
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<tr>
<td>PSI</td>
<td>Product Sustainability Index (Ford)</td>
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<tr>
<td>RAE</td>
<td>Royal Academy of Engineering</td>
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<tr>
<td>SMMT</td>
<td>Society of Motor Manufacturers and Traders</td>
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<tr>
<td>ULEV</td>
<td>Ultra-low Emissions Vehicle</td>
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<td>ZEV</td>
<td>Zero Emissions Vehicle</td>
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1 Introduction

This report covers the first six months of the doctoral project. It considers the initial business, technical and academic context of the doctoral research project, and identifies areas for further literature and organisational research. It will be developed by subsequent update reports throughout the engineering doctorate programme.

The project is intended to support the incorporation of sustainability concerns within Ford’s toolsets to allow a consideration of a wider range of issues, and thus enhance their ability to assess and select technologies or products to address these issues. The research is planned to have three phases, of investigation (looking at which knowledge and tools are already available internally to Ford, and in the wider industrial and academic community), of development (working on methods to fill any identified gaps and developing something suitable for use by Ford), and potentially of application ( trialling and/or roll-out of any methods or tools). The work will contain elements of risk and strategy theory as well as technology assessment and product innovation processes. Finally, as the industry is currently in a state of economic and technological flux due to the global recession and the drive towards cleaner automotive technologies, it is planned to produce useful insights along the way, and to modify the project objectives over time as the needs of the sponsor develop. At this point in time the initial objectives and scope of the project have been set, and these are described in brief in section 1.1 below, and in more detail in section 3.

The project was created jointly by the University of Surrey’s Centre for Environmental Strategy (CES), the Research Engineer (RE) and Ford of Britain (FoB), and is funded by the Engineering and Physical Sciences Research Council (EPSRC) and Ford of Britain. The research is carried out by the Research Engineer who is seconded from CES to Ford, and based at their Dunton, Essex, Research and Development centre.

1.1 Organisational Context

There are two views of the organisational context of the project, one process-oriented and one structure oriented. Taking the process one first, Ford can be represented as part of a feedback loop, selling cars to customers then responding to their experiences and outside influences to modify their future products accordingly.

As this project is concerned with external inputs to the company which affect the market and technology strategies, it sits at the front end of this simplified loop; see Figure 1. The loop was originally drawn when considering Electric Vehicle (EV) development but the issues of resupplying the vehicle with energy in some form, and the infrastructure to support this, are generic.
Within Ford the project is owned and supervised by the Powertrain Product Development division, and specifically the Powertrain Sustainability Manager. It is supported and funded by the Government and Universities Collaboration (GUC) department also within this division. It will be focussed by a group of stakeholders from relevant functions, for example Sustainability, Advanced Marketing and Product innovation, working across the European (and even Global) company divisions. This use of stakeholders is to ensure that the research is designed to complement and support sustainability work already happening inside the company, by capturing the various needs that exist. The stakeholders will be drawn from those who are potential users of the research outcomes, so that they can inform the objectives and scope of the project, and provide direction during its execution. The stakeholders will also provide continuity should the industrial supervisor change during the project, as ownership of the research project may stay attached to the post and not the individual manager. Ford managers often change job every 2 years.

Finally the stakeholders will provide extra technical input to the research on occasion, and confer a degree of legitimacy and perceived balance to the project within the company by their collective presence. This avoids the research being seen as a "pet" project belonging to one particular function, and will aid with the acceptability of any results later.

Please see Figure 2 for an organisational diagram showing the position of the research engineer within Ford and the potential membership of the stakeholder group identified so far.

1.2 Strategy Planning Process

This project will look at the input side of the sponsor’s strategic processes. Within Ford there are four main parts to the process used by the departments involved in strategy planning (whether technology or product):

1) Explore near and long-term trends  
2) Generate product & service alternative options  
3) Evaluate the product concepts and technologies  
4) Recommend future product strategy

These steps include the consideration of activity by competing companies, and interpolating their strategies, as well as considering internal options and decisions. They already utilise a set of metrics common throughout the company's processes, both quantitative such as cost, quality or weight, and qualitative such as driveability. Qualitative values can be established by a consensus (such as technical feasibility) or by a form of
Figure 1- Simplified process view of initial project scope
Figure 2- Organogram showing Ford project stakeholders
survey (such as scoring driving experiences with a particular product type amongst a group of expert or non-expert drivers, usually using a Likert scale).

This is normally an iterative set of activities, running on an annual cycle with a status review at the half-year point (see Figure 3). At any stage, information is fed in by various levels of the company, usually by request, upwards to senior executives who meet and make decisions according to the strategic need of the moment. Fleshing out of the study or implementation details, including finding solutions and assessing them, is passed back down the organisation to the appropriate level, whether middle management, technical specialists or engineers. These layers then report their results back up the hierarchy, forming a set of iterative loops until the strategic issue is considered addressed, usually by a final decision.

The executive officers of the company use strategy planning to arrive at a product cycle plan, which extends some distance into the future. All projects from small changes to large ones appear in this plan, and only work appearing in the plan will be given resources. The strategy planning activity may also trigger larger corporate activities such as buying or divesting of other companies, new strategic enterprises and so on. These are conducted outside of R&D, within the corporate centre of the organisation and may have even longer timescales.

As strategy decisions are considered commercially sensitive, staff involvement is limited to a "need-to-know" basis, so most employees and contractors never encounter
strategic processes; although they may provide information for them, and enact any
instructions, or support goals which are cascaded down. They can therefore be unaware of
their existence, and usually are also unaware of longer term goals or changes until they are
required to carry out associated tasks, typically with nearer term time-horizons. This
mainstream development activity, close to product launch timing, is where most of the R&D
workforce operate.

How do the strategic process and this day-to-day R&D activity fit together? The
closer to product launch an activity occurs, the more structured it tends to be and the more
visible it is within the everyday R&D workings of the company. Ninety days after a product is
launched, responsibility for it formally passes from R&D (Forward Model) to Production
(Current Model) functions. Development from Program Start to Launch is run using a
process called the Ford Global Product Development System (GPDS), which can last up to
four years depending on the level of design change required. At Program Start all the
necessary technologies and products must be well enough developed to have a good idea of
their feasibility, cost, forecast quality and other metrics, although several alternatives may be
carried into the program until a definitive design decision can be made. (The same metrics
are used where possible all the way from strategic studies through the various processes to
launch and beyond, to ensure consistency).

For any new technologies which must be developed and trialled, there is a Research
and Advanced Engineering (R&A) process feeding into GPDS called the Global Technology
Development System (GTDS), which is less detailed and structured than GPDS. This
overlaps with the GPDS timing to some degree, for example whilst technical details are
being finalised, but also extends earlier, adding typically another 2 years of work (see Figure
4). Some advanced projects can take much longer, but all are chosen with some eventual
application in mind, which in turn has been identified by the strategy planning process. Due
to the lesser amount of information available this far in advance, these advanced activities
are less structured and formal than the GTDS or GPDS ones. These are the ones with which
the project is intended to work.

The development of metrics and methods, used in steps 2 and 3 of the strategy
process, happens only occasionally. This is a key area for this project, which is intended to
enhance strategy planning in two main ways;

- Support the analysis of longer term future scenarios
  - including sustainable development issues
- Propose supplementary metrics (and methods) for evaluating technologies,
  products and services for sustainability
Ideally metrics and methods which can be slotted into the existing Ford strategic planning toolsets

The goal of this work is to enhance the business’ resilience to changes, including the increasing importance of sustainability in business decision-making. Business resilience is discussed in more detail in section 3.1 as are the initial project objectives. But first it is necessary to examine why a large player in a mature industry might consider it now needs extra tools to enhance its performance.

![Figure 4 - Overlapping Ford processes](image)

### 2 Economic and Environmental Context of the Research

The automobile and its commercial vehicle relatives are thoroughly embedded within Western society's structure, consumer psychology and ideas of personal freedom and expression; it is intertwined with global industrial and financial systems, and it may even have co-evolved with the global credit system (Wells, 2009a). The manufacture and use of cars is a voracious consumer of resources, whilst underpinning the global economy and providing a livelihood for millions of people worldwide (Wells, 2010). It is one of the most pervasive and polluting products created by mankind, and yet, well-managed road transport can also be an enabler to economic development in the developing world (WBCSD, 2009).

For example in Africa the high level of food waste, and hence poverty and food shortages, are contributed to by poor transport and infrastructure access (Anon., 2009)
which, combined with high temperatures and humidity in some regions, allows food to rot before it can reach the markets. Poor or rural populations with less access to transport (usually by road) can suffer in turn from other disadvantages, such as poor access to work or health services (WBCSD, 2009).

The following section considers the current state of the industry and where it may be headed, alongside the challenges of retaining its major benefits (personal and freight mobility from its products, and employment for thousands of people worldwide from its operations), and abating or removing its disadvantages (mainly pollution and climate change), whilst trying to transform it into something which supports sustainable mobility in the long-term.

2.1 The Automotive Industry- an Overview

The global automotive industry faces many challenges. It suffers from economic and structural problems, mass-producing resource-intensive products with low to negative profit margins, which are also environmentally unsustainable (Lovins and Cramer, 2004) (Orsato and Wells, 2007). The capital-intensive industrial structure typical of the industry presents very high entry costs to new companies; but as the likely profit margins are so bad, few new players wish to reproduce the same set-up (Christensen, 2010) (Wells, 2010). Despite this, the emerging automotive markets in Asia, driven by consumer demand and supplied by the development of regional incumbents and joint ventures with Western automakers, show every sign of replicating the more mature Western markets, complete with their structural issues (Wells, 2010). It might be said that the automotive companies are digging themselves into a deeper hole, strategically, in doing this.

A curious result of these structural problems is that, collectively, vehicle manufacturers (and here we are referring primarily to makers of cars and light trucks, known collectively as Light Duty Vehicles, LDVs) have somehow jointly ended up in a position where their franchises may make a profit, their suppliers sometimes make profits, but they, the original equipment manufacturers (OEMs), typically do not make much profit in the long term. A 2% or larger profit, before the recent recession, was considered an exceptionally good year (Wells, 2010). It could be assumed that OEMs must break even over the long term in order to survive, but as they are large complex organisations and sometimes receive governmental support it is quite difficult to tell exactly how profitable, or unprofitable, they really are, unless an event like the recent recession affects the car markets and reveals weaknesses. One article on these recent events (Wells, 2009a) points to inflated demand caused by cheap finance, which was then badly affected by the credit-crunch and the recession beginning in 2008. Wells posits that the full effects on the industry will take some time, possibly many years, to play out.
Despite the recent loss of some large automotive suppliers, it is still a very large industry, strongly influencing global commodity prices and contributing significant proportions of the Gross Domestic Product of countries where it is based (Wells, 2010). For example in the UK even during economic difficulties, it accounted for 10.6% of exports by value in 2008, worth over £26 billion (SMMT, 2010b) and in 2009 the industry was the largest investor in research and development (R&D) in Europe (ACEA, 2011).

The industry’s product, road-going vehicles, also contributes significantly to the carbon emissions of developed nations. Domestic transport in the UK accounts for 21% of total UK CO\textsubscript{2} emissions, of which road transport is dominant at about 19% of total emissions (DfT, 2009a), a figure typical of the EU as a whole (EC, 2010b). Passenger cars in the EU account for 12% of total EU CO\textsubscript{2} emissions (EC, 2010a). Additionally, whilst other sector greenhouse gas (GHG) emissions have reduced, road traffic emissions have increased as a result of increased car population and use, undoing any technical gains or positive outcomes of the Kyoto Protocol (Frondel et al., 2010). Plus, the manufacturing side of the industry contains some of the heaviest polluters such as steel plants and foundries (Wells, 2009a).

At a time when global environmental impacts need to be reduced by perhaps an order of magnitude to mitigate climate change effects (Tukker and Cohen, 2004), this alone makes LCVs a target for environmental legislation. As a whole the European automotive industry is being pushed to reduce its environmental impacts by a combination of legislation focussed on limiting CO\textsubscript{2} emissions, market incentives for cleaner vehicles and consumer demand (Christensen, 2010). These pressures are being applied at industry, organisation and product levels (Nieuwenhuis and Wells, 2003) and will only increase over time (Orsato and Wells, 2007), especially if the IPCC assessments of climate change continue to worsen (Block, 2009).

The automotive industry is also perhaps the first large industry to truly have to face its own environmental unsustainability, both in terms of resource consumption and driving increases in CO\textsubscript{2} emissions as the industry grows (Wells, 2010). Aviation may appear to be an issue in the green media, but it is far less subject to emissions regulation. For example it has few if any targets set for CO\textsubscript{2} reduction. The current level of emissions, coupled with projected growth and technology improvements in the UK, mean aviation would account for at least a quarter, but possibly up to the entire national carbon budget by 2050: attention will fall on the need for reductions, but this has not happened yet. In 2004 it accounted for 7% of national CO\textsubscript{2} emissions in the UK (Bows and Anderson, 2007).

Although the car is a technologically mature product it is environmentally inefficient (Orsato and Wells, 2007), presumably as it developed in an era when fuel was cheap and emissions were not an issue. Therefore there is an acute need in this industry for the application of sustainability tools, which consider social, environmental and economic


aspects; Life Cycle Tools for example can help identify better-designed products with better profit opportunities (Graedel and Allenby, 2010) (Finnveden et al., 2009). Wells states that the inherent value systems within Life Cycle tools allow better value-creation for consumers and companies, and therefore assist the long-term survival of companies which use them; although he does not give examples (Wells, 2010).

Despite its problems the industry is so big, that its continued survival (in one form or another) is considered vital to the EU's economic future –both in its own view and that of the EC (ACEA, 2010a). It is difficult to tell what the automotive companies really think of their own sustainability, as naturally they and industry bodies tend to put a positive spin on any news. For example the UK's Society of Motor Manufacturers and Traders (SMMT) presents the industry as a "sustainability leader" (SMMT, 2009) as does its European equivalent the ACEA (2010a), although in the latter case the term sustainability seems to refer mostly to the economic variety.

2.2 The Importance of CO₂ Regulation to the Industry

The most urgent sustainability issue is the avoidance of dangerous levels of Climate Change, which is driven by GHGs and particularly CO₂ levels (IPCC, 2007). Developed countries such as the UK which are the largest emitters, and have the biggest reduction obligations (DfT, 2009a). The focus on Climate Change and CO₂ is strongest within Europe (MacLean and Lave, 2003), possibly as this is the region where environmental awareness and concepts such as sustainability have first developed.

For example the UK Climate Change Act sets targets of a 34% reduction in CO₂ emissions by 2020 and of 80% by 2050, using 1990 levels as a baseline (UK Government, 2008). Additionally the strategy required to reach the targets requires a 14% reduction in UK transport emissions between 2008 and 2020 alone (DECC, 2009). The Royal Academy of Engineering's 2010 report on the UK's energy grid concluded that to meet these targets, conversion of part or most of the UK vehicle fleet to electric and hybrid electric vehicles will be needed. Depending on the interaction of demand reduction, and allocation of fossil fuels towards or away from transport priorities, up to 80% of energy for UK transport would need to be electrified by 2050 (RAE, 2010b). These vehicles would need to have drastically reduced lifetime CO₂ emissions, through a combination of partial or full electrification, grid decarbonisation, other approaches such as innovative design, and manufacturing decarbonisation. As the UK is a fairly typically developed European country, one can reasonably extend these forecasts to the rest of the Western EU members at least; and these countries form the majority of the European automotive market for passenger cars and light vans (ACEA, 2010b).
The European Commission is enacting specific legislation for the automotive industry to assist with meeting 2020 and 2050 targets, such as the EU new car CO\(_2\) emissions regulations (European Parliament, 2009), much resisted by the industry (Frondel et al., 2010). This has been necessary as a form of control as transport has not yet been included in the EU emissions trading scheme (ETS), and voluntary agreements to reduce emissions by the industry have under delivered (Frondel et al., 2010). The new regulation sets a limit on a manufacturer's average fleet emissions, which reduces over time. Although it is phased in previous to this, the average limit for 2015 is 130 gCO\(_2\)/km (expected to give a 19% reduction already by 2012\(^1\)) and the next milestone is planned to be 95 gCO\(_2\)/km by 2020 (EC, 2010a), which equates to 40% less than 2007 levels (DECC, 2009). The penalties for exceeding the limit sound small, for example €5 per vehicle for the first g/km, but are multiplied by the entire annual European volume of the manufacturer; so that €5 for example becomes €7.5 million if a company produces 1.5 million cars a year, a typical mass-production volume for one company (ACEA, 2010b). The penalties rise steeply after that, at €15 for the second gram, €25 for the third, and €95 per g/km thereafter (EC, 2010a).

Although there are further subtleties to how the limit interacts with vehicle weight (the Regulation uses a limit-value curve), small producers, special allowances for innovative green technology and so on (European Parliament, 2009), this legislation is driving the European car industry hard to reduce CO\(_2\) emissions and causing a surge of interest in technologies such as hybrid vehicles. One point of note is that the regulation results in a much higher effective price per tonne of excess carbon emission for a company, than if the industry were included in the EU ETS- for example using the common design-life of 150,000km, this price is €633 per (metric) ton compared to around €30 in the ETS (Frondel et al., 2010). Frondel argues that the ETS would have been more economically efficient, but appears to miss the point that a higher price (effectively a fine) allows companies to spend more on technological developments for emissions reduction, because it changes the business case and the perceived risk.

Although the industry is regulated in many other ways, (safety legislation, and end-of-life vehicle recycling targets for example), the current focus is on CO\(_2\) as the latest and newest policy requirement to be met; and also possibly because general awareness of Climate Change and other sustainability issues amongst consumers means that this is reflected in the industry's public relations efforts.

\(^1\) No baseline is given on this webpage but the author believes it is probably 2007 as both pages mentioned here refer to the same piece of legislation
2.3 CO₂ Reduction Strategies

As a consequence of this regulatory activity, car manufacturers are developing carbon reduction "roadmaps" which are intended to help them meet the UK and EU carbon targets, to target government funding supporting low carbon vehicle research, and also to maintain the UK's position in the global automotive industry as an R&D leader (NAIGT, 2009) (Ricardo UK, 2010). One implication clearly apparent already is that no one solution will achieve the necessary reductions, and a combination of many technologies will be needed; another is that many of the necessary technologies are not fully developed yet (RAE, 2010a).

One example is that of the large, long-lived, deep charging cycle propulsion batteries which are necessary for hybrid and electric vehicles, for energy storage and release. Although these batteries exist in vehicles now, they are not particularly energy-dense compared to ICEs and liquid fuels such as gasoline (MacLean and Lave, 2003), and they have to be very large to deliver the high flows of energy required to quickly accelerate and propel heavy conventional vehicles.

For all battery technologies to date, this leads to weight and performance tradeoffs (Smith, 2010), also implying that technology alone will not be sufficient to deliver the required reductions; vehicle configurations and weight must also be considered. Full battery electric vehicles (BEVs) are not so good at long distance high-speed travel, where their CO₂ benefits are reduced because the technology is not working at its optimum point (Smith, 2010), which means yet more technological development such as an extremely lightweight design is needed, to find a way around this problem. New niche vehicle makers such as Tesla (who make electric sports cars) are using batteries from other fields such as consumer electronics, adapted for automotive use; but mass-produced, large capacity durable EV batteries and EV designs suitable for all types of vehicle and all types of driving are not yet available (Bullis, 2010) (MacLean and Lave, 2003). Therefore the UK's Automotive Council, an industry and government joint body, includes battery development as one of its key pieces of required research on the industry's roadmap (Ricardo, 2010).

Another example of an undeveloped technology is the decarbonisation of exhaust gases. Unlike for a power station or other large facility which runs more steadily, it is not really feasible to capture the carbon in liquid fuels, when it emerges in CO₂ in the exhaust of vehicles. One way round this would be to convert various fuels to hydrogen (on or off-board) for use in fuel cells, where the carbon does not appear in the exhaust, only water vapour (MacLean and Lave, 2003). But this makes fuel cells less efficient and they are are still expensive; the jury is still out as to whether they always offer an emissions or cost advantage over their lifecycle, compared to more conventional vehicles (MacLean and Lave,
2003). Again more research and demonstration of fuel cell technology appears in the UK Automotive Council's roadmap (Ricardo, 2010).

There are multiple R&D strategies available to any company, assuming sufficient funding, but each company lacks the resource to develop every solution; nor would this be an efficient use of resources. And the future of sustainable mobility is likely to require changes not only to vehicles but to the infrastructure that serves them, the political frameworks surrounding them and to individuals' behaviour. This demonstrates a need for strategic co-ordination across the industry, and beyond, far exceeding anything previously attempted (RAE, 2010a). However, not all actions taken to reduce CO₂ seem to have the desired result.

2.4 The Rebound Effect and Price Signals

Previous reductions in CO₂ emissions per vehicle have been related directly to technical improvements in fuel efficiency, and have been swamped by the rebound effect. This is often attributed to the more efficient car being cheaper to drive, thus encouraging people to drive more (Druckman et al., 2010). However this seems a little too simple—few people actually calculate their driving cost per mile or rationally base decisions upon it (Lane and Potter, 2007). In one US study an active interest in fuel economy only seemed to occur when the cost of travel took up a larger than usual part of household income, through lower income or long journeys. The same study found that rising driving costs (in this case from fuel price changes) did not seem to make drivers change their travel behaviour or buy different vehicles, but that other complex values such as environmental concern did affect travel and buying behaviour (Turrentine and Kurani, 2007).

The upside of consumer irrationality about the cost of car use is that consumer opinion seems sensitive to changes in fuel price, although dissatisfaction with high fuel prices resulted mainly in anger at oil companies in Turrentine and Kurani's study (ibid). At the time of writing, the popular UK press is speculating on the economic effects of the high cost of fuel and calling for fuel duty cuts (Chapman, 2011). And yet at the current price of about £1.40 a litre, the cost of refuelling an average small car (40 litres for a Fiesta so £56 per tank, then used at an average of 35mpg) is still only directly comparable to the sunk cost of buying and running it in the first place, assuming an average mileage of 12,000 miles per year (AA, 2011a) and an original cost of about £10,000. The average owner spends £182 per month on fuel compared to £181 per month of "standing" running costs including purchase, finance, insurance etc (AA, 2011b).

Some sophisticated modelling by a European research team predicts that consumers would choose more efficient vehicles in a new purchase, particularly if there are market interventions to encourage this. As with the US study, data indicated the travel demand was
inelastic, not changing in response to higher fuel prices (de Haan et al., 2009). However this study was undertaken when fuel costs were still less than vehicle purchase costs. This offers some hope that further rises in fuel prices could provide a strong signal with consumers, as perceived in terms of refuelling costs, pushing them towards the adoption of more efficient vehicles. However this tends to get muddied somewhat by Government policy— for example the current UK proposal to buffer the consumer from the effects of oil price volatility (Chapman, 2011), and the tendency of consumers not to factor in all the costs properly (Lane and Potter, 2007). This and other consumer behaviours are discussed further in section 2.6.1

Whatever the cause, the rebound effect appears again and again as a result of setting sustainability targets, and must be accounted for in any plans for reducing CO2 emissions (Druckman et al., 2010). The industry therefore has to find extra solutions just to make sure the target reductions are achieved. It is also worth noting that the current emissions legislation focuses on the usage phase of vehicles only (European Parliament, 2009). While this is dominant for conventional Internal Combustion Engine (ICE)-based vehicles (Alonso et al., 2007) (Muñoz et al., 2006), it is likely for vehicles with large batteries such as hybrids, that the manufacturing life-cycle phase may become dominant (Zackrisson et al., 2010), and this must be carefully assessed to ensure savings in the use phase are not offset in the production phase.

For both technology and price reasons, it seems that the use of Lifecycle thinking will be key to achieving a true reduction of emissions, through both policy and behavioural changes, not simply changing when or where the emissions occur (Graedel and Allenby, 2010). An important example can be seen in Delucchi’s recent overview of biofuels research, which finds that biofuels are not automatically better than fossil fuels in terms of climate change; because their emissions are heavily dependent on the type of crop and growing regime, their processing and land use considerations (Delucchi, 2010).

### 2.5 Balancing CO2 and Other Emissions

For any technology based on combustion, there is a trade-off between CO2 and other tailpipe emissions, particularly NOx (Oxides of nitrogen). The RAE notes, for example, in a general response to a UK Government call for evidence, that reducing NOx frequently causes higher CO2 emissions (RAE, 2008). A slightly richer fuel-air mix is often used to cause a cooler combustion leading to lower NOx formation, but obviously as more fuel is burnt, more CO2 is formed and the engine efficiency is lowered. In order to reduce both emissions, other more high-tech solutions such as selective catalytic reduction (SCR) for NOx, or active DeNOx systems which inject fuel into the exhaust, are needed, which require extra equipment, and may use exotic materials or dangerous chemicals (urea in the case of...
SCR which has to be carried on the vehicle). These therefore tend to be far more expensive, heavier, less feasible for reasons of space or customer acceptance, and therefore involve other kinds of tradeoff (Stone, 1999).

At the moment there is separate legislation governing these two gases; NOx falls under the EU vehicle emissions standards (Europa, 2010) but CO₂ under the new fleet average regulation. As the legislation is not fully integrated, there can be a clash between the two aims, and this leads to industry complaints that achieving both is impossible.

For all technologies, not just combustion, there is also the problem of shifting emissions between lifecycle phases, and shifting from one kind of emission to another (Graedel and Allenby, 2010). For example, some form of tailpipe carbon-capture technology might be developed, which is suitable for ICE vehicles, but there will be associated emissions from its manufacture, and these must be carefully assessed against the gains in the later phases to ensure an overall benefit. And current diesel particulate traps, designed to stop small particles of soot from escaping from an LDV exhaust system, then burn off the accumulating soot periodically to clean the filter, creating gaseous CO₂. The emissions may require some kind of equivalency or prioritisation amongst different categories of environmental and other impacts, to enable an overall assessment of the new technology. This demonstrates a need for consistent sustainability methods and metrics to handle these types of tradeoffs.

There is however a rather more fundamental problem with cars and their design.

### 2.6 The Problem of Design Eco-Inefficiency

Despite the strategies and roadmaps to reduce emissions, there remains an underlying problem with the automobile as a design concept, as it currently exists. The first part of the problem is that the automobile has developed into a generalist device. As a rule, consumers buy one vehicle which must cope with any and every task thrown at it, from daily solo commuting to once-yearly holidays towing a large caravan whilst fully laden with family and luggage. This leads to it being massively over-equipped and over-engineered for the vast majority of tasks it actually performs during its life; and in some cases it will have functionality which may never even be needed; for example, if its owner lives in a congested, temperate city centre and works nearby they are unlikely to make many trips requiring the vehicle’s high-speed crash capability, or a four-wheel drive system. Occupancy is possibly the biggest example here, with 60% of UK car journeys being single-occupancy in 2009 (DfT, 2009b), rising to 85% for commuters (DfT, 2009c), yet the vast majority of cars are specified for 5 people or more.

This is quite apart from considerations of fashion, competitive consumption or perceptions of safety which can for example lead to the purchase of even larger vehicles...
such as SUVs, with even more equipment and larger engines. A good example of this was GM's Hummer, the mainstream version of a military vehicle designed for combat zones (di Stefano, 2010) - surely somewhat over-specified for most commutes and the school run. However that is an extreme example. This issue of overly large vehicles for the actual purpose of (mainly) transporting one person from A to B leads to the need for a vehicle of around 1300kg (based on the approximate average Focus kerb weight, (UKTow.com, 2011)), as a representative "average" car, to move a person weighing about 77kg in the UK (NHS, 2009). That means only roughly 5% of the energy expended is achieving the main purpose.

The other aspect of the problem arises from the inefficiencies inherent in conventional motor vehicles. Conventional vehicles use internal combustion engines (ICEs). A typical thermodynamic Carnot Cycle efficiency is that of the 1.6 gasoline engine used in the Ford Focus, at 32% (Helle-Lorentzen, 2007). This can be improved for example by a few percent using a very efficient engine; or using a diesel engine instead - at around 35% efficiency (MacLean and Lave, 2003) but much of the energy is lost as heat in the exhaust, with a smaller amount lost as heat to the vehicle, mainly coolant (Heywood, 1988).

Exploring this further and using data for a typical 1.6l gasoline Focus car, further losses occur at idle (about 8%), transmission and driveline losses (1.5%), alternator and accessory losses (3%) leaving only about 20% of the calorific value of energy from the fuel available for moving the vehicle. This is then used to overcome the aerodynamic drag and rolling resistance in the tyres which take perhaps another 11%, and finally, to provide the acceleration and braking with the remaining 9% of the energy (Helle-Lorentzen, 2007). Combining this result, with the over-specification weight ratio issue, shows us that we are only actually using about 1% of the fuel energy we put in for the original purpose - transporting a person (5% of 20%).

Whilst this is a simplistic analysis, and the exact figure will vary, it does indicate the size of the problem if only technological improvements to current car concepts are considered. It would be tempting to think that technology can solve everything; but in fact humanity cannot reach the reductions in environmental impacts needed without a serious rethink on what sustainable mobility really means. For example, fuel cells, which typically use hydrogen-based fuels in an electro-chemical reaction and do not emit CO₂, are not limited by thermodynamics of combustion and therefore are typically more efficient than gasoline ICEs (Hellgren, 2007). For example when used on cars Proton Exchange Membrane (PEM) fuel cells can be up to 50% efficient (Barbir and Gómez, 1997). But they often need to reform their hydrogen fuel from a liquid one, which reduces their efficiency (MacLean and Lave, 2003). Even when they can be designed to be more efficient than ICEs, this only offers an incremental improvement, not the orders of magnitude required, because the weight ratio issue still remains.
The concept of a Battery Electric Vehicle (BEV), also sometimes called a Zero Emissions Vehicle (ZEV), looks promising, but is misleading because usually some kind of fuel is still burnt at the power station (Graedel and Allenby, 2010); although they can at least double the eco-efficiency of the vehicle emissions, the supply grid has to be decarbonised to drastically reduce CO₂ emissions (Smith, 2010). And again the vehicle is still inefficient by definition, because the over-specification and weight ratio remains more or less the same.

Considering the near future, hybrid technologies also offer some improvement for ICE-based vehicles, by recovering some of the energy lost during driving, such as from braking. Typically a well-designed hybrid car with today’s technology would roughly double the CO₂ efficiency of the vehicle in use (Bickerstaffe and Scoltock, 2011). And yet, because the basic vehicle does not change, it still only achieves perhaps an extra one percent of total efficiency (2% versus 1%); that is, the total energy consumed as opposed to that achieving the fundamental purpose. Therefore it is necessary to deploy as many solutions as possible, including fundamental redesign (Lovins and Cramer, 2004) and demand reduction (WBCSD, 2009), together to dramatically reduce CO₂ emissions from transport.

Whether for the purposes of attempting to eliminate lifecycle emissions and thus Climate Change, or for energy efficiency in a future where cars are ultimately powered by scarce, expensive, and/or intermittent renewable energy sources, it seems that the concept of sustainable personal mobility for the majority will have to evolve significantly beyond the current automobile. This implies not just new technologies fitting into, or services built upon, the current product, but a much greater shift in the basic paradigm of personal mobility. Therefore new metrics and methods will be required to assess technologies and products against these new paradigms and their requirements.

2.7 Business Issues- Lock-in and Disruptive Technologies

As mass producers in mature core markets, the major automotive companies have become locked-in to their capital-intensive manufacturing facilities and proprietary technologies through a process of lean manufacture and optimisation against narrow margins. Their R&D processes are also typically optimised for an earlier era of slower, more evolutionary change (Christensen, 2010) (Orsato and Wells, 2007). The lean optimisation for a particular status quo can also leave companies vulnerable to sudden changes in their environment, hampering their ability to evolve or soak up shocks (Taleb et al., 2009).

Changes to products or market positions, including technology strategy, have very large associated costs, for example in development costs and for factories, which are difficult to fund in a low-profit environment (Wells, 2010). An engine factory is only really very good at making engines; anything else requires a refit, and it may be cheaper to simply start again somewhere else (Wells, 2009b).
This has led to path-dependent development of cars, with engines as the dominant form (Dijk and Yarime, 2010). Another interesting point is that a significant amount of technological development takes place in the suppliers rather than the OEMs, even for new EV and HEV variants (Dijk and Yarime, 2010). This might be related to the relative levels of profit available for reinvestment in R&D at the two levels. Suppliers are unlikely to limit access to their technology, as they tend to deal with quite a large cross-section of OEMs, and it is also unlikely that most OEMs could afford to pay for exclusive access to, say, a new battery technology. This could mean that any threat from competitors accessing new technology could come from several directions at once, and therefore it can be wise to be an early-adopter or fast follower, if not the first to market (Christensen, 1997). This might be why Ford was the third company to launch a hybrid vehicle, producing the hybrid Escape SUV in 2006, which uses parts of the Toyota hybrid powertrain, after Toyota's Prius and Honda's Insight were launched; meaning it is now perceived as pro-hybrid vehicles by industry analysts (Dijk and Yarime, 2010). However as Ford were buying their hybrid powertrain from elsewhere, it is worth noting that they did not acquire any in-house ability to make hybrid powertrains from this manoeuvre, so they remained locked-in to conventional engine plants.

There are other kinds of lock-in too. The practice of using standard accountancy tools such as Discounted Cash Flow also mitigates against change, by assuming that doing nothing does not eventually have a downside in reduced sales or revenues (unlikely in a competitive market). Sunk and fixed costs for current production machinery, for example, mean it is assumed to be useable in the future even where this may not be the case. This and too much emphasis on share price leads to a shorter time horizon in decision-making, meaning companies may stick with their current technology or processes for too long in the face of new competition and not optimise their longer-term costs. New companies should automatically pick a more optimal solution, because they have no already-existing brands or factories to distort their decisions (Christensen et al., 2008).

In the case of the various vehicle architectures required by the new vehicle types, there is also a lower-level decision which locks companies into a particular path of design and development. If alternative vehicles develop gradually from a conventional vehicle they will tend to use a similar set-up, with for example a propulsion unit such as a battery replacing or supplementing an engine. These power sources tend to interact with the gearbox or axles directly and in parallel, as in a Toyota Prius. This has the advantage of reusing facilities and designs which already exist; but when all-electric vehicles are needed this may not be the optimum arrangement. Designers working from scratch might choose to have several motors within the wheels themselves, giving more design flexibility, as with the Nissan Leaf, and this needs different production facilities and design concepts. There is an optimum point to change architecture which depends on the company’s approach to the
evolution of their vehicles, in order not to stay with a design and production system which starts to become a disadvantage. As different companies have varying opinions on the future prevalence of EVs and HEVs they are adopting different strategies; Asian OEMs are noticeably more keen on alternative vehicle architectures (Christensen, 2010).

Christensen also believes that standard management practices tend not to work when faced with "disruptive technology", which brings a new customer proposition and therefore opens up new markets or changes established ones. Disruptive technologies are typically new, lack data for making decisions, and are therefore considered riskier and difficult to predict, so even when they occur inside established companies, they are often sidelined or ignored. Also, importantly for large companies like most of the incumbent car OEMs, they initially are in new small markets, which do not offer enough growth for a big company, and can have a higher chance of failure. However although they tend to perform badly in traditional established markets, they usually develop to dominate the new market, and so incumbent firms can find themselves locked-out, or following too late to get the benefit (Christensen, 1997).

Christensen tested his theory by considering the battery electric vehicle (BEV), and concluded it would be a disruptive technology, because it shows most of the signals he claims are exhibited by disruptive technologies. It is simpler, potentially smaller, more reliable and convenient, and cheaper to run; lastly, although it has a poor conventional performance in areas such as range, these are improving steadily. Returning briefly to the discussion of fuel price in section 2.4, the cheaper running cost is important as it offsets the initial high purchase price; and he estimated that the BEV would be competitive with conventional vehicles by about 2015-2020 (Christensen, 1997). Later estimates which consider HEVs and BEVs have proposed competitive dates around 2020-2030, but note that this is heavily dependent on the trend in fossil fuel prices (MacLean and Lave, 2003).

A current example of disruptive technology (or at least disruptive competition) in emerging markets, could well be the launch of the Tata Nano. Tata as a domestic incumbent decided to tackle the problem of delivering an affordable, basic, robust vehicle suitable for the majority of Indian buyers, the "base of the pyramid" where there was an unsatisfied demand; cars were too expensive and most families used motorbikes instead, leading to terrible accidents. (The relative effect on total carbon emissions was not included in the decision process; it would be interesting to see what that is projected to be). This simplifying approach was used rather than following the usual approach of external OEMs who tend to sell relatively expensive, high specification vehicles based on their developed market offerings, which are only suitable and affordable for the richest customers. Tata has gradually worked its way down through the market levels for vehicles in India since starting domestic vehicle manufacture in 1969, and as a very wide-ranging company (it includes food and
textile divisions amongst others) it has a good insight into the differing needs of its customers (Ray and Kanta Ray, 2011).

Looking at Christensen’s original list of “signals” for disruptive technology, again the Nano is cheaper (half the price of the next vehicle up), simpler and more reliable (deliberately both to reduce initial costs and enable low cost maintenance), plus smaller and cheaper to run (designed for congested Indian cities with a very small engine). It has a lower performance than other products in the market but meets an unaddressed need. The design is also modular, so that versions with more features or higher performance can be built on the same platform for domestic markets or even export; the Nano can follow the developing market up from the bottom, and pose a threat to the more luxurious upper segments in future, disrupting their market. Another key point is that the distribution, assembly and maintenance arrangements are also novel, using networks of small operators despite targeted high volumes; moving away from the capital-intensive factories which cause traditional car manufacturers some of the structural issues described earlier.

Finally, Henderson observes that a company which is very expert in a particular area of business may fall into an organisational form of lock-in called a competency trap, where it is difficult to change the very things that make it competitive, and thus senior management may decide it would be too difficult and costly to make such a change. They may also underestimate any new, or especially disruptive technology by missing a subtle change in consumer needs in their own market, or see the effort as too expensive to move a significant distance from their core business and develop a new market. The necessity of focussing on their major customers may also blind executives to other opportunities which arise, or may mean resources stay assigned to current business (Henderson, 2006).

The home markets of Western automotive companies are already mature and have overcapacity leading to fierce competition on price (Wells, 2010), which could also mark a product which is over-performing compared to market demand, and is therefore ripe for the emergence of disruptive technologies (Christensen, 2010). Arguably this has been the case for some time, but the results of this and the recent global recession have not yet fully played out (Wells, 2009a). Either way the sudden multiplication of technologies on offer, being driven by CO₂ emissions legislation and perhaps the prospect of Peak Oil, means that the chance of disruption happening in the mainstream car markets must be rather higher than before. Incumbent companies in particular need to be able to cope with disruption and other crises- or better yet, benefit from it by changing if necessary, by being resilient (Hamel and Välikangas, 2003).
2.8 Shrinking and Changing Markets

On top of all the other issues come the predictions that sustainable transport for developed nations such as the UK will likely have to involve a reduction in car use (WBCSD, 2004) (DfT, 2009a), and therefore presumably a reduction in car ownership and sales. Automotive as an industry relies on perpetual growth to overcome its structural issues (Wells, 2009b), and has until recently assumed that the next phase of growth would come from developing nations, mainly in Asia, and that any fall in developed markets would not be significant enough to outstrip developing market growth.

Therefore the possibility that these new markets will simply bypass the love-affair with the automobile enacted by the West, for sustainable development reasons (IGES, 2010) and also resource scarcity reasons such as Peak Oil, constitutes a major problem, because although the global market for traditional cars may grow, it will not reach the same levels of ownership as in the West and is unlikely to grow as fast as predicted. For example Beijing city administrations in China have both recently introduced tight limits to the number of new registrations allowed per year in their city, and times when non-local drivers are allowed on the city's roads, in order to limit pollution and traffic (Demick, 2011). Shanghai has had limited registrations since 1994 and uses the funds thus raised to develop public transport systems; Delhi introduced congestion zone charging recently (Garside, 2011).

The same set of underlying issues is causing a move away from cars in both developed and developing urban markets. The IGES report on sustainable production and consumption in Asia identifies four main megatrends (IGES, 2010 Executive Summary, page xvi):

- **Globalisation**

  This is mainly about the fast growth of Asian economies, in particular China and India, as they become the dominant production centres globally, with their concomitant increases in emissions, pollution and resource use.

- **Urbanisation**

  The population of Asia is still dramatically increasing and is quickly moving into very densely populated cities, for example meaning about 55% of the population will be in cities by 2030 and regional demand for energy will grow by an estimated 45% by 2030, from 2006 levels.
• **Lifestyle aspirations**

The emerging middle class in Asia currently aspires to a Western style of consumption, from vehicles to wine, as historical and cultural patterns are influenced by the consumer culture of developed nations. This is not sustainable in terms of resource use.

• **Resource constraints**

Various issues including land use are reported, and the three of nine main planetary biophysical boundaries which have been compromised, due to humanity's dominance as a species in the planetary ecosystem. To avoid irreversible changes to the atmosphere and climate a change of consumption and production practices is needed.

In terms of the response to these trends, IGES recommends reducing energy consumption in transport, through reducing unnecessary travel, shifting towards mass transport and improving energy intensity (mainly via fuel efficiency standards). This is potentially easier in Asian cities, as they tend to be far more dense than those in the West, and the report suggests "leapfrogging" Western development by using new technology and transport trends. Singapore is cited as a model example with a mass transit system serving high proportions of the population, and relatively low car ownership at 1 in 10 people (IGES, 2010, Executive Summary, page xxi).

The high-consumption, unsustainable Western lifestyle is already a reality in most developed countries (Abdallah et al., 2009). The issues of globalisation, urbanisation and resource constraints are global in any case; thus it can truly be said that these four issues apply in all regions, if at different intensities.

This year these "megatrends" have become visible in the industry's mainstream, with OEM officers in trade magazines discussing the need for new business models and forms of personal transport to deliver sustainable mobility (Bickerstaffe and Scocoltock, 2011). In February BMW launched a new sustainability "sub-brand" for electric and hybrid vehicles, BMW i, to explore and develop this area (Reed, 2011). Even Ford, not renowned as the greenest of car companies, are exploring different technologies and ideas. In a January interview and again in March, Bill Ford, the current family head of Ford Motor Company, discussed how "global gridlock" might cause issues for the business as well as individual citizens, stopping the flow of foods and medicines but also rendering cars useless for their main purpose, transportation. He suggests new technology will be needed, but also asks how in dense future cities, where people may have no car at all, Ford can offer them a useful service or product (Ball, 2011) (Woodall and Krolicki, 2011). This all seems to indicate a
serious reconsideration of what it is that current car companies might be doing in the next few decades; and confirms that these trends are considered real and important by the industry.

2.8.1 Interaction With the Consumer

Ford's business model is currently focussed on the individual sales transaction, when a consumer buys a new car from one of their dealerships. Interactions with fleet buyers are similar although they involve more vehicles. All other market influences are interpreted through this lens. Ford must currently sell high volumes of correctly-priced mass-produced cars in order to make any profit, so it is worth spending a moment to consider this dependency on consumer buying decisions, in the light of alternative offerings.

As discussed earlier, the large-scale adoption of EVs and HEVs is of importance to governments for climate change policy delivery, and to mass-market car manufacturers as it defines the business case for these products and informs the manufacturers' market and technology strategy. Surely then, in developed countries at least, OEMs could begin to manufacture alternative vehicles and they would be adopted by the consumers?

There has been much research attempting to predict how much more, and when, consumers would pay for alternative powertrain vehicles (or indeed whether they were willing to pay more or can be influenced to by fiscal policies). For example there was a detailed analysis resulting in a prediction of reasonable market take-up (roughly 14% of Canadian volumes) of electric vehicles even with a purchase price differential of around 20% (Ewing and Sarigöllü, 1998). This particular research also captured that price, along with concerns about technological capability, appeared to form the main drivers of consumer choice (Ewing and Sarigöllü, 1998).

According to more recent European research the proportion of the population actually buying greener products or altering their behaviour is only 17%, as opposed to 75% who indicated they would do this despite added cost (EC, 2008). Recent research on consumer preferences in the Netherlands by van Rijnsoever et al., similarly found that although 66% of the sample population expressed a "positive attitude to the environment" only 11.5% of this subgroup matched this with real-life reported behaviour (van Rijnsoever et al., 2009).

This ratio demonstrates the well-known attitude-action gap between consumer attitudes and behaviour. This extends to passenger vehicles, in that volumes of consumers purchasing “green” models has not fulfilled the predictions of earlier studies. EVs and HEVs have a low but increasing market penetration. The SMMT forecast a total UK volume of approximately 2 million vehicles for 2010. They recorded up to the end of November 2010 that Alternatively Fuelled Vehicles (AFVs) accounted for only 1.1% of these UK sales, growing by 55.6% compared with September 2009 (SMMT, 2010a). In this case the category
"AFVs" includes conventional vehicles using alternative liquid fuels such as bio-ethanol or Liquid Petroleum Gas as well as EVs and HEVs; the volume of hybrid or full electric vehicles is even lower.

One possible reason for this behaviour gap is that research on hypothetical decisions can produce results different from real-life situations, because different behaviours may be activated in the consumer in each case (Teisl et al., 2008). Another reason for lower than predicted adoption is that in the case of technological innovation and diffusion, new products are not adopted by the all the market segments. Rejection by consumers is a result of complex interactions between prior and new experiences and knowledge, and underlying values, for example levels of environmental concern (Coad et al., 2009). This renders prediction and influencing of consumer take-up of new products such as cleaner cars more difficult than attitude surveys indicate.

The low volume of EV and HEV sales indicates that these products are still at the first-stage or "niche" phase of innovation adoption according to Coad (ibid), covering innovators and early adopters. They are not yet taken up by any sectors of the mass market. In this initial phase, environmental buying behaviour is promoted by the provision of further information; in the second phase financial incentives work better, although education still helps. Figure 5 shows this market segmentation in graphical form (ibid). Sales of low carbon vehicles could rise significantly before they enter the mass market phase; therefore both segments are of interest when addressing barriers to mass adoption.

As Bill Ford puts it in a recent interview (Ball, 2011):

"When it came to cars, people wanted everybody else to be an environmentalist, but they wanted to drive what they wanted to drive."

Commonly cited aspects of the purchase decision which are believed to underlie the attitude-action gap concern the (normally low) level of awareness of the true financial cost and environmental impact of cars and their use (Lane and Potter, 2007), and the effects of prior experience and beliefs on the consumer's ability to correctly interpret information at the decision point (Teisl et al., 2008).
Figure 5 - A sketch of the dynamic process of the adoption of clean technologies\(^2\)

In this instance EV and HEV sales, at less than 1\% of UK vehicle sales, lie in the left hand end of the curve in the “innovators” segment. The mass-market segment for automotive manufacturers is typically considered to be the early and late majority segments in the middle. The height of grey areas corresponds to the rate of takeup of a new product by each market group, in the author’s opinion.

Although graded eco-labels such as those used for white goods and now cars in the UK (LowCVP, 2010) can be shown to improve market response (Bleda and Valente, 2009), this addresses neither the issues around improving understanding of environmental issues and the level of involvement, nor true cost awareness and enabling more accurate use of information by addressing misconceptions (i.e., prior beliefs) \textit{before} the purchase. Eco-labelling has sometimes been seen to have little effect or none, depending how and where it is used, and this finding persists even when the eco-product is functionally the same as less green competitors (Bleda and Valente, 2009). Consumers have also exhibited a poor understanding of the costs or effects of their own driving in surveys (Lane and Potter, 2007).

\(^2\) Taken from Coad et al., (2009, p2081)
Provision of cost information (simply calculated from an individual's fuel use) and driving feedback can correct misunderstandings (especially if the individual's data is compared to the general population of drivers and/or vehicles). Together these effects can overcome some of the attitudinal barriers to adoption (Lane and Potter, 2007) (Teisl et al., 2008). Such feedback could also assist with the feeling of ownership or agency, increasing the consumer's sense that they themselves can have a positive effect, leading to an increase in eco-behaviour (EC, 2008).

Returning for a moment to the idea of lock-in, it seems that most consumers in developed countries are mentally "locked-in" to one particular concept of personal mobility, in the form of the conventional car. Moreover, car purchase is so tied up in other intangible and even unconscious considerations such as social participation, aspiration, and identity, that trying to pick out purchase (or non-purchase) reasons in a rational way is like trying to see the back of your own head. It could well be, given Christensen's model of mature markets (Christensen, 1997), that if cars as a product are overperforming, adding "greenness" is just another feature that the customers have not felt it important enough to pay for, despite socially desirable responses in surveys.

At the recent rates of uptake it does not seem likely that spontaneous consumer adoption of HEVs and EVs could deliver any of the European emissions reductions targets; indeed both the RAE and UK Government have already concluded this, as discussed in section 2.2 and propose other actions including policy changes (RAE, 2010a) (RAE, 2011) (DfT, 2009a). But one side effect of Peak Oil and political instability in oil-producing regions can certainly increase the speed of adoption: the rising price of oil. Back to Bill Ford again:

"As soon as their economic interest started to align with that- i.e. fuel prices going up-then you started to see real alignment between what people are saying and what they actually do." (Ball, 2011)

It seems that new innovative vehicles need to reach a certain critical mass in order to survive. Dijk et al. predict that HEVs may manage this where earlier BEVs stalled, by partially addressing issues of higher price and lower range, but comment that predicting the interaction of emerging niches with dominant market paradigms is very hard; another sign of a disruptive new technology (Dijk and Yarime, 2010).

Evidently major social change is needed as well as technological innovation, to reach the holy grail of sustainable mobility. Together with the eternal migration of manufacturing to cheaper countries in developing regions (Wells, 2009b), the emergence of different business models for vehicle manufacturing and interaction (Lovins and Cramer, 2004) (Woodall and Krolicki, 2011), of multiple new disruptive technologies (Christensen, 2010), and disruptive competition from local incumbents in the new markets such as Tata in India (Ray and Kanta
Ray, 2011), this kind of change will intensify the need for risk-spreading strategies (Wells, 2009b) and innovative responses.

The industry's view of the challenges facing it is surprisingly consistent: that a combination of sustainability pressures on automotive vehicles, of demographic changes in where and how people live, and how they relate to personal mobility, forms a set of megatrends which will drive a great deal of change in the industry and the markets it serves in the next few decades. What each incumbent carmaker (and the new players) then chooses to do in response to this is different according to their strategic stance, but the underlying consensus is similar from all sides.

2.9 Cultural Change

Finally, an understanding of culture change may be important for two reasons within this research. Firstly, theories about consumer culture may shed light on why consumers seem reluctant to adopt "green" products, as discussed in the previous section, and how this might be addressed. Considering this area might also provide insights into how consumer culture might change as a result of the "megatrends" in the future. Secondly, in order to enable the acceptance and useability of any research results by the sponsor, it is necessary both to understand the sponsor's currently prevailing culture, and assess where this culture may shift towards over time (especially if a high degree of change and possibly resulting stress are both present). This will allow both effective communication of the research by the RE and in the opposite direction, a better understanding of the needs of the sponsor.

There has been little opportunity to explore this area within the research so far. However, a number of useful concepts have been identified during background reading for modules. For example, there are some general observations on the difficulty of affecting consumer and business behaviours from two key writers. Jackson (2009) notes that although the recent global recession and credit-crunch offered some opportunities for change, the immediate priority to stabilise the global financial system has meant the propping up then continuation of business-as-usual capitalism, including a return to a political focus on economic growth. He and Porritt (Porritt, 2007) also note that capitalism tends to self-reinforce, encouraging citizens to keep spending and consuming to keep the system stable and growing, and that this makes it extremely difficult to change away from this system for individuals; not least because they may have to give up participating in mainstream culture.

In terms of affecting behaviour by consumers, Earls (2007) posits that they have to be approached as groups via influential individuals rather than persuaded individually, because we are not actually rational actors, but social apes, and thus instinctive “herd” beings. This might explain some of the attitude action gap (EC, 2008), if everyone around an
individual is following status-quo behaviour. Earls' approach is based on recent developments in neuroscience, psychology, and marketing theory and may provide further options for changing consumers into sustainable citizens. In particular he develops the idea of sudden, non-linear behavioural phase transitions from earlier writers such as Ball and Gladwell, and expands on how to bring them about through social interactions of socially-influential (as opposed to materially influential) individuals. Recent psychological and neurobiological research indicates that as a social ape we have evolved to be hyper-aware of threats and this makes us more prone to seeing the downside of situations, and therefore more conservative about change. So, a positive goal is needed to counteract this natural tendency when attempting to change human behaviour (Earls, 2007). Many change approaches aimed at organisations and individuals use a positive vision which acts as a desirable goal; but they also use techniques aimed at causing values- and therefore behavioural change (Hopkins, 2008) (Ostrom, 2010). Earls discusses the mechanisms of influence but still does not go into exactly how the values of one person get transferred to another (Earls, 2007).

The most useful theory for values-change covered so far in this area of background reading for this project, is memetics, the study of memes:

"Meme: A cultural element or behavioural trait whose transmission and consequent persistence in a population, although occurring by non-genetic means (esp. imitation), is considered as analogous to the inheritance of a gene."

Oxford English Dictionary Online

Meme theory offers an explanation for human culture (such as consumerism) in which ideas and behaviours are passed from one person to another by imitation; for example from parent to child, or from adult to adult. Memes are self-replicating and can be viral especially in today's hyper-connected information society. Different memes compete and suffer a form of natural selection (Rose, 1998). Consumer capitalism can be seen as a set of particularly successful and dominant memes; affecting which motivators people choose to value, for example favouring status competition over belonging and co-operation (Murtaza, 2011). Memes do not have to be logical or assist survival. There is debate over whether humans (as products of memes themselves) can consciously select a new meme to use. Rose was very unconvinced but mentions Dawkins as a supporter of this idea (Rose, 1998).

Combining meme theory with mass-behaviour theories offers the possibility that influential people can spread values such as sustainability. Earls (2007) gives the Join-Me movement as an example of positive culture spread virally through social influence (a group of random UK citizens committed to “acts of random kindness”). The Transition movement is
another one of these positive memes, spreading quickly across the globe, and attracting regional and local organisations such as county councils as well as individuals (Hopkins, 2008). In 2009 Costa Rica topped the 2009 Happy Planet Index survey and balances contentment and sustainability rather better than many richer economies. Here the local cultural value of "pura vida" (Abdallah et al., 2009) may enable the more widespread adoption of sustainable behaviours because it is a similar cultural meme.

On a more general note, the cultural values of individuals also will be important as they inform the decision made by the officers of the sponsor company. It would be useful to find out whether affecting the values of individuals without necessarily changing the corporate culture at the same time, leads to different business decisions; also whether there is a consensus on the cause of behavioural phase transitions, and more literature searching might be useful on this topic. Please see section 5 for further details of planned future research.

Now that the project background, the automotive industry and the consumers it serves, has been described, it is time to consider the content of the research project.

3 Defining the Ford Project Objectives

The challenge for this research project is to examine how an established company can best deploy limited R&D resources to adapt to all of these challenges, whilst continuing as a sustainable company in the full sense of the term. During the first six months of the project its objectives have been given an initial level of definition.

3.1 The Project Goal- Enhanced Resilience

The objectives were derived by considering the original intent of the project, which is to enhance the resilience of Ford as an organization. This does not mean remaining unchanged despite external pressures, but is used in the sense employed by Hamel and Välikangas (2003) and the Transition Movement (Hopkins, 2008), of the ability to absorb shocks, e.g. from peak oil, economic disturbances or rapid market changes, whilst changing as necessary, e.g. by developing new services, goods or business models. It is about proactive adaptability and continuation, and therefore, in a time of "eco-austerity", as Wells puts it (2010), about sustainable business in the widest sense. It is possible to be environmentally sustainable without being resilient (Hopkins, 2008). Traditional car companies might eventually go out of business, due to environmental or economic pressures alone. So, if such a company wants a long-term future, it is necessary to consider not only the sustainability of its operations and products, but also the need for resilience to meet unforeseen future events.
The objectives shown in Figure 6 were developed between the project sponsoring department Sustainability Planning, the RE, and other teams working on product strategy. The objectives therefore reflect that the sponsoring department's remit is to provide solutions to meet issues connected with sustainability in the future, and other teams garner information during their work on future scenarios, which they use to develop new products and strategies. The objectives are also reacting to the three megatrends independently identified by Ford as key for future sustainable mobility.

Figure 6 is focussed around a simplified view of the interaction between the company and its customers- traditionally via the sale and later servicing of new vehicles. Other business models already exist (Ford themselves lease their cars to some consumers) and new ones will also develop as a result of new technology which changes the economics of the business case; or as a result of the megatrends influencing how the consumers interact with vehicles, for example through the paradigm of access and not ownership. It is illustrating the fact that there will be a range of possible solutions, not all of which the company can afford to develop. Therefore the company must select a set of solutions to develop in such a way, as to manage its risk exposure, balancing risk reduction with exploration of new high-potential technologies or business models in an appropriate way. The solution pool shown on the left in this case shows the example of different vehicle types which could be selected, and which therefore affect market and technology strategies.
The Sustainable Mobility EngD project will:
1) Support the analysis of longer term future scenarios
2) Propose supplementary metrics for evaluating new technologies, products, and services for sustainability

Figure 6 - Ford EngD Project Objectives and Context (Skipp, 2011)

The issues identified when scoping the project are generic to the whole vehicle and to the whole range of Ford businesses. For example potential changes in the interaction between the consumer and the vehicle – from ownership to leasing, or even merely access arrangements to "sustainable mobility" via a third party- affect not only Ford Motor Company the vehicle manufacturer, but Ford Credit the financial service provider and leasing agent, and Ford Dealerships and Service centres who sell and maintain vehicles. The literature relevant to each objective is considered in the next two sections.

3.2 Objective 1 – Support Analysis of Future Scenarios

One major requirement is for this project to add a wider consideration of sustainable development to any work with future scenarios by Ford. Sustainability in commercial conversations classically refers to economics alone (Taplin and Aeron-Thomas, 2005), and despite the gradual broadening of perspectives, this element still tends to take precedence, certainly in the automotive industry (Wells, 2010). Then again, arguably if a company cannot make a profit, it will not be able to even begin being sustainable in other ways. This does not necessarily have to be a tradeoff of different types of cost, for example environmental
against product performance (Lovins and Cramer, 2004): according to some writers sustainability tools can offer alternative ideas for profitable products or services, and enhance an organisation’s general performance by, for example, eliminating wastes (Graedel and Allenby, 2010) (Finnveden et al., 2009). In the next phase of research, evidence for this kind of benefit from using sustainability tools will be sought.

Life Cycle approaches allow investigation of future consequences of current design choices and new products or services (Pennington et al., 2004) (Rebitzer et al., 2004), but work best when based on current or near-future practices with good quality data (Nieuwenhuis and Wells, 2003) where changes are relatively small (Ehrenfeld, 2003). The tools can also be very sensitive to the boundaries and assumptions chosen (Lee et al., 1995) and this means they can be strongly affected by assumptions about future scenarios. Höjer et al. noted in 2007 that analytical tools such as Life Cycle Analysis and Life Cycle Costing may be problematic when working with future scenarios due to their need for data. This would especially be the case with large changes such as in “transformative normative” studies, for example analysing how to achieve the large carbon emissions reductions necessary to meet 2050 targets. They call for further work and the development of new approaches combining both qualitative and quantitative methods in developing scenarios, to address this. They also suggest the development of a set of generic scenarios for use by analysts to avoid creating scenarios for every study, and therefore to reduce the resource-intensity of these new methods (Höjer et al., 2008). Spielmann also suggests using generic scenarios and demonstrates the Formative Scenario Analysis technique, using software applications, to compare different transport options (Spielmann et al., 2005).

The creation of scenarios within Ford does not appear to follow such a formal process. The high level strategic analysis and decision making part of the process may lie outside the scope of this work; however the scenarios which influence lower level product and technology decisions need to be understood, and more research within the organisation is required to do this. A further literature search will be done to look at how future scenarios can be used with sustainability tools, and how risk and uncertainty are handled. The use of scenario techniques in business strategy planning is fairly recent (Bradfield et al., 2005) and it is necessary to gain an understanding the links and consistency (or otherwise) of this compared to generation or analysis of scenarios within sustainability methods. As the scenarios to be considered are likely to be antagonistic to the current business model of Ford, this will probably cause conflict and controversy, and may result in strategic inertia, as noted by Wright et al. (Wright et al., 2008). It is therefore important to consider how organisations react to this kind of analysis, and how a successful use might be made of it. More research will be done on the literature in both areas.
3.3 Objective 2 – Establish Assessment Methods and Metrics

Ford already uses a number of standard industry metrics for decision-making, both quantitative such as cost, weight, or quality, and qualitative such as customer satisfaction or "driveability". A newer addition is the metric of predicted grams of CO$_2$ per km for a vehicle under development. These metrics are reviewed at gateways within the GPDS or earlier GTDS processes, and can be used both to track the status of a program against its targets, and to decide between design alternatives. The decisions are multi-criteria in that they require the balancing of many variables and targets, some of which may conflict; for example high performance usually requires more costly designs. There is no particular formal method for making these decisions; rather it is down to the contributing function managers (such as engine design or manufacturing) and the senior management responsible for various aspects of the program (such as Finance or Quality) to reach a negotiated agreement. They are held responsible for meeting targets for each program which are presumably informed by product strategy decisions. This method and set of metrics is generic to all projects within GTDS and GPDS, although different emphasis may be placed on the metrics or their targets according to the type of program.

Ford does also make use of a sustainability tool called the Product Sustainability Index, which uses some extra sustainability-oriented metrics in the earlier phases of product development. The use of these has previously been confined to major change programs, for example the development of a new car in a particular size and weight class (platform), and is not present in all parts of the company. It is currently used in European Vehicle programs only and for example is not used within sub-divisions such as Powertrain or Chassis. This tool is described in more detail in section 4.1 from published papers. However more research is needed into exactly how it is used within the company, how early in the various processes it occurs, and how much effect it has on the design outcomes, for example.

As this research is focused more on strategic decisions, which usually have a longer time-horizon than immediate product development ones, this tool, which is based on Life Cycle methods, may not be suitable for simple expansion or supplementing for this use; for reasons as noted in the previous section. It might however be possible to incorporate a new method for dealing with future scenarios and uncertainty, if a suitable one has been developed, or it may be necessary to find another kind of tool for strategic decision support. It could be an advantage to be able to use PSI as a basis for further work as it was internally-developed, and is integrated within the company, therefore already familiar to those needing to use it. The feasibility of this will become more clear over the next few months of research. Further research will be done into suitable methods and metrics.
The next section explores the use of sustainability tools and metrics within the automotive industry generally, and then goes on to describe the Ford PSI tool, and other sustainability metrics they already use, in more detail. It then considers other kinds of metric which might support decision-makers in search of resilient strategy, and briefly how the research results might be incorporated into Ford.

4 Sustainability Tools and Metrics in the Automotive Industry

The development of sustainability approaches, especially those of Life Cycle Thinking, has often involved the automotive industry and even resulted in industry-specific guidelines such as those enshrined in EUCAR (Ridge, 1998). Being large, complex, commonly-used products which pollute also makes cars in particular an obvious subject for analysis (Graedel and Allenby, 2010). The car, with over 20,000 component parts is in fact one of the most complex mass-produced consumer products (Ochsner, 2000) and therefore any tools used to look at improving car design must cope with this complexity.

Sustainability tools such as Life Cycle Management ones are designed to cope with both this and the complexities of environmental impacts (Baumann and Tillman, 2004) (Graedel and Allenby, 2010). However as the automotive industry is so unprofitable and cost-sensitive (Wells, 2010) (Christensen, 2010), full versions of sustainability tools tend not to be used as they are considered too costly in terms of resource and require expert input to be interpreted (Nieuwenhuis and Wells, 2003) (Graedel and Allenby, 2010).

Life Cycle Thinking is the main way a systems approach to environmental problems and solutions is achieved (Lifset, 2006) (Guinee, 2002). It is key in order to avoid today's solution creating tomorrow's problem, in that it considers all life cycle stages (Graedel and Allenby, 2010). Although the tools can be complex and resource-intensive with informed use they can offer a rewarding insight into where environmental impacts and solutions truly lie (Baumann and Tillman, 2004), and can offer guidance on both risks and new opportunities for companies (Graedel and Allenby, 2010).

Ford's own experts have previously acknowledged the need for Life Cycle tools to allow companies to incorporate sustainability in their decision-making (Schmidt and Butt, 2006), and decarbonise Western consumption (Schmidt, 2001). The IGES report for example suggests the tools are vital to identify the most sustainable options for mobility, this enabling people to make informed decisions and not delay due to lack of information (IGES, 2010). The tools can also help a company learn about where its product impacts arise, and which it can best affect; to develop defensible environmental information about their activities and products (Baumann and Tillman, 2004) and to make a more persuasive case to policymakers (Berkhout and Howes, 1997) (Baumann and Tillman, 2004).
Life Cycle Analysis (LCA) is the most common method used to assess environmental impacts, and analyse the best ways to improve product impacts (Guinee, 2002). It is a key method for comparing the impact of various options, or establishing and improving the impact attributes of a product lifecycle, especially when considering different stages in the product life (Pennington et al., 2004). It is best deployed early in the development of a product so the results can be incorporated into the design (Rebitzer et al., 2004) (Graedel and Allenby, 2010). It can be a lengthy and expensive exercise, but with expert help can be streamlined or simplified to render it suitable for commercial use (Baumann and Tillman, 2004) (de Haes et al., 2004).

Life Cycle Costing (LCC) is another key tool which allows organisations to best balance environmental and economic requirements, by including the costs of emissions and other impacts during all the lifecycle phases. It is not as well-developed as LCA and therefore more difficult to include in development decision-making, especially when trying to give direction to design decisions (Schmidt, 2003).

Other tools exist under the umbrella of Design for the Environment (DfE) or more recently, Design for Sustainability (DfS) (Schmidt, 2001) but LCA and LCC are the most well known, and the most familiar to the automotive industry. Where there are experts they tend to be few and have other additional responsibilities (Berkhout, 1996) (Graedel and Allenby, 2010), requiring the recruitment of other resources such as academia and the supply chain (Alonso et al., 2007), and even competitors (Schmidt et al., 2004). Most published work seems to originate within academia or government bodies, such as those compared by MacLean and Lave (2003), where there is more resource (and possibly interest) for carrying out full-scale studies. Streamlining or simplifying the tools is another way to make them useable by industry (Baumann and Tillman, 2004).

Ford in the US experimented at one point with a simplified tool called "Modified LCA" but did not adopt this long-term (Sullivan et al., 1998). More recently Ford of Europe has developed a simplified Lifecycle tool, the Product Sustainability Index (PSI), based on primarily LCA, supported by Life Cycle Costing (LCC) and Cost of Ownership (COO) (Schmidt and Taylor, 2006). Although claimed to be the first tool of its type (Schmidt and Taylor, 2006) there was a similar tool developed at Saturn (GM) called Life Cycle Design (Ochsner, 2000). The Saturn tool appears to contain a more detailed version of LCA and costing methods which may have made it unwieldy, but it appears to be less complete than Ford PSI in terms of full spectrum sustainability, as PSI does also cover some arguably social impacts such as noise and safety. Toyota also have a Life Cycle tool although this was aimed only at packaging decisions; their Environmental Packaging Impact Calculator (EPIC) (Early et al., 2009). Like the Ford tool, this limits the freedom of users but is underpinned with carefully chosen data, to produce timely consistent and accurate results.
It is difficult to tell exact dates and content, as the companies frequently delay publication and deliberately omit details due to concerns about commercial advantage. There may be other similar tools in use within the industry, but either they are not published in the literature searched so far, or they do not mention LCA as a key technique.

4.1 The Ford Product Sustainability Index (PSI)

Ford's PSI uses a simplified toolbox approach, containing 5 environmental, 2 social and 1 fiscal indicators; the data are derived, as mentioned, from underpinning LCA, LCC and COO work, combined with information produced normally by the company during new vehicle projects. Tool use is triggered by a large-enough level of design change to provide meaningful results (Schmidt and Butt, 2006). A spreadsheet allows non-expert engineers, minimally trained in lifecycle tools, to calculate the indicators for closely-related design alternatives. (Typically one design would be assumed in any reporting-out). These eight indicators represent the most critical impact categories directly affected by Vehicle Product Development, so that any improvement efforts are focussed to maximise effectiveness (Schmidt and Taylor, 2006). This increases ownership by decision makers, key in large organisations where this can be dissipated (Wells, 2010).

The results of an LCA can be confusing to non-experts if not interpreted for them. However although some writers believe LCA results can be extended to include social and fiscal costs (Finnveden et al., 2009), interpretation such as classifying impacts, weighting them or converting them into one equivalent unit, introduces subjectivity and decreases transparency (Graedel and Allenby, 2010) (Baumann and Tillman, 2004). Different Lifecycle tools can also give conflicting direction for decisions- such as a study of electrical parts by Ford and their supply chain where LCA and LCC indicated different optimal designs (Alonso et al., 2007). Ford chose to avoid these issues of over-interpretation and equivalence by leaving the outputs of their PSI tool in eight separate category impact units (Schmidt and Taylor, 2006). The outputs of, for example, the Life Cycle Impact Analysis are grouped according to ISO 14040 into only a few categories, of which only Global Warming Potential and Photochemical Ozone Creation Potential are then used (called Lifecycle Global Warming and Lifecycle Air Quality in the PSI report). These are chosen as being the dominant impacts for Ford's vehicles (Schmidt and Butt, 2006).

The indicators derived are tracked through the early stages of major vehicle projects when design decisions are still being made, and are integrated into Ford's normal multicriteria decision making processes along with many others (Schmidt and Butt, 2006) (Schmidt and Taylor, 2006). It is not clear in the published papers whether targets are set for the indicators, but the output of the tool (see the figure on the next page) implies that they are compared to an estimated best-in-class for similar vehicles. The new vehicle is also
compared to previous versions, to show improvement (FMC, 2009b). As such the indicators do not recommend any particular course of action to the decision-makers but provide extra information. They are presented in a decision-wheel format; see Figure 7.

It is not yet clear to the author how much effect use of this tool has on technical decisions within Ford's product development processes, as this is not made explicit within the published papers. Taking the recent new-model Fiesta, the two most noticeable improvements of the new models over the old concern an increased ENCAP safety rating and the introduction of a TUV-tested allergy-friendly interior (FMC, 2009b). These changes could easily have been driven by customer demand or competitor position.

The tool was designed using an independently verified LCA, performed to ISO 14040, which was in turn used to verify the tool's results. The tool is based on current vehicle design and business models, as cars and the companies that make them change relatively slowly. It also uses the results of LCC and COO work carried out alongside the initial LCA, although obviously users must enter cost data particular to their project. This does mean however that good quality data is available when using the tool. It is complementary to tools and techniques already used by the company- for example there are separate indicators for safety, fuel consumption and tailpipe emissions which all have legislative requirements upon them (Schmidt and Butt, 2006).

PSI was developed internally by Dr Wulf-Peter Schmidt at Ford in Niehl, Germany. Dr Schmidt is a well-respected sustainability expert within the industry, having been involved in several key projects such as the LIRECAR lightweighting study, (Schmidt et al., 2004) and has also helped write one of the key academic references on Life Cycle Analysis (Rebitzer et al., 2004). He is one of the key potential stakeholders in the project as he is part of the same sustainability function (Sustainability Planning) as the project's sponsoring department, Powertrain Sustainability.

The PSI tool may provide a starting point for further work, and shows that sustainability methods can be made suitable for use within an automotive company such as Ford. However it is mainly concerned with the effects of small design changes based in today's technology. Each time a moderately new vehicle design is considered, the spreadsheet tool which represents the set of basic assumptions, has to be redeveloped. For example there is currently an internal LCA study underway, assessing the data for an number of alternative powertrain designs such as hybrid and electric vehicles. This is needed because the impacts of these propulsion technologies, and which phase they occur in, can be very different from that of a conventional vehicle. As a result different indicators might be selected for the PSI tool for these vehicles.

An example of the different environmental impacts of alternative vehicles is that, whereas a conventional vehicle produces most of its impacts in use (Muñoz et al., 2006)
(Alonso et al., 2007), and the least impact during recycling (Schmidt et al., 2004) (Alonso et al., 2007). By way of contrast, although a BEV has zero tailpipe emissions and therefore drastically reduced impacts in use, there are impacts from electricity generation and battery manufacture to consider (Funk and Rabl, 1999). For hybrid vehicles based on lithium-ion batteries, the production phase is expected to dominate the impacts. However because most of these technologies are not yet in production, data have to be estimated or are missing and therefore the outcomes of studies may not be reliable yet (Zackrisson et al., 2010). When different studies are compared they can conflict (for example some studies on transport biofuels (Larson, 2006) (Delucchi, 2010)). Van Vliet in particular recently found that different
Figure 7 - Example output from Ford PSI tool for 2009 Fiesta
Studies of alternative powertrains were almost impossible to compare, making it very difficult to draw generic conclusions (van Vliet et al., 2010). He concluded that the boundaries and assumptions were not always clear; this is something LCA in particular is sensitive to (Ehrenfeld, 2003). This may indicate that Ford will struggle to make meaningful comparisons; the study is not complete yet. However at least all the options in the study are being worked on by only one organisation, so any generic assumptions should be the same.

At the moment the PSI tool does not appear to be used at points in Ford's business process where strategic decisions about whole products (vehicles) or services are made; although this needs more investigation. It definitely appears within the decisions which are made once a product has been identified, when a product cycle plan has already been mapped out in essence. That is, within the GTDS and GPDS processes described in section 1. Therefore it may be used to decide between, say, different types of powertrain, but it might not be used to make the original decision about whether to develop say a BEV or PHEV. That original decision might be however be informed by any LCA or LCC study results.

Even so, the studies are not likely to incorporate full analysis of any exotic business models, as insufficient data would be available — a common problem with analysing concepts (Rebitzer et al., 2004) and certainly known within the car industry (Nieuwenhuis and Wells, 2003). Some other kind of sustainability tool may be needed, or another toolbox approach including strategic paradigms, to support these kinds of decisions. The research over the next six months will investigate in more detail how the PSI tool is currently used and whether it might be suitable as a basis for further work to develop strategic decision support metrics and methods. The research will also consider whether the PSI tool can accommodate the use of alternative future scenarios.

### 4.2 Other Sustainability Metrics at Ford Motor Company

Sustainability in general is handled within Ford by the Sustainability, Environment, and Safety Engineering (SE&SE) function (see the organogram in section 1.0 for an overview). Within this, Vehicle Environmental Engineering (VEE) within Europe for example are responsible for ensuring that Ford products meet regional legislation, for liaising with external bodies to develop, interpret and influence legislation, and more non-specifically for managing the sustainability requirements within projects and the supply chain. The Automotive Safety Office (ASO) is responsible for ensuring that the products meet or exceed regional safety legislation and that the company maintains its chosen competitive position on safety attributes; it too has an external liaison role. The Environmental Quality Office (EQO) is responsible for meeting environmental legislation and reducing the environmental impacts of manufacturing, meanwhile. These departments interpret legislation and other
requirements for use by other functions. The SE&SE function also produces the corporate annual sustainability report, which is large enough to need its own publicly-accessible website (FMC, 2009c).

Therefore metrics associated with sustainability and used by Ford within their day to day processes (outside of the PSI tool), tend to be around impacts for which there is legislation. This includes for example tailpipe emissions compliance, both the "basket" of gases covered by Euro Stage 5 or 6 (Europa, 2010) and the separate legislation on CO₂ fleet emissions (European Parliament, 2009); the regulation of chemicals (EC, 2011) and many assorted pieces of safety-related legislation. However very few of these metrics are monitored throughout the organisation and up to a high or strategic level, unless there is some question raised about how best to meet legislation; most detailed metrics are only tracked within the relevant functions as it is assumed that meeting legislation is not optional. Also not all of the detailed metrics are used in the product design and development processes. Instead, the metrics tracked at high level are known as vehicle attributes and are those considered to affect the purchase decision by future buyers, whether fleet buyers or individuals. Therefore the main exception in the tailpipe emissions, for example, is CO₂ which is currently tracked as an attribute as this is believed to be of interest to fleet buyers.

Ford do use a form of triple-bottom-line reporting in their annual sustainability report, for example grouping selected performance indicators into the classic "economy/ environment/ society" headings (FMC, 2009c). A useful overview is given in the summary of this report (FMC, 2009a). These indicators tend to be corporate aggregated ones such as global energy use, averaged quality data, or the net annual profits. The societal ones concentrate on the safety and satisfaction of employees and customers, and charitable donations, but not on other indirect impacts to society such as a rating for pedestrian safety in accidents. Therefore the set of indicators seems to be incomplete in terms of sustainability, but also is at too high a level for use in this project. However the information which is aggregated to form these indicators may be at the right level of level to inform strategic decisions. More research is needed to work out which sustainability metrics are used around the strategic product and technology level decisions within Ford.

4.3 Resilience and Other Metrics

Resilience of Ford as an organisation is the original overarching goal of the project. If resilience is a wider concept than sustainability, what kind of metrics are, or could be, used to indicate it? How does it relate to full-spectrum sustainability, and the ability to both innovate and withstand disruptive technologies and other forces?

This is a relatively new topic within this research and a full literature search has not yet been done for published work on the full-spectrum business meaning. The more
common business meaning of resilience seems related to disaster-recovery and business-continuity planning, mainly arising from the IT or facilities functions; certainly this is the meaning adopted by IBM and Gartner (Gaddam, 2004) (Bell, 2002).

Walker et al. discuss an ecological definition of resilience based on work by Hollings, which is usefully close to the sustainable business meaning, and identifies three main characteristics of resilience: the amount of change a system can undergo and still retain its structure and function, the amount of self-organising a system does and therefore the level of sensitivity to variations or errors in management actions (more self-organisation equates to less sensitivity), and capacity for learning and adaptation (Walker et al., 2002). The context for the article was ecological management. The ecology perspective is probably where the Transition Movement definition derives from, as applied to resilient communities (Hopkins, 2008).

Hamel and Välikangas in contrast, compare the concepts of business revolution, renewal and resilience, as forms of innovation. They view revolutions as creative destruction (an idea borrowed originally from Marxism), which means that many companies go out of business (are destroyed) when the industry rules change. Renewal is viewed as something more likely to come from new companies, who can invent new business models and cause a crisis for existing players; but incumbents can also reinvent their strategies, in a process of creative reconstruction. Resilience is given as a capacity for continuous reconstruction to keep up with changing circumstances, and to avoid a pattern of alternating success and failure. They point out that older companies are by necessity more efficient than young ones usually, and longevity is needed to fully reap the economic or functional benefits of companies, therefore it is advantageous to imbue them with resilience. The only exceptions would be companies who have outlived their original purpose somehow. They also point out that variety –exploring wider alternatives- also helps build resilience, as it means you are more likely to have the solution in hand, and be able to adapt when a disturbance happens along. (Hamel and Välikangas, 2003). If the future of sustainable mobility does not include cars in some nearly-current form, this would be the danger for car manufacturers. It would therefore be wise for them to decide on an approach, early enough to either form a managed exit strategy and minimise losses, or develop the resilience necessary for the bumpy ride to some other future purpose.

It may be that sustainability metrics can be made to stand proxy for those of resilience, but more work is needed in this area to identify any research linking the two concepts, and to identify the current practice and needs of the sponsor.

Another possible source of useful metrics is the theory of disruptive technology or, as it has been termed more recently, disruptive innovation, most notably developed by Christensen in the "Innovator's Dilemma" (Christensen, 1997). Disruptive innovation is of
interest to Ford as an incumbent, because it represents an opportunity (whether the innovation is internally or externally generated) to diversify into a new business model or market, using the company’s existing assets, efficiency and expertise; but it also represents a threat as it can disrupt their existing markets, especially if it is generated by a competitor or new player. It is therefore useful to be able to recognise these disruptive innovations ahead of time, to be able to make strategic decisions on how to respond to them (Henderson, 2006).

The original interpretation was that incumbents tend to fail when confronted with certain kinds of disruptive innovation, but this is not always the case, and some incumbents are themselves the source of such innovations, or able to adapt to and even adopt them (Danneels, 2004) (Henderson, 2006).

Christensen cites a number of “signals” for disruptive technology (Christensen, 1997), but does not give criteria which are consistent enough to allow the reliable identification of disruptive technologies; indeed not all innovations which were disruptive in his examples appear to have all of the signals (Danneels, 2004). Moreover one automotive technology, BEVs, which he proposed as a future disruptive technology (Christensen, 1997), does not yet appear to have developed this way; although HEVs look like they might fulfil this promise in the next few years. Currently it only seems possible to identify successful disruptive innovations in hindsight, and Danneels believes that the theory needs further development, and perhaps cross-fertilisation from other techniques used to forecast the future value of innovations, to make it useful as a predictive tool in business contexts (Danneels, 2004).

As an example of the need to identify and react to market changes and innovations, consider the ramifications of one of the meg-trends identified earlier: urbanisation. For a company which makes cars, the implications, as discussed previously, are decreasing car-ownership as cities become more densely populated and congested. Particularly if efficient mass-transit transport modes are available, a large proportion of people would not even need access to traditional cars in their day-to-day life. This would be an extreme form of future scenario and pose a serious problem for car companies, even if they are thinking of becoming mobility service-providers.

However as we move away from the centre of cities the mass transport networks become more distributed and the need for some kind of personal mobility device re-emerges (arguably there is a need even in the city centre); but rather than the over-specified traditional car, perhaps some kind of single-occupancy commuter "pod" would be more suitable, available on demand and capable of joining a smart traffic grid in an automated, connected mode, at high density. Functionally this is somewhere between a bicycle and a car, but more evolved. Such pods could be much smaller, cheaper and lighter than conventional cars as automated traffic flow would drastically reduce accidents; but they could be mass-produced. This is the kind of disruptive technology combined with leverage of
their current expertise, which appeals to mass-producers of current cars; but this kind of product or service is also more open to new players, whether start-ups or companies diversifying from other fields or segments. Better opportunities may lie elsewhere too, within the provision of connected transport or personal mobility solutions. How can the incumbents identify the best opportunities to be the instigators of such a disruptive innovation, as opposed to its victim? How can they tell which strategies are likely to succeed? Or, do they need to create small spin-off companies to investigate, which will not cause a disaster if they fail, and can be reabsorbed or grown if they succeed (Hamel and Välikangas, 2003)?

Conversely, the growth of a car-less urban population has implications for freight distribution; or rather of goods and services. Mass transit systems for people are not really designed for the transport of freight as well, and small pods optimised for personal commuting would probably lack the capacity for the weekly shop. It seems likely that online shopping, and home delivery would see an increase in local freight, especially of bulky and heavy items. Within congested cities, the last phase of delivery is typically done by small commercial vehicles, which is the other half of the LDV product and manufacturing expertise of most car companies. Although unlikely to provide substitutional volumes for the shrinking car market, this is a sector that might continue, perhaps offering a little growth and developing technologically as it goes.

This kind of sector may constitute what Christensen calls a sustaining technology, which uses the existing abilities of the incumbent and develops incrementally (Christensen, 1997) (Danneels, 2004). Together with any remaining more traditional vehicles in (rather depopulated) rural areas, it would allow the main part of a company to continue to operate whilst any spin-offs were being developed for new markets (Hamel and Välikangas, 2003). It could also enable the incumbent companies to raise revenues to allow them to develop their new cleaner technologies in a modular way (Christensen, 2010) that could be used by both the rural vehicles and delivery vehicles, and which works with their current product development style. However, the incumbent would still need to be able to detect any disruptive innovations in these segments, especially if its business model were dependent on them for some time whilst developing new ones.

The theories of resilience and disruptive innovation seem to be linked via their effects on strategy, and arguably sustainability requirements can act as the driver towards more innovation and therefore disruption. It would therefore seem likely that sustainable engineering and management tools would offer a way to identify opportunities and threats from these drivers. This area needs more investigation to see if there are any promising tools and metrics already developed, which could fulfil a need within the sponsor.
4.4 Strategy, Risk and Sustainability

Ford's approach to risk, except in the sense of product quality and product design (to avoid failure modes), is not very explicit in the day-to-day activities of development engineers, at least. One might expect risk analysis in the business sense to be connected to strategy and strategic decisions; as the research has not yet covered this area at the sponsor this is an area which needs more investigation.

As the metrics and methods to be developed by the research are intended to inform various levels of strategy, it is important to consider the kinds of inputs strategic decisions require, and whether they vary according to approach. The research has not yet reached the stage of identifying how Ford's strategic decisions are made, and which parts of the process will be relevant to the research scope. Over the next six months involvement of the internal stakeholders should assist with this scoping and internal information search, and a further literature search will be used to identify useful techniques.

Ford's sustainability strategy is not explicitly stated within the corporate annual sustainability report. It does however list goals and commitments for improving its five most important sustainability issues or "material issues", which it lists as

- Climate change
- Mobility (sustainable)
- Human Rights
- Vehicle Safety
- Sustaining Ford (as a competitive business)

The report also contains a commitment to reducing CO₂ emissions from Ford's US and European new vehicles by 30% by 2020, relative to 2006, and a technology migration plan to support this (FMC, 2009c). Beyond 2020 this plan shows a mass volume use of alternative vehicles (battery electric, plug in hybrid) and some planned use of fuel cell vehicles. The summary of the report mentions an analysis of long-term reductions to deliver atmospheric CO₂ stabilisation, which at least implies some buy-in to the 2050 targets set in, for example, the UK (UK Government, 2008). The report also acknowledges the need for "sustainable mobility" to be affordable environmentally and socially as well as economically in a more crowded future. It refers to some pilot projects exploring "mobility solutions" which integrate public and private transport modes; but does not include any specific plans (FMC, 2009a).

This brings us back to the need to somehow factor sustainability into the analysis of future scenarios, and provide methods and metrics to assess any solutions; the two initial
objectives which will feed into product and technology strategies, to avoid the situation outlined below:

“A company can be operationally efficient and strategically inefficient.” (Hamel and Välikangas, 2003).

4.5 Supporting Decision-Making

The desired outcome from the project is to produce data which can be used in strategic decision making processes within Ford, whether on products or technologies. However it is not yet clear how much if any of the project content will concern the process of decision making rather than merely interpretation of data.

4.5.1 Integrating the Results into the Company

Although the aim is to support an increased level of resilience and, hopefully therefore, profitability, initially the methods and metrics will be used in the same low-margin hyper-competitive environment as now. Therefore they will need to produce significant results which add value to strategic decisions without consuming large amounts of extra resource.

The company is well-established with its own very strong culture and toolset; again although eventually the output of the methods and metrics may affect culture and tools, initially they must be able to be integrated into the company’s day to day business in such a way that they complement existing tools. The actual task of integration and roll-out is likely to fall to the Process Leadership team after the finish of the project but this aim should inform the design of any research tasks, methods and metrics.

5 Summary and Future Work

The research so far indicates that there is definitely a need for the sponsor to be able to work with sustainable engineering and management tools, both when assessing future scenarios and assessing solutions against them. This need arises directly from legislative pressures, market incentives (both policy-driven) and consumer demand (both fleet and private individual), in what is already an over-supplied car market in the mature Western economies. Sustainability is effectively an externally-imposed driver of change.

The business' internal need for improved resilience arises due to the high degree of change in the industry’s environment expected over the next few decades; from global trends affecting market demographics and size, or economic turbulence; to sustainability concerns driving innovation which may pose a threat, opportunity, or both, to incumbent companies. Use of sustainability methods is intended to identify better business
opportunities, that allow a transition away from the currently flawed business model, and enhance organisational resilience.

There was an opportunity in this project in early 2011 to participate in future scenario discussions, in a joint workshop with a major supplier and partner company. This was useful in confirming the presence of the "megatrends" in mainstream awareness within the industry, and in confirming the unusually large challenges ahead, not least strategically and economically.

5.1 Results Achieved So Far

The reading and topic choice for taught module assignments was targeted, wherever possible, to later support the general literature review, which worked well and has allowed some broad background reading as well as more scope-specific searches. Although the review so far is not exhaustive in any subject area, it has provided sufficient information to steer the next few research tasks, and further reading. Thus far the reading has confirmed the basic premise of the project, for which further supporting evidence will be sought, but it does not yet allow the scope to be fully identified.

Further work is required to identify which Ford strategic processes are relevant to the project scope; also to define how the output of the research (metrics and methods) is intended to be used by the stakeholders, in their own view. Further literature searching is needed on the inputs to strategy, further metrics and methods for establishing sustainability, resilience and disruptive innovation, to see which will be relevant to the sponsor's needs. Another important area to investigate, cutting across all techniques and theoretical areas, is the use of future scenarios and how uncertainty and risk is handled. This work is broken down into a planned set of tasks, as detailed below.

5.2 Future Work Plan

The most urgent pieces of work are twofold; to establish the project's expected boundaries and to find supporting data for trends occurring at the moment. Other tasks listed here are also needed to support the planning of the research work for following years.

5.2.1 Establish Project Boundaries

The plan is to work on this from April until late July, making use of input from the internal stakeholders. This task must answer the following questions, so that the research scope may be set by the end of the academic year and the research tasks planned at high level for the project duration. The questions are:

- What do the Ford stakeholders need and expect from the research?
• How does the research fit into other sustainability activity within Ford?

• What do users of the research output (metrics and methods) need?

• How will the output be used in existing Ford processes?

This task must also begin to address the academic question:

• Where will the original contribution to knowledge arise?

This academic question will take longer to answer, so an initial target of identifying at least one candidate area for original contribution by September has been set. This can then be further developed.

Part of the whole task will be a process of setting and managing expectations amongst all the stakeholders, both academic and industrial supervisors, and the extra stakeholders identified.

5.2.2 Find Supporting Data About the Industry and Ford

There is an initial need to check that the available recent data (or papers summarising it) supports some of the key assertions about the industry background, made by papers already reviewed; such as the fundamental unprofitability of car manufacture. Key questions to be considered are:

• Will the technology roadmaps for the industry deliver the necessary European carbon reductions by 2050?

• What contribution will current transport policy roadmaps also make?

• Is car mass-manufacture as unprofitable as Wells claims, and how might the roadmaps affect this?

• What is Ford’s relative position within the industry?

• How are markets changing now in established Western regions (eg US and Europe) and emerging regions (India and China)?

• What do these market trends mean for Ford in the future- how will they interact with the identified “megatrends”?

This set of questions also needs to be answered by late July as it sets the background for the project, identifying the business drivers for the research. The answers
will be used to build a case for how Ford may be affected in future by trends beginning to emerge now, and how that differs from previous market situations.

5.2.3 Find Supporting Data About Possible Metric and Method Options

The second set of data-related work looks at the research area covering possible solutions, that is ways to incorporate sustainability into future scenario work, and methods and metrics for assessing design solutions. Firstly more information is needed about two assertions made in the literature: are there examples to support or deny these?

- Sustainable engineering methods, and tools (such as PSI), have a positive effect on the sustainability of a company’s products
- They also have a positive effect on the company’s profitability

These underpin the business case to Ford about the benefits of using such tools and methods. Assuming the evidence is mainly positive, this leads to work on the following question:

- Which sustainability methods and tools work best for a large manufacturing company like Ford?

There are also some questions about resilience which need investigation as background to the project:

- Is there a consensus on the definition of business resilience?
- How is it measured or forecast?
- Are there examples of resilient companies which have changed over time?
- How would Ford rate on such a resilience metric?
- How is it possible to know when strategic change is required from this?
- How would we apply this to Ford?

This set of questions assembles evidence for how the proposed use of methods and metrics can assist decision makers in improving company resilience, and thus longevity and profits. It also aims to establish whether (assuming the metrics are meaningful) a need for strategic change is present for Ford. It should be possible to find some initial data by the end of August; the first two questions will in any case need to be answered by then, as the project is built on the premise that these tools will be able to help address the issues raised for Ford by changes in the market. However, the questions are likely to run through the
research for some time, as they are fundamental to the project. Therefore the plan is to review the status of this set of work in August, and to include any outcomes within the scoping of the following research; but the task will continue beyond into year 2 of the project.

5.2.4 Find Out More About Strategic Change and Disruption Theories

The level of need for change in terms of technology or business strategy for Ford is driven by how well the current strategy (or planned future strategy) fits a developing scenario, how close in time the future scenario is predicted to occur, and the risks or opportunities this generates. There is a need to review the supporting evidence for the following assertions:

- It is possible to identify winning (resilient) and losing companies during industry turbulence before their position is affected
- It is possible to actively respond to such turbulence in a way that it improves business outcomes
- It is possible to identify business conditions which promote disruptive innovation
- It is possible to identify a disruptive innovation before it begins to significantly affect the market
- It is possible to respond to disruption in a way which manages the disruption and/or maximises the benefit to the organisation

If these are well-supported, this will lead to work on further related research questions:

- How does resilience theory fit with sustainability theory?
- How does resilience theory fit into strategic theory?
- Can the metrics and strategic tactics for resilience and disruption be combined, or do they overlap?
- How can they/should they be combined with sustainability metrics?
- How do these metrics and methods handle risk and uncertainty?

It may be possible to make a start on these before the end of year 1, however the plan is to work on these in year 2, in the autumn of 2011 and into the spring of 2012. The task will probably extend further. Any incidental progress by late August this year will be reviewed in case it affects the list of ideas and questions, when scoping the research tasks for year 2.
5.2.5 Routes to the Future

A number of interesting research sub-themes have been identified, most of which inform the project background and are therefore a lower priority than the tasks above. However they should be investigated when a suitable opportunity arises. They mostly relate to analysing future scenarios, establishing a future vision, or a path to attain this.

5.2.5.1 Business Strategy Routes

One set of questions lies around the product and business environment for Ford:

- What might sustainable personal mobility look like by 2050?
- Which parts of this could interest a mass-manufacturer such as Ford?
- Which other parts could interest a large international shareholder-owned company such as Ford, if it changed strategy?
- Does backcasting from 2050 CO₂ targets and scenarios indicate a gap where a faster or step change is required?
- What might that mean for extra legislation or other policy interventions?
- What do sustainability theories such as "convergence" and "prosperity without growth" mean for the future of large businesses?

5.2.5.2 Future Consumer Behaviour

The other set of questions considers how future consumers of sustainable mobility might act, and how the required change in behaviour might happen: in particular some interesting theories concerning mass behaviour are mentioned in the popular book "Herd" by Earls (2007), obtaining the original academic research for which would be useful. Although it is essentially a marketing book, it addresses the difficulty of changing mass behaviour and looks at using social influence. The current list of questions is, in no particular order:

- Does sustainable mobility require large behaviour changes of consumers?
- What are the barriers to this, and why are they so persistent?
- Should a large manufacturer like Ford attempt to proactively change its consumers’ behaviour, or only passively respond?
- If humans are "super-social apes" (Earls, 2007), how might social influence be used to combat these barriers?
• What can the paradigm of addiction (to oil, and in this case cars) used by the Transition Movement (Hopkins, 2008) also tell us about the required behaviour changes?

• Can theories about how ideas diffuse into society (for example meme theory) inform work on behaviour change?

• Will behaviour change follow the path laid out by policy, and deliver the carbon savings needed?

• What happens to Ford’s business environment if behaviour change does not deliver?

At the moment these questions have been put to one side to pursue more urgent research. The task of investigating any of these will be reviewed every six months or more frequently as the opportunity arises; it is not planned that significant work on these background questions will occur in the next six months. A visual summary is shown below:

This plan is designed to confirm the project overall direction at 12 months, and help scope the next set of tasks; plus identify a possible area for the contribution to knowledge. The list of questions under each of the five main tasks is not exhaustive. It is likely that some of the assertions and theories found so far may not be supported by a more thorough search of the literature, or that clear real-life examples are not available for each and every one of them. Other useful theories and information will also come to light which could be incorporated into the work. The active detailed sub-tasks will therefore be reviewed on an ongoing basis.

Julie Winnard 1st April 2011
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