Electric Vehicle Manufacturing: An Industry Study

SUS 6103 Implementation of Sustainable Business Practices

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1.0 Background

Electric Vehicle Industry – Early History

The electric vehicle industry can trace its roots back over 180 years. In the 1830's, the first electric car was built in Scotland. It used a non-rechargeable battery and was essentially a horse-less carriage. By 1881, rechargeable lead-acid batteries had been developed which were practical for use in vehicles. Electric vehicles were so mainstream in 1887 that New York City had a fleet of electric taxis. By the turn of the century, 38% of cars in America were electric. They were a more practical car for the day as gasoline powered vehicles were dirty, noisy, and a rough ride. In addition, internal combustion engines had to be started with a hand crank. The 1902 Wood's Phaeton was a typical car of the day, and had a range of 18 miles and top speed of 14 mph. It wasn't until 1912, when the electric starter was invented, that internal combustion engines started to become more popular than the electric and steam powered cars. New oil discoveries in Oklahoma and Texas, infrastructure improvements allowing for longer trips, along with Henry Ford's innovations in production all contributed to the eventual domination of gas powered vehicles.

The electric vehicle never disappeared entirely, though its use was extremely limited. Unsurprisingly, the oil crisis in the 1970's spurred the development of many EV concepts. Legislative efforts led by California in 1990 spurred development in a new way. Major auto manufacturers, including: Ford, Chrysler, Honda, Toyota and Nissan all started limited production of electric vehicles. The most famous of these was General Motors EV1. For a variety of reasons, including the repeal of regulations in California as a result of lobbying efforts by automakers, GM confiscated all of the EV1s and literally destroyed them. It was emblematic of the apparent sentiment of major automakers.

Electric Vehicle Industry – Current Activity and Key Players

Today, market conditions have motivated even the major auto manufacturers to invest in EV's. Late 2010 saw the release of the Chevy Volt; a plug-in electric hybrid. 2011 has already seen the release of the all electric Nissan Leaf, and should see a counterpart by Ford enter the market by the end of the year. Within a few years, nearly all of the major auto manufacturers will market plug-in hybrids or EVs. In addition to general market offerings, there is a wide variety of specialty vehicles such as the performance oriented all electric Tesla Roadster and the ultra-narrow Tango EV commuter.

At this point, no major players or technologies have emerged as leaders in the sector. The economics of manufacturing and purchasing EVs are still maturing. Federal and state incentives for purchase alleviate some of the relatively high cost of EVs. However, those incentives are designed to phase out after a manufacturer has sold 200,000 vehicles ("Consumer Energy Tax Incentives," n.d.). Conversely, pricing of EVs should drop as efficiencies of scale take hold. This is particularly true for the most expensive part of the vehicle: the battery (Kanellos, 2010). Fuel prices and the effect on the total cost of owning an EV will be a major factor in EV adoption.

It is unclear whether plug-in hybrid's, all-electric vehicles (EV)'s, or some combination, such as the Chevy Volt, will find more traction with the American public. Although the range of today's EV is sufficient to meet the needs of most drivers the majority of the time, it is an important factor in determining which technology will prevail. There are sustainability considerations that arise from hybrid technology which requires the manufacturing of an additional internal combustion engine for each vehicle. Currently, EVs have been incorporated into the existing manufacturing system, and sustainability considerations revolve around product use instead of production.

2.0 Industry Trends

The electric vehicle manufacturing industry is comprised of two categories of manufacturers: those that only produce EVs and those that produce both internal combustion engine (ICE) and EVs. Manufacturers that exclusively make EVs (one to two models at most) are relatively small in size. The most well known player in this category is Tesla Motors, although there are others such as Coda Automotive and Th!nk City. The majority of these electric only manufacturers are low volume or limited run production operations. The other category consists of large, traditional automobile manufacturers who have also begun to offer EVs. The front runners in this category are Nissan, with the all electric Leaf and Chevy, with the electric-ICE hybrid Volt. Given the breakdown of the two major players we will look at trends affecting the larger automotive industry and trends that are specific to electric vehicle manufacturing.

Automotive Industry Trends

The most significant trend affecting the auto industry is rising and volatile gasoline prices. Gasoline prices have increased, on average, over a dollar a gallon from the same time last year. The average price for a gallon of gasoline in the U.S. was $3.96 on May 9 ("U.S. Retail Gasoline Prices," 2011).

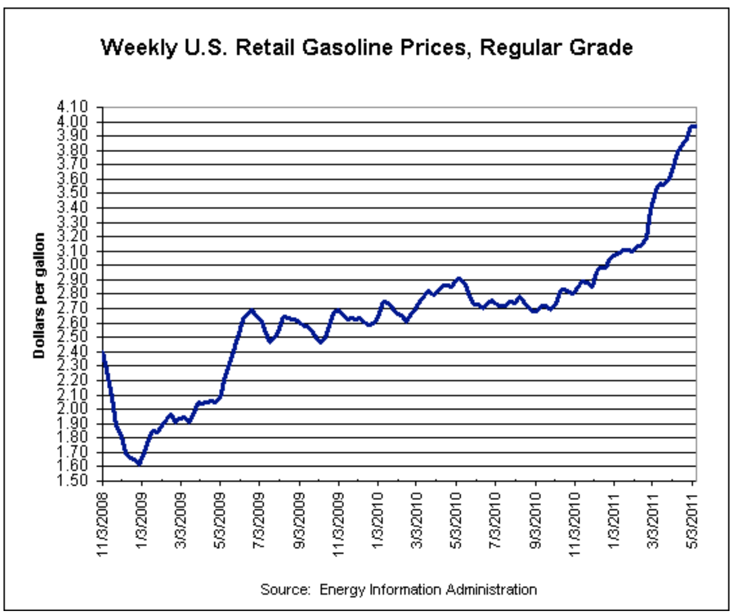


Figure 1: Weekly U.S. Retail Gasoline Prices, Regular Grade ("U.S. Retail Gasoline Prices," 2011)

Continuing political uncertainty in major oil producing regions including the Middle East, Africa, and South America combined with the depletion of petroleum stocks will likely cause this trend to continue

Utilities and regulators such as, California Public Utilities Commission (CPUC), are beginning to roll-out time of use rate (TOU) to encourage off peak (typically at night) charging of EVs so that the energy grid is not overloaded. According to Robert Levin, Senior Analyst at CPUC, the "price of electricity charged to EV owner should be appropriate to reflect the cost of off peak generation...if not, there will be artificial barriers to EV adoption...EV owners should charge at night when they sleep" (Levin, Personal Communication, 2011). TOU rates means that EV owners will be able to charge their vehicles during off-peak times at a discount from the typical electricity rates.

or intensify in the future. Rising pump prices directly impact consumer's pocket books and create an economic imperative for auto manufacturers to produce alternative fuel vehicles and fleets with better fuel efficiency. It is likely that eventually pump prices will reach a level where EV's total cost of ownership will be less than that of traditional autos.

There is also growing green consumer sentiment, which includes concern about pollution reduction, energy efficiency, and an increasing awareness regarding carbon emissions and climate change. Consumers are systematically seeking out green products that they perceive to be healthier and better for the environment. According to a 2009 survey this trend continued to increase even during the height of the recession, with 34% of those surveyed saying they search for and purchase green products (World Business Council for Sustainable Development, 2009). A 2009 survey of consumers online sustainability discussions saw a move from skepticism or confusion around sustainability issues in 2007 to ones focused on taking action, with over 50% of online posters indicating they were taking some type of action such as cutting back electricity use and buying green products ("Consumer Sentiment On Green Topics Moves from Skepticism to Activism," 2009).

These two trends have led to increasing consumer acceptance and demand for non-traditional vehicles such as the Toyota Prius – Hybrid vehicles had 2.8% of the market in 2009. (Market Dashboard, 2009). This may explain why hybrid and electric sales continued to experience growth during the recession, one of the few bright spots for troubled U.S. automakers.

Finally, there are federal legislative and regulatory trends that are creating risks for auto manufacturers that focus on heavy, high-powered cars. In 2010 The U.S. Environmental Protection Agency updated the Corporate Average Fuel Economy (CAFE) standards for the first time in 10 years. The average fuel economy is set to increase from 27.5 MPG to 34.1 MPG by 2016. The U.S. EPA now has authority to regulate CO_2 emissions more broadly and has mandated that CO_2 emissions not exceed 250 grams per mile. Also, Congress continues to consider broader climate change legislation (Abuelsamid, 2010).

Electric Vehicle Industry Trends

Previous forays into EV's were driven by government mandates in California. The most significant trend is that auto manufacturers are now internally motivated to produce and market EV's. This motivation is driven by all of the larger auto industry trends and has led to every major auto manufacturer offering an EV, or having plans to offer an EV in the near future. Industry experts predict that 841,000 plug in hybrid vehicles (PHEV) and electric vehicles (EV) are predicted to be sold in the US by 2015 (Pike Research, 2010).

Since GM cancelled the EV1 eight years ago technological advances have made electric vehicles more cost competitive. The biggest barrier to EV adoption is the cost of batteries. In 2007 lithium ion batteries were running over $1,000 per kWh. The EV manufacturer Better Place has a contract to receive batteries for $400 per kWh in early 2012, a 60% reduction in three years, which is illustrative of continuing price/performance advances in EV batteries (Kanellos, 2010). The U.S. government is predicting that battery prices will fall further, as much as 70% over the next five years ("Price of EV batteries to go down by 70% over 5 years," 2010).

There is significant attention, funding, and research and development efforts within the greater battery and electric motor industry. "The Obama administration has provided more than $5 billion in grants and low-cost loans to battery manufacturers and auto companies to support projects intended to spur the development and sale of rechargeable electric cars and plug-in hybrids ("Price of EV batteries to go down by 70% over 5 years," 2010)."

Another major barrier to EV adoption is the availability of public charging stations. The U.S. Department of Energy just announced a $5 million grant program to expand EV charging infrastructure over and above the $400 million that was made available in 2009. Local governments are supporting the deployment of the EV charging infrastructure, however EV infrastructure projects must compete with other initiatives for limited discretionary funds (King, 2011).

Timothy Boroughs, Sustainability Coordinator at the City of Berkeley, stated that "lack of funding and staff is currently keeping them from moving forward with EV infrastructure" (Boroughs, Personal Communication, 2011). This sentiment was echoed when interviewing Peter Brandom, Sustainability Manager at the City of Hillsboro, who said "not all incubation should come from government...local governments role is at the front end." He also believes that "private development and the market must also act" to meet EV infrastructure needs" (Brandom, Personal Communication, 2011). The City of Hillsboro has currently installed 16 public charging stations.

Despite these barriers, the trends in the EV and larger auto industry all point toward growing consumer acceptance and demand for electric vehicles. Manufacturers are embracing this demand as an opportunity for growth and differentiation in an increasingly competitive market place.

3.0 Rationale for sustainability

The business case for sustainability is still rooted in the business fundamentals of reducing expenses, increasing revenues, and recognizing profits. In order for sustainability initiatives to gain traction they must provide a "bottom line" benefit. This is certainly true today in the besieged automotive industry. Often the deciding factor in the incorporation of sustainability is the time frame required for a return on investment. Since creating a new auto line is an inherently long term investment, it makes sense for automakers to apply a long-term view when making decisions about sustainability. Therefore this study will make the assumption that the business case for sustainability accounts for factors with impacts from 5-25 years from the current date. The business case for sustainability typically boils down to the business drivers of expense reduction, risk management, and market opportunities.

Expense Reduction

Reducing expenses by leveraging eco-efficiencies is typically the easiest and most cost effective means of investing in sustainability related initiatives, especially for manufacturing organizations. In the automotive industry optimizing the use of materials and energy reduces current expenses and directly increases gross profitability. The sustainability efforts of auto manufacturers to date have focused in this area and manufactures such as Ford have reduced their energy usage by 35% since 2000 (Voelcker, 2011). Standards, such as ISO 14001, and tracking methodologies, such as Ford's LCA based Product Sustainability Index, have already been implemented and the industry has a relatively high level of achievement in this area. Significant gains are often limited by manufacturer's ability to change existing production lines. Since EV's are expected to differ from traditional autos, the introduction of EV models represents an opportunity for auto manufacturer's to make radical changes in the materials usage, production process, and end product that should not be squandered. Ford's River Rouge plant, rebuilt as a green showcase by William McDonough in 2000, is an example of the possibilities that await the auto industry. The 10 acre living roof decreases energy costs by 7% and improves air quality by 40% (Voeckler, 2011). The roof, porous cement parking lot, and efficient use of waste-water obviated the need to build a $50 million water treatment plant (Voeckler). By continuously enhancing designs and improving the production process manufacturers can decrease raw material inputs, energy consumption, emissions, and the usage of rare materials. This results in immediate cost savings, and more importantly reduces exposure to escalating materials and energy costs in the future.

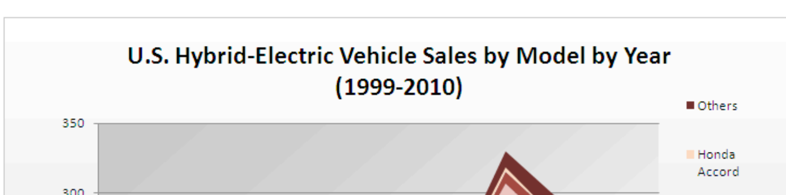
Risk Management

Reducing exposure to liabilities is universally applicable and desirable for business. Regulatory liabilities pose a threat to many industries, especially transportation related sectors including auto manufacturers. Automakers that proactively pursue sustainability in production shield themselves from the negative impacts of increasing and unpredictable government regulation in emissions, hazardous materials, and even safety. The impact of auto emission standards, CAFE standards, and vehicle safety standards create an incentive for advances in product design. Those manufacturers who ignore sustainability place themselves at the mercy of the ever changing and unpredictable regulatory landscape. Pursuing sustainability translates to staying ahead of the regulators, and a competitive advantage over rivals without equal foresight.

A combination of liabilities and negative perception may threaten a company or industry's license to operate. Organizations that are perceived to produce products and manufacturing by-products that degrade the environment, resource stocks, and societal benefit risk consumer backlash, media scrutiny, and alienating stakeholders. Insincere or incomplete efforts to address these issues can easily result in accusations of greenwashing and make matters worse. Such occurrences would certainly reduce profitability, however a combination of fines, additional compliance costs, boycotts, and reduced revenue can effectively revoke an organization's license to operate without any formal charter revocation. Although the benefits derived from EV product usage should create goodwill, detrimental environmental and societal by-products resulting from the production processes of both traditional models and EV's (including life-cycle battery material issues) represent a liability that can be mitigated by sustainability efforts.

Market Opportunities

Changing demographics, technological improvements, and shifts in consumer preferences translate into opportunities for more nimble and innovative companies. With pump prices nearing all time highs, and a growing awareness of GHG emissions and other environmental considerations that are directly tied to the auto industry consumers are demanding a different vehicle than the gas guzzling Escalades and Hummers of a few years ago. Demand for hybrids has resulted in almost 2 million sales over the last decade (*Alternative Fuel Vehicles in Use*, 2011). To further illustrate this shift in consumer demand, in 2008 hybrid sales were up 3.2% and SUV/Minivan sales were down 11.8% ("2009 Car Buying Statistics," 2009). Manufacturers who do not respond to this demand will almost certainly experience reduced revenues as well as brand value (*Alternative Fuel Vehicles in Use*, 2011).



This trend also represents a significant opportunity to profit from new models. In the core markets of North America and Europe, auto manufacturers have experienced a sharp reduction in demand for existing product lines. Yet, hybrid and EV's represent a high growth sector. One analysis places EV's with a 50% market share by 2035. New markets in the developing world will most likely be focused on resource efficient models as well. Manufactures who do not respond to these shifts, they are likely to be left behind, just as Detroit was in the 70's. Especially as competition will become more fierce

Figure 2: U.S. Hybrid-Electric Vehicle Sales

as India, China, and start-up US companies enter the traditional and EV markets.

In April 2011 Toyota announced the sale of its millionth Prius in the US ("Toyota Sells One-Millionth Prius in the U.S.," 2011). The Prius serves as a prime example of the benefits associated with the market opportunity associated with sustainability. The story of the Prius also illustrates how winners and losers are created within the auto industry. Toyota not only developed a solution to the technical challenges of hybrid vehicles earlier than competitors, they produced a better and differentiated product as a result of its focus on the sector. This made the Prius synonymous with hybrid vehicle, resulting in Toyota's unquestioned leadership in a high-growth category, a new highly profitable model, and an increase in brand value. Other entrants into the hybrid category have not fared nearly as well.

One can expect a similar scenario for manufacturers in the next booming market, electric vehicles. However, it is interesting to note that Toyota has eschewed the EV market. Manufacturer's such as Nissan and Chevrolet are attempting to capitalize on this by establishing category dominance in a sector that may eclipse hybrids in the future.

The industry today is under siege and most auto manufactures will be tempted to eschew the pursuit of anything other than short term profitability. Businesses that take such a short-term view are unlikely to see long term prospects improve. Current trends in consumer demand, society, and resources indicate that manufactures can't afford not to become more sustainable.

4.0 EV Industry Impact Analysis

In considering the impacts of the EV industry it is important to consider societal as well as environmental impacts. It is also equally necessary to recognize considerations based on production as well as product use. Since EV's share much in common with traditional vehicles, the most useful analysis compares the cumulative impacts of EV's in relation to petroleum powered autos.

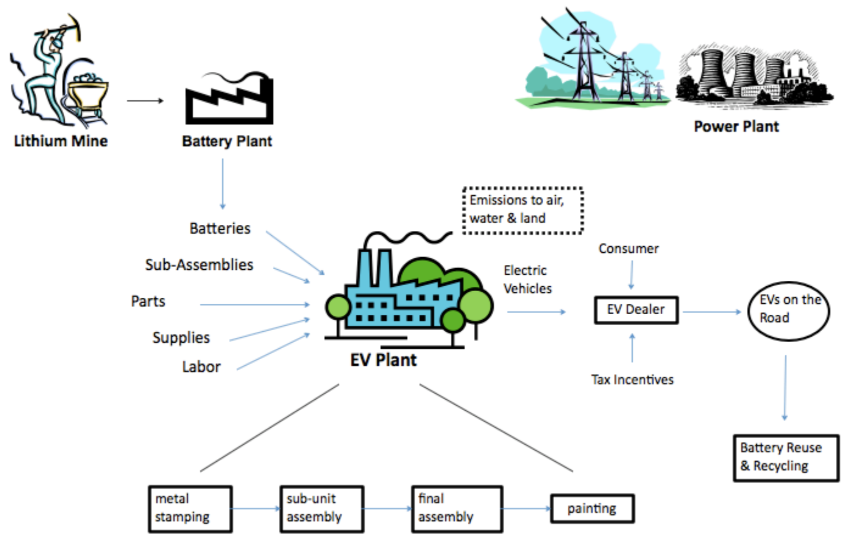


Figure 3: EV Industry Process Diagram

Key Environmental Impacts of EV Industry

Environmental Impacts of Production Processes

The process of manufacturing an automobile, regardless of whether it's an EV, has significant impact on the earth. In all automobile manufacturing, there are a number of different chemicals used throughout the process. Steel blast furnaces and coke ovens produce air pollutants including sulphur dioxide, particulates and organic compounds. Red mud from the smelting process sometimes leaks from holding tanks and contaminates water with caustic soda and metals. Aluminum production produces fluorocarbons that degrade the ozone layer and is a greenhouse gas. The rinse water from metal finishing processes can contain zinc, chromium and lead but is treated before leaving the factory to remove these harmful metals. The painting process releases many volatile organic compounds (VOCs) than can be harmful if ingested (DTI, 2000).

Environmental Impacts of Material Inputs

Many materials are used in the construction of an automobile. Figure 5 below lists the main materials used.

Automotive Material Usage 1984 to 1994 Model Year (in pounds)*

Material	1994	1992	1990	1988	1986	1984
Conventional Steel	1,388.5	1,379.0	1,246.5	1,337.0	1,446.0	1,487.5
High Strength Steel	263.0	247.0	233.0	227.5	221.0	214.0
Stainless Steel	45.0	41.5	31.5	31.0	30.0	29.0
Other Steels	42.5	42.0	53.0	46.5	47.0	45.0
Iron	408.0	429.5	398.0	426.5	446.5	454.5
Aluminum	182.0	173.5	158.5	150.0	141.5	137.0
Rubber	134.0	133.0	128.0	130.0	131.5	133.5
Plastics/Composites	245.5	243.0	222.0	219.5	216.0	206.5
Glass	89.0	88.0	82.5	86.0	86.5	87.0
Copper and Brass	42.0	45.0	46.0	49.5	43.0	44.0
Zinc Die Castings	16.0	16.0	19.0	19.5	17.0	17.0
Powder Metal Parts	27.0	25.0	23.0	21.5	20.0	18.5
Fluids and Lubricants	189.5	177.0	167.0	176.5	182.5	180.0
Other Materials	99.0	96.0	88.0	89.0	89.5	88.0
TOTAL	**3,171.0**	**3,135.5**	**2,896.0**	**3,010.0**	**3,118.0**	**3,141.5**

Source: "Material Usage, Vehicles Retired From Use and Vehicle Recycling" - from *AAMA Motor Vehicle Facts & Figures '94.*

Figure 4: Automotive Material Usage (EPA, 1995)

The main material in manufacturing automobiles is steel, which accounts for almost half of the car by weight. Energy used in steel production represents about 2.5% of domestic energy and about half of this energy comes from coal (EPA, 1995). Steel production in the U.S. produces these emissions whose contributions to smog are the most injurious to health (EPA, 2008).

- Volatile organic compounds (VOCs): 39,365 tons per year
- Nitrogen oxides (NOx): 99,966 tons per year
- Fine particles, under 2.5 micron (PM2.5): 45,431 tons per year
- Hazardous air pollutants (HAPs): 2,971 tons per year

Most EV manufacturing processes are to those employed to build traditionally powered autos. For instance, the frame, interior, and body manufacturing is essentially the same. Where EVs deviate is mostly in regards to the power train and battery. Some types of motors in EVs use rare earth elements in their magnets. China accounts for 97% of the global production of rare earth elements (Huffington, 2010). Countries are now scrambling to find other sources for these rare earth elements including re-opening mines that previously had become unprofitable. A positive trend is starting to emerge in the EV industry as companies like Tesla are redesigning engines to eliminate the use of rare earth elements.

Another aspect of the EV that sets it apart from traditional cars is the battery. The Nissan Leaf has a Li-ion battery pack that can power it for 100 miles and contains 4 kgs of lithium (Sylvester, 2011). There are some concerns that current lithium production is not great enough to support the upcoming surge in EVs. Also while lithium has the greatest impact, batteries contain many other materials as shown in Figure 6 which have impacts themselves (EMPA, 2010). Currently only the nickel and cobalt in batteries is recycled while the lithium and the rest of the materials are simply shredded and disposed of (Taylor, 2009).

Component	Material	Formula	per kg cell (grams)	per Leaf Battery Pack (kg)
Cathode	Lithium Manganese Oxide	$LiMnO_2$	240.8	36.6
	Collector Foil	Al	143.7	21.8
Anode	Graphite	C	162.3	24.7
	Collector foil	Cu	124.8	19.0
Separator	Separator Film	PE	51.4	7.8
Electrolyte:	Etheylene Carbonate - Solvent	$C_3H_4O_3$	171.2	26.0
	Diethyl Carbonate - Solvent	$C_5H_{10}O_3$	Unknown	Unknown
	Lithium Hexaflurophasphate	$LiPF_6$	19.7	3.0
Electrodes	Tabs	AL	15.8	2.4
Total Pack			1000	152.0

Figure 5: Components of Li-Ion batteries (EMPA, 2010)

Cumulative Environmental Impact Comparison of EV Industry

In terms of overall impacts, EVs are far ahead of their gasoline counterparts as shown in Figure 4. In comparison to conventional ICE vehicles, EVs have 220% less total cumulative impact on the EcoIndicator 99 Scale, which assesses damage to human health, damage to ecosystem quality and damage to resources (Gauch et al., 2009). This is based on full lifecycle impacts and includes the 15% additional environmental burden associated with producing an EV (EMPA, 2010). After factoring in product usage, EV's reduce GHGs by 72% throughout their entire lifecycle (Yubanet.com, 2010). Despite the fact that EVs have far less impact than their traditional counterparts, usage still accounts for half of the overall impact of the EV.

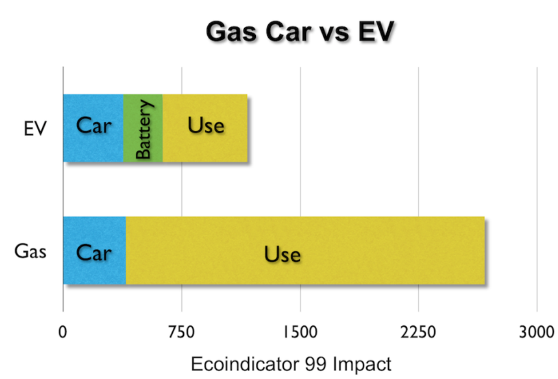


Figure 6: ICE vs. EV Lifecycle Impact Comparison (Gauch et al., 2009)

Even though the entire EV lifecycle impact is less than that of traditional gasoline powered cars, the manufacturing process of EVs and standards cars is similar and will be explored in more depth below. The net result is that EVs are substantially more environmentally friendly over the entire lifecycle of production and use.

Key Social and Economic Impacts of EV Industry

The primary human health impact from automobiles in general is the loss of life and injury from accidents. In 2009 92 people per day were killed in automobile accidents; that is over 30,000 people during the entire year. The AAA estimates that in 2008 automobile accidents cost the United States over

$164 billion, though the National Highway Traffic Safety Administration thinks the number may be much higher. This translates into an average annual over $1,000 per person in the U.S. Thus, the most significant social and economic impact that the industry could have would be to increase automobile safety (Clifford, 2008).

The resurgence of the U.S. EV manufacturing industry is also positively impacting society through job creation. For instance, Nissan is opening a plant in Smyrna, TN to manufacture the Leaf and Tesla is re-opening the closed NUMMI plant in Fremont, CA (Nissan, 2011; Tesla, 2010). In addition, while the bulk of EV batteries are currently made abroad, there are many US companies with growing battery sales including A123, Altairnano and EnerDel. To support EV charging, charging stations are being installed in homes and in public places and this is creating both jobs and charger sales. Some industries will suffer job losses, for instance in gas delivery and gas engine repairs (Becker, 2009). However, a net increase of 1.9 million jobs is expected by 2030 because of vehicle electrification (Electrification Coalition, 2010).

5.0 EV Industry Framework and Vision

Given the major environmental and social impacts identified with the EV manufacturing industry in the previous section, The Natural Step (TNS) is the framework most suited to increasing sustainability. The Natural Step is a Swedish nonprofit organization founded in 1989 with a mission to create a sustainable society. In an effort to meet this mission, founder Karl-Kenrik Robert created the TNS framework. The Natural Step framework outlines the system conditions for sustainability, based on the laws of thermodynamics. The system conditions are reframed into principles of sustainability, so that communities and businesses can leverage the framework to incorporate environmental, social and economic considerations to make decisions that better incorporate sustainability. Table 1 shows the four system conditions and the corresponding principles.

Table 1: Natural Step System Conditions and Principles

The Four System Conditions...	**...Reworded as The Four Principles of Sustainability**
In a sustainable society, nature is not subject to systematically increasing:	To become a sustainable society we must...
1. concentrations of substances extracted from the earth's crust	1. eliminate our contribution to the progressive buildup of substances extracted from the Earth's crust (for example, heavy metals and fossil fuels)
2. concentrations of substances produced by society	2. eliminate our contribution to the progressive buildup of chemicals and compounds produced by society (for example, dioxins, PCBs, and DDT)
3. degradation by physical means	3. eliminate our contribution to the progressive physical degradation and destruction of nature and natural processes (for example, over harvesting forests and paving over critical wildlife habitat);
4. and, in that society, people are not subject to conditions that systematically undermine their capacity to meet their needs	4. eliminate our contribution to conditions that undermine people's capacity to meet their basic human needs (for example, unsafe working conditions and not enough pay to live on).

There are three main reasons why TNS is the best sustainability framework for the auto industry. First, the language used in TNS is both industrial and scientific. This language style is familiar to engineers and already resonates with the auto industry. The second reason is again based on familiarity. TNS relies on a planning approach called backcasting where an organization first sets desired future conditions and then defines the steps necessary to attain that vision (TNS, n.d.). The auto industry is not likely familiar with the term backcasting, but they are familiar with the practice. Manufacturers currently create strategic plans and roadmaps to meet government mandates in areas such as safety and fuel efficiency. Backcasting from an envisioned sustainable auto industry would be a shift in priorities, but not a drastic change in practice. Lastly, TNS is compatible with other guidelines tools used by the auto industry. For example, ISO 14001, a detailed environmental standard already widely used in the auto industry is a perfect complement to TNS. The ISO 14001 standard provides the guidelines and processes to develop an environmental management system, but does not provide guidance on what to measure, and therefore, what to manage (TNS, n.d). The TNS Framework fills this gap by providing guidance on a complete strategic and sustainability level, without impeding the ISO 14001 system. The TNS website provides a very helpful metaphor: "Think about running a ship, where the ISO standard provides guidance on how to run a ship well, but does not suggest where to go. On the other hand, the TNS Framework provides a compass to guide the ship to where it needs to go, but does not say how to manage the ship."

Building on the tools already used by the auto industry, The TNS framework can serve as a general lens for decision making to ensure that the industry is heading in the right direction, particularly in terms of manufacturing. In order to become more sustainable, the auto industry needs to expand its definition of sustainability and application of sustainability tools, which currently focus almost entirely on the products and not the manufacturing process. TNS would assist the EV industry in rethinking inputs and manufacturing processes. TNS would prioritize refining batteries to be lighter, less expensive, and last longer. TNS ultimately requires that the EV production would be based on closed loop processes with upcycling of all materials. Combining the innovative spirit and engineering capabilities inherent in the EV industry with the guidelines of The Natural Step, a truly sustainable EV industry is possible, however the biggest and most important change is for the industry to commit to evolving to a sustainable version of itself. The following section will explore this vision in more detail and put specific metrics around how to achieve the goals desired in accordance with TNS.

6.0 Industry Metrics

The metrics developed to improve the sustainability of electric vehicles production and their performance targets are shown in the Table 2 below. There are two metrics for each of the four Natural Step Sustainability Principles. Targets are based on ten year goals, in order to recognize the long time horizons required in terms of planning for process and material changes and associated capital requirements.

Table 2: EV Industry Metrics

Natural Step Sustainability Principles	EV Industry Metrics	2021 Target

1. eliminate our contribution to the progressive buildup of substances extracted from the Earth's crust.	% recycled content in vehicle average fleet vehicle weight	60% overall 15% reduction
2. eliminate our contribution to the progressive buildup of chemicals and compounds produced by society.	% hazardous materials used in production – emissions and disposal % renewable energy used in production energy used to produce % of miles driven charged by renewable energy	15% reduction 50% overall 50% overall
3. eliminate our contribution to the progressive physical degradation and destruction of nature and natural processes.	% sustainable materials used (recycled and natural) water used for vehicle production (gallons)	85% overall 20% reduction
4. eliminate our contribution to conditions that undermine people's capacity to meet their basic human needs.	life cycle ownership costs % of cars with 5 star safety rating	15% reduction 80% with 5 star crash test ratings

Vehicle Recycled Content

Rationale: one way to reduce the buildup of substances extracted from the earth's crust is to reduce the demand for products that directly or indirectly lead to increasing concentrations. This can be accomplished by closing material loops so more recycled content is used and reducing the demand for virgin material. According to the U.S. Environmental Protection Agency 94% of vehicles in the U.S. are scrapped and 75% of material collected is recycled. Seventy percent of recycled material is ferrous metals, so there is an existing recovery system. Since 50% of a vehicles weight is steel there is large opportunity to increase the proportion of recycled content used in vehicles (U.S. EPA, p. 32). Lithium batteries can be recycled as the batteries reach their end-of-life. Battery recycling will be a thriving $2.2b market by 2022, providing an adequate supply such that no new mining is needed (Frost & Sullivan, 2011).

Measurement: manufacturers already have detailed material and parts lists for their automobiles. This metric would require them track the recycled content of inputs into the production process.

Average Fleet Vehicle Weight

Rationale: another option to reduce buildup of substances extracted from the earth is to reduce the amount of the material needed in manufacturing the product. The most obvious example for automobiles is through weight reduction, which has the added benefit of improving mileage and reducing pollution. The sales-weighted average of automobile weight has been increasing by 1% per year since the early 1980s and in 2008 the average vehicle weight was 4,144 pounds (MIT, p 43).

Measurement: vehicle curb weight is already required to be reported by the U.S. EPA. Manufacturers only need to begin setting goals to begin reversing the trend of annual vehicle weight increases.

Hazardous Materials

Rationale: the volume of hazardous materials sent to landfills or emitted as a byproduct of production has a direct impact on the buildup of chemicals in the environment.

Measurement: companies should begin tracking the volume of hazardous chemicals used in the production of an automobile and take steps to reduce the volume of chemicals. Hazardous chemicals are defined by the Resource Conservation and Recovery Act, which sets out regulations for how hazardous chemicals are transported, stored, used and disposed of. These regulatory requirements should provide sufficient information for companies to begin tracking and reducing their hazardous chemical use.

<u>Renewable Energy Used in Production</u>
Rationale: 50% of electricity in the U.S. is generated from dirty coal, which directly leads to the buildup of hazardous chemicals and also results in significant human health impacts. A 2009 National Research Council report estimates non-climate change impacts of coal fired power plants at over $62 billion annually.

Measurement: the percentage of production related energy that is produced from renewable sources.

<u>Miles driven charged by renewable energy</u>
Rationale: the source of energy used to generate the electricity that powers EV's can reduce the benefits derived from product use. See above rationale in Renewable Energy Used in Production for statistics.

Measurement: the energy mix of regions is publicly available and can be combined with EV distribution statistics to determine in general a percentage of miles driven by EV owners that were charged by renewable energy sources. Improving this metric would require EV manufacturers to work with their end customers to encourage the purchase of renewable energy if available in their area. EV manufacturers could also provide incentive for the installation of solar charging stations by brokering volume discounts with installers.

<u>Sustainable Material Use</u>
Rationale: increased use of sustainable materials, (e.g. soy-based set foam vs. petroleum-based foam) will help reduce the degradation of natural systems.

Measurement: the percentage of material inputs into the production process by weight that are sustainable.

<u>Water Use</u>
Rationale: waste water is one of the primary pathways for hazardous and toxic substances to leave the production facility and accumulate in the environment. Thus, reducing water use can lead to reduced environmental degradation. In addition, water is an increasingly scarce resource, and its overuse leads to direct degradation of natural systems. A 2010 report by the Natural Resources Defense Council predicts that fully one third of U.S. counties (1,100) will higher risks of water shortages by 2050, with 400 facing extremely high risks.

Measurement: average gallons of water used in vehicle production

Life Cycle Ownership Costs

Rationale: the ability for individuals to meet their needs and those of friends and family is directly impacted by transportation costs. For example, cost effective transportation provides access to a wider array of employment, education, recreation, and retail options.

Measurement: Ford currently measures life cycle ownership costs as a combination of purchase costs, fuel costs, maintenance costs, insurance and taxation, minus any residual value over a specified time frame. Other manufacturers could use a similar measure over a 5 year time frame to estimate life cycle ownership costs.

Vehicle Safety

Rationale: avoidance of serious injury or death in a car accident goes directly to an individual's capacity to meet their own basic human needs and those of their family and friends.

Measurement: the U.S. Department of Transportation requires all cars to go through front and side impact crash tests. At least 80% of cars receive a 5 start rating on the NCAP (New Car Assessment Program) front impact crash test and the LINCAP (Lateral Impact New Car Assessment Program) side impact crash test.

7.0 Key players and practices related to sustainability

Best Practices

Most EV manufactures are touting zero emission vehicles and concentrating marketing efforts on the environmental benefits of the electric vehicle in use. With roughly a third of a vehicle's ecological footprint coming from the manufacturing process, this report finds that most electric vehicles manufacturers have focused little, if at all, on addressing this aspect of EV's impact on the environment.

Some attempts have been made such as the use of recycled materials and limited integration of renewable energy into the manufacturing process. Many US manufactures do state they are moving towards environmentally friendly manufacturing but at present there are few actual examples of this commitment. It would seem that EV manufacturers are relying on the benefits of product use to offset the manufacturing process, rather than making EV's as holistically sustainable possible.

In examining best practices we will concentrate on the Nissan Leaf, Ford Focus EV, and GM Volt. The Nissan Leaf appears to be slightly better than the others for sustainable EV manufacturing.

All Electric Nissan LEAF

According to Nissan's website, wind turbines do power a portion of the factory; although Nissan has chosen to concentrate sustainability efforts on recovery, recycling, and reuse. It is difficult to determine the specifics of this effort, but according to Nissan the LEAF is "designed for both recoverability and recyclability" but it does not specify which components. (Nissan US Website, 2011).

This is supported by various efforts. Nissan is using materials taken from vehicles that have reached the end of their life and reducing the use of non-renewable resources and substances that will end up as waste. Insulation layers in the floor and skin fabric of headlining are made with fibers from recycled plastic, the fabric for the seats and armrests used in the Leaf is made from recycled plastic bottles, bumpers are made from used or damaged recycled bumpers, etc. At the end of life of the Nissan

Leaf a new life starts with recycling: 99% of the car and 100% of the lithium car can be recovered. Efforts extend to the battery since it maintains 80% of its capacity after 5 years of use it can be given a second life, otherwise it can be dismantled and its materials recovered," (Zero Waste Europe, 2011). Nissan and Sumitomo Corporation have established a new joint venture for this reuse.

In Europe, efforts extend to a focus on "how to design waste out of the system: the environmentally damaging substances are reduced, a new chemical-free system to remove paint from the bumpers is used, and the lithium-ion battery can get a second life as energy storage solutions" (Zero Waste Europe, 2011).

All Electric Ford Focus

The Ford Focus also utilizes renewable energy and the Michigan assembly plant has a "500 kWh solar power generation systems that it includes a 50 kWh facility where Ford is testing how they can reuse EV batteries for energy storage systems"(Dailey, 2011).

Efforts to improve the interior's sustainability leverage "soy-based foams, which are used on more than 20 Ford vehicles, with seat cushions shaped from 8 percent soy-based content." Lignotock a material used behind the cloth on the door is derived from 85 percent wood fibers and is lighter resulting in weight reduction and provides sound- deadening benefits compared to conventional glass-reinforced thermal plastics (Ford Website, 2011).

Other environmentally friend processes include a three-wet paint process that applies all three coats of finish in sequence before oven curing, ensuring high-quality paint finish and a significant reduction in energy use. There is also the Fumes-to-Fuel system, an eco-friendly, industry-leading pollution-control system, which converts emissions from the plant's paint shop into electricity (Media Ford, 2011).

GM Volt Plug-in Electric Hybrid Vehicle

The GM Volt is a plug-in hybrid electric vehicle (PHEV). The anticipated vehicle range is 40 miles electric before the internal combustion generator kicks in. According to, GM's Manager of Public Policy, Environment and Energy Communications, Dave Barthmuss, GM "considers the internal combustion engine (ICE) to be a range extender...GM plans to begin making the Volt range extender run off E85 bio-diesel in Europe and Fuel Cells in China in 2012" (Barthmuss, Personal Communication, 2011). Even so, the Volt's product use benefits are not strictly comparable with a true EV.

According to GM website, GM does use renewable energy in the manufacturing process consisting of solar, hydro and landfill gas resources. They have reduced CO_2 emissions from production facilities by" 39 percent from 2005 to 2009" and also "reduced the amount of water used by worldwide facilities by nearly 35 percent" (Chevy website, 2011).

Waste reduction has been a priority and 76 facilities around the world which has earned a landfill free certification. The Volt does use some recycled materials which includes materials, salvaged from the Gulf of Mexico, that have been re-purposed for auto parts used in the Volt (Chevy website, 2011).

It was difficult to find out which other recycled materials are used in the Volt. Most likely the Volt makes use of similar recycling methods employed in other GM vehicles including the use of old bumpers in the Chevrolet Camaro, Impala, Traverse and the Cadillac CTS; as well as the recycling of worn carpets to produce mirror frames, fascia brackets and door-handle parts for the GMC Arcadia (Motavalli, 2010).

General Motors and Swiss power and electric giant ABB announced Tuesday that the two companies will jointly research ways to reuse old batteries from GM's Chevy Volt for storing power on the grid to provide community back-up power, renewable power management, grid balancing, and peak price arbitrage (John, 2010).

The analysis of the manufacturing of these three vehicles confirms that EV auto manufacturers are producing electric vehicles in a mostly similar fashion to ICEs. Electric vehicle manufacturing is still in its infancy so it is not surprising that there have been no major departures in the manufacturing process. However, EV's afford manufacturers an opportunity to "get it right" this time. It is recommended that when building the new production lines for EVs they utilize sustainability frameworks, such as TNS, to redesign and rethink manufacturing to create true sustainability gains.

8.0 Sustainability Reports and Results

It was difficult to compare the sustainability of manufacturing processes of the Leaf, Focus, and Volt because the manufacturers are concentrating efforts in different areas. Based on available information manufacturers appear to be focused on using recycled materials, leveraging renewable energy, reducing emissions, and protection of air, soil, and water.

Table 3: Sustainability Report for Manufacturing Process (1= low, 5 = high)

	Natural Step Principle	LEAF	FOCUS	VOLT
Reducing Emissions	2	4	4	3
Protecting Air, Water, Soil	2	4	4	4
Uses Recycled Components	1,3	4	3	3
Recycling Program for Battery	3	3	3	3

Based on the information available Nissan barely wins the comparison. Nissans' advantage primarily is based on its greater usage of recycled materials. It still remains to be seen which EV manufacturer will make the biggest sustainability innovations in the long term.

Conclusion

EV manufacturing is still in its infancy stage. Nissan and GM appear to have first mover advantage; however, no major players have materialized as the clearly defined industry leader. It is also unclear which technology, plug-in hybrid, all electric, or even another technology, will finally emerge as the winner.

While EVs do boast zero emissions from their tailpipes, the EV manufacturing process is almost identical to the highly unsustainable traditional vehicle manufacturing process. The only caveat is the lithium-ion battery that EVs use. The battery does add to the environmental footprint of the EV and battery end of life use and recyclability is still relatively unknown. However, even with the battery, EV's do reduce GHGs by 72% throughout their entire lifecycle (Yubanet.com, 2010)

This report recommends that the industry apply the four principles of the Natural Step to EV manufacturing by developing a standardized set of performance metrics that can be used across the industry. The metrics listed in Table 2 recommend that EV manufacturers take a systems approach to manufacturing by incorporating recycled materials into production, developing end-of-life programs, and reducing the amount of energy, natural resources and hazardous substances in the production process. By applying these principles to EV manufacturing, automakers can greatly reduce expenses through leveraging eco-efficiencies, improve sustainability, mitigate risk, and position themselves to profit by capturing new market opportunities.

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Appendix A: Interview Summaries

Dave Barthmuss. GM, Manager of Public Policy, Environment and Energy Communications.
GM has released 1500 Volts and 40,000 Volts will be released by 2012. GM considers the Internal Combine Generator to be a “range extender”. GM will begin in 2012 making the range extender run off E85/ Diesel in the EU and Fuel Cells in China. Considers $7,500 Federal tax credit for EV’s to be very important to driving down the cost of Volt leases to $349 per month.

Peter Brandom. City of Hillsboro, Sustainability Manager.
Very concerned about government having to pay for EV infrastructure. Believes the private sector and markets must play a part. Believes not all incubation should come from government. and the role of governments is at the front end.

Timothy Boroughs. City of Berkeley, Sustainability Coordinator.
Lack of funding and staff is keeping them from moving forward with EV infrastructure. Wants transportation be looked at from a systems perspective and integrated with public transportation, bicycles and carshare.

Ron Coury. North Bay Nissan, eCommerce Director.
Banks are not treating EV's loans any differently than Internal Combine Engined vehicles. Nissan does qualify for the $5K state tax credit with a lease but you must hold the vehicle for 36 months. CARB (California Air Resources Board) ruled that the Volt does not qualify because they are considering the Volt to be more of a hybrid. This may change next year. CARB has $6M in tax credits and roughly $2M are claimed.

Felix Kramer. Calcars, Founder.
Calcars is a non-profit that converts Internal Combustion Engines cars to EV. The original goal was for EV and and Plug in hybrids to become mainstream but now they concentrating on fleet vehicles and big vehicles that tend to last longer. Wants higher Federal tax credits for conversion. Currently the credit is up to $4,000 but on average these conversion cost $10,000 to $15,000.

Robert Levin, PHD. California Public Utilities Commission, Senor Analyst.
Believes the price of electricity charged to the EV owner should be appropriate to reflect the cost of off peak generation. If not, there will be artificial barriers to EV adoption. EV owners should charge at night when they sleep.

Edward West. Mission Motors, Founder.
Confirmed that EV manufacturer's have major anxiety over battery life and the liabilities of batteries. Believes that they have accumulated significant data, but that they want more. Cautions that they are already seeking to gather this data, and that many are planning on software similar to GridREV’s interface (including Mission Motors). Believes that auto manufacturer's’ will work with V2G, but, that it will continue to void warranty for the foreseeable future.