Project 3: Electric cars – sample analysis

The numbering of the sections corresponds to those of the 5 steps of the analysis. The CES EduPack Sustainable Development Edition helps with fact-finding in ways described in the green boxes.

1. Clarify the Prime objective and scale

Prime Objectives and Scale are defined in the project-statement. The Prime Objective is the de-carbonization of road transport. The stated scale is large – 10% of existing car production globally, equating to 8 million cars per year in 2020.

Step 1

2. Stakeholders and their concerns

The national press reports the views of government, industry and the public about electric cars. Here are seven examples:

Step 2

- In his 2011 State of the Union address, widely reported, President Obama called for putting 1.2 million electric vehicles on the road by 2015. This equates to 10% of the annual car sales in the US.
- *"Bloomberg Endorses Preparing Parking Spaces for E.V. Charging."* (The New York Times, 14 February 2013). The mayor says he wants New York City to be a "national leader" in electric vehicles.
- *"That Tesla Data: What It Says and What It Doesn't."* (The New York Times, 14 February 2013). The New York Times reporter responsible for covering energy, environment and climate change discovers the hard way that the claimed range of electric cars is sometimes a little overstated.
- *"CO_2 emissions 0g/km."* (The London Times, 24.February 2013). Advertisement for Nissan Leaf.
- *"Are electric cars bad for the environment?"* (The Guardian 4 February 2013) Norwegian academics argue that electric cars can be more polluting than claimed[1].
- *"Leaf stalls"* (The London Times 5 March 2013). Nissan admits that customers hesitate to buy its Leaf EV because of price and range anxiety.
- *"Biofuels could cut CO_2 'cheaper than electric cars'"* –Businessgree.com report the conclusion of a new (2013) report commissioned by oil giant BP, which part-owns the Vivergo ethanol plant[2].

These reports give an idea of the controversy surrounding electric vehicles. They also give an insight into the stakeholders and their relationships (Figure 1). Among them are:

- *National Governments* encourage the take-up of electric cars in order to meet carbon-reduction targets and to reduce dependence (where it exists) on imported hydrocarbons.
- *Local city or state government* foresee pressure to provide charging points and specialized recycling facilities, particularly for battery materials.
- *Car makers and their suppliers* seek consistency of Government policy to support a market for electric cars and a secure source for essential materials. They are uncertain of public acceptance of electric cars, making investment decisions difficult
- *Battery makers* seek to establish secure supply chains for the raw materials of the batteries, which include Lithium and Rare earths elements.

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[1] http://www.bbc.co.uk/news/magazine-22001356

[2] http://www.businessgreen.com/bg/news/2295231/report-biofuels-could-cut-co2-cheaper-than-electric-cars

- *Mineral resource producing nations* who are in a position to control materials supply chain and may wish to protect domestic car and battery makers rather than supply competitors with raw materials.
- *Oil companies* wish to retain their share in the provision of fuels for future transport systems.
- *Labor Unions* are concerned about job-creation, stable employment and improved pay and working conditions in the automobile sector.
- *Automobile associations and the driving public* share concerns about the range, battery life and replacement cost, and depreciation of electric cars.
- *Green Campaigners* lobby in favor of electric cars because of their concerns about the impact of gasoline and diesel-powered cars on the environment.

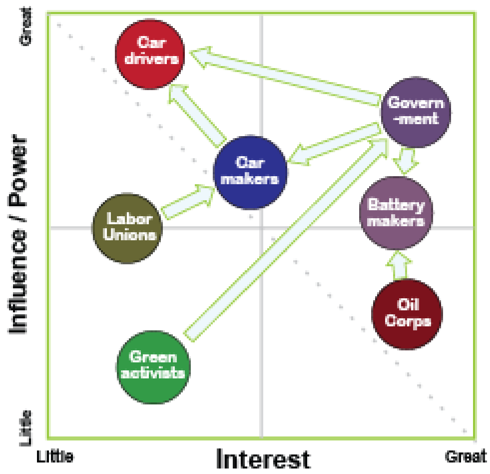

Figure 1. Stakeholder interest and influence

Summary of the significant stakeholder concerns

- *Will electric cars really reduce the carbon footprint of transport?*
- *Is the electric car market viable without government subsidies?*
- *What critical materials are required for electric cars? Is their supply chain secure?*
- *Can the limited range of electric cars be overcome?*
- *Will there be enough charging points?*
- *How will electric cars impact the job market and demand for skills?*

3. Fact-finding.

Step 3

What information is needed to support or refute the claims made for them and the concerns expressed about them? What additional facts do we need for a rational discussion of the Prime Objective – 10% of cars fully electric by 2020? These questions are explored in the sections below. Figure 2 gives a overview.

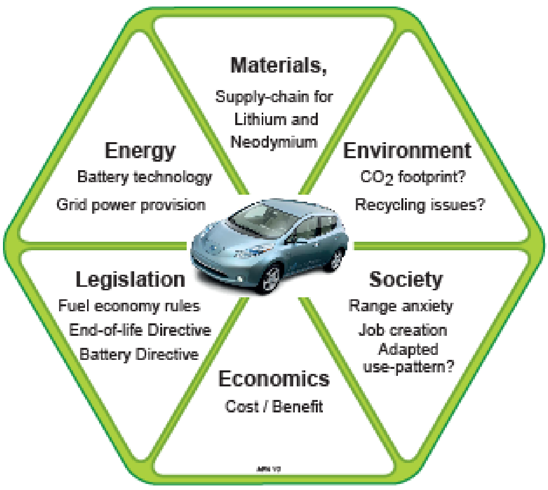

Figure 2 A fact-finding summary

Energy and power. Batteries are heavy. Weight is minimized by selecting the battery with the highest energy density. Figure 3 plots the energy density for energy-storage systems[3]. Lithium-ion batteries out-perform all other battery types, although their energy density, 0.6 MJ/kg, is still a factor 75 less than that of gasoline or diesel fuel.

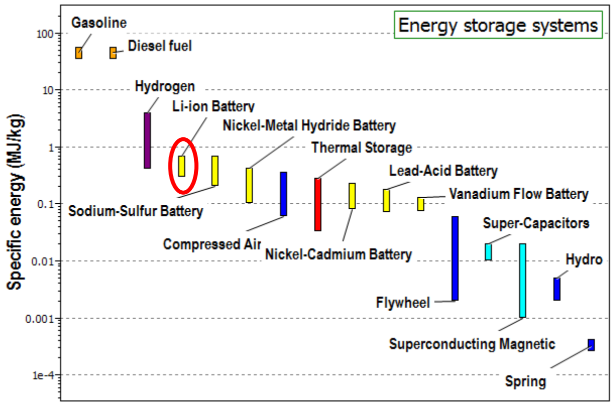

Figure 3. The specific energies of alternative energy storage systems using the Energy Storage data-table.

The at-wheel energy required to propel a small car is about 0.6 MJ/km. Thus the battery weight per unit range is roughly 1 kg/km. An acceptable range of 500 km (300 miles) would need a battery weighing half a tonne and costing, at today's prices, about \$50,000.

There are about 1 billion cars on the world's roads. If 10% of these were EVs, driven 17,000 km (10,000 miles) per year, each consuming 0.6 MJ/km, they would draw

$$10^8 \times 0.6 \times 17{,}000 = 10^{12} \text{ MJ / year}$$

from the national grid. An average power station produces 4×10^{10} MJ / year, so 23 additional power stations would be required to charge the cars. A country the size of the UK, France or Germany would require at least one additional power station to cope.

Figure 3 is made with the Energy Storage data-table of the Sustainability database. You can add the data for gasoline and diesel fuel the data-table, right-clicking on the header and selecting "New record". Insert a name ("Gasoline") in the top box, scroll down to "Specific energy" and enter values (43 to 46 MJ/kg). Do the same for a second new record ("Diesel fuel"). Then create a plot of Specific Energy. It will look like Figure 3.

Materials and countries of origin.

One element of interest here is Lithium (Li). Table 1 lists the main producers. The annual world production of Lithium at present stands at 34,000 tonnes per year. The supply-chain of Li is relatively diverse – 67% comes from Chile and Australia, the rest from a range of other Nations.

Table 1 Lithium producing nations (2011 data)

Nation	Tonnes/year
Chile	12,600
Australia	11,300
China	5,200
Bolivia	5,000
Argentina	3,200
Portugal	820
Zimbabwe	470
Brazil	160
World	**34,000**

Minerals.usgs.gov/minerals/pubs/commodity

The envisaged production of 16 million electric cars per year, each with 16 kWhr battery pack requiring 7.3kg of Li, would, if battery design is unchanged, require

$$7.3 \times 8{,}000{,}000 \approx 58 \times 10^6 \text{ kg} \approx 58{,}000 \text{ tonnes of Li / year}$$

or 170% of current world production. If car-range is extended to meet consumer concerns the demand would be higher unless an alternative storage system can be found.

The supply-chain and availability of Neodymium (Nd) is the subject of another Project. Here is a summary of the position. The present annual global production of Rare earths metals is about 134,000 tonnes per year, of which 15% (20,000 tonnes), on average, is Neodymium.

[3] MacKay, D.J.C (2009) "Sustainable energy – without the hot air" UIT Press, Cambridge, UK and Ashby, M.F. (2013) "Materials and the Environment" Butterworth Heinemann, Oxford

Over 95% of supply is from a single nation. The envisaged production of 16 million electric cars per year, each containing 1.5 kg of Nd would require, using today's technology

$$1.5 \times 8{,}000{,}000 \approx 12 \times 10^6 \text{ kg} \approx 12{,}000 \text{ tonnes Nd / year.}$$

This is 60% of current global production. There are no substitutes for Nd-based magnets that offer the same performance, so the constrained supply-chain is a concern.

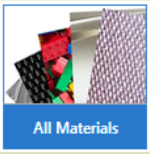

Table 1 is printed from the Materials data-table of the Sustainability database. It lists the countries of origin of materials and the contribution of each to total world production.

The Environment – can the Prime Objective be met? Electric cars will be charged from the National grid. Consider the carbon footprint of the car, if the grid is largely fed (as in many Nations it is) by gas-fired power stations. Delivered electric power from such stations has a carbon footprint of 500 g/kW.hr, or 140 g/MJ[4]. The energy in the form of gasoline or oil required to propel an efficient small car is about 2 MJ/km[5]. The conversion efficiency from gasoline to crankshaft power is at best 1/3, so for equivalent performance the electric motor replacing the IC engine must deliver about 0.6 MJ/km. The combined efficiency of a lithium ion battery / electric motor set is at best 85% when the recharge cycle is included, so electrical energy of 0.6/0.85 ≈ 0.7 MJ /km must be provided from the grid. This carries a carbon penalty of

$$140 \times 0.7 \approx 100 \text{ grams per km.}$$

The median carbon emission of today's cars is about 200 grams per km, but a number of contemporary models already emit less than 100 grams per km. Thus until the grid is decarbonize, carbon emissions from electric cars are no lower than those from an efficient gasoline or diesel powered vehicle. Power predominantly from nuclear sources (as in France) or from renewable sources (Norway, Iceland) changes the equation.

The records in the Power Systems data-table of the Sustainability database list the carbon footprint per MJ and kW.hr of both fossil fuel and low carbon electricity generating plant.

Legislation and Regulation. A search for legislation relating to private vehicles retrieves a number of European Directives and US Department of the Environment Acts:

European legislation:

- EU Automotive Fuel Economy Policy on carbon emissions
- Fuel taxes
- EU Battery Directive
- End-of-Life Vehicles Directive (ELV)

US legislation

- CAFE rules
- Fuel taxes

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[4] See, for example, www.defra.gov.uk/publications/files/pb13773-ghg-conversion-factors-2012.pdf Table 3c

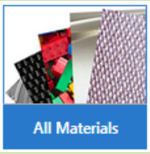
[5] An efficient small car does about 16 km/litre of gasoline. One liter of gasoline has an energy content of 35 MJ/liter.

All have a bearing on the viability of electric cars. We highlight one: the EU Battery Directive forbids the dumping of batteries in landfill; all must be recycled. Infrastructure for recycling Li-ion batteries on a large scale does not yet exist (3% of Lithium-ion batteries are at present recycled[6]).

The "Search" facility in the Sustainability database using "Cars" as a search term retrieves legislation relating to private vehicles. It also brings up records for materials used in cars and much else.

Economics[7]**.** Batteries for electric cars are still very expensive – as much as $10,000 to $15,000[8], or one third of the price of the vehicle –and can provide only limited range. The price of Lithium-ion batteries fell during the 1990s but flattened out at about $600 per kWhr. With fuel at $4/gallon (~$1/liter) in the US and about $1.8/liter in Europe, the economics of electric cars looks unattractive. However a 2012 analysis carried out by McKinsey & Co[9] predicts that the price for lithium-ion batteries could fall by as much as two-thirds by 2020, down to around $200 per kilowatt-hour. This, coupled with rising fuel price, might tip the balance.

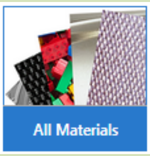
A current economic concern is the investment in recharging points: providers are waiting for the number of electric car drivers to rise but drivers are waiting the number of stations to rise. Some governments are willing to subsidize charging points, but mainly in the cities.



The "MaterialsUniverse" data-table of the Sustainability database contains data for the current price of Lithium and that of gasoline, diesel fuel and electrical power (both domestic and commercial) are in the "Nations of the World" data-table.

Society. Automobiles give independence. Their manufacture creates employment. They also occupy space and, in conventional form, are responsible for noise and emissions. Secondary benefits of the electric car include reduction in noise and the ability to confine carbon release to power stations where it can be handled more effectively.

The cost, the limited range and absence of charging points for electric cars impedes their acceptance at present. Governments recognise these as problems and seek to reduce their impact by subsidies on EV purchase and installing and subsidising charging points.



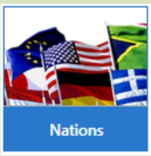
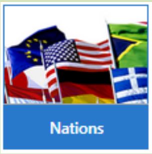


Table 1 is printed from the Materials data-table of the Sustainability database. It lists the countries of origin of materials and the contribution of each to total world production.

[6] Telens Peiro, L. Villalba Mendez, G. and Ayres, R.U. (2013) "Lithium: sources, production, uses and recovery outlook" JOM Vol 65, pp. 896 – 996.
[7] The Washinton Post, April 2, 2013. http://www.washingtonpost.com
[8] The Wall Street Journal, April 17, 2012. http://online.wsj.com/article/SB10001424052702304432704577350052534072994.html
[9]McKinsey July 2012. http://www.mckinsey.com/insights/energy_resources_materials/battery_technology_charges_ahead



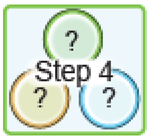
Cars have a price and electric cars are more expensive than ordinary ones. Affordability is an issue. The "Nations" data-table of the Sustainability database contains data GDP per capita and the median wage in the Nations of the World.

Summary of significant facts

- *The supply-chain for neodymium and lithium is at present inadequate to support making 8 million electric cars per year.*
- *If charged from a national grid fed by gas or coal-fired power stations the carbon footprint of the car is at least 100 grams CO2 /km.*
- *The weight and cost of batteries limits the range to less than 160 km per charge.*
- *Sales of electric cars at present depend on government subsidies of up to 20% of the price of the car.*
- *Legislation requires that 85% of the car, including the batteries be recycled. Facilities for recycling lithium-ion batteries and neodymium magnets are not, at present, in place.*

4. Synthesis with the Three Capitals

What, then, is the likely impact of the wide use of electric cars on the three Capitals? These are questions for debate, informed by the data generated by the Fact-finding step. Here is **one** view for discussion, summarized in Table 2.



Natural Capital. Electric vehicles that use today's technology rely on a least two "critical" elements: Neodymium and Lithium. The analysis of demand created by EVs and the distribution of source-Nations for these elements was not reassuring. The projected demand for Neodymium for cars in 2020 is about half the current (2011) global production, most of it coming from a single Nation. Some of the demand in 2021 could be filled by recycling, not at present practiced. The design life of an electric car is of order 12 years. If the vehicles are leased, so that large groups of them are managed by a single enterprise, the recovery, reconditioning or recycling at end of life is straightforward. If they are sold, as cars are now, to individual purchasers then collection for recycling becomes more difficult but still manageable. A similar exploration for Lithium indicated a broader supply base but a demand in 2020 that exceeds current production capacity. These facts point to a technology that makes large demands on critical elements with inadequate supply.

Does the all-electric car achieve its Prime Objective, that of helping to de-carbonizing road transport? The carbon footprint of the electric car, if charged from the national grid of a typical Western nation, is roughly 100 grams per km. An increasing number of small IC driven cars already do better than this. We conclude that the Prime Objective is not achieved until the national grid is itself de-carbonized or an independent low-carbon source of electrical power is available. Neither appears achievable in the short (6 year) term.

Manufactured Capital. The aim of 8 million EVs per year by 2020, using today's technology, is achievable only if three conditions are met: the supply chain for the critical elements on which they depend is expanded and given a broader base; provision for recycling these elements is established; and grid-electricity generation capacity is increased.

Creating plant to build more than a million electric cars per year is a large investment in manufacturing technology. Is it a good investment? Some argue that it is not because, like wind-turbines, EVs are not competitive in cost without a government subsidy. As with all energy-using products the unknown is the price of hydrocarbon fuels over the next 20 years and the currently externalised cost of carbon-induced climate change.

Human Capital. A healthy manufacturing base makes a positive contribution to Human Capital: the jobs created by the automobile industry contribute to wealth and potentially to the well-being of the population of the nation in which they are built. But electric vehicles can contribute to human capital in this way only if they are widely accepted by the driving public. The limited range, at present, is an obstacle to acceptance.

Table 2. Synthesis: influence of the facts on the three capitals

	Human and social capital - People Health? Wellbeing? Convenience? Culture? Tradition? Associations? Perceptions? Contributes to equality? Morality?	**Natural capital - Planet** *Can prime objective be met? Are stakeholder concerns addressed? Are there unwanted consequences*	**Manufactured capital - Prosperity** Cost – Benefit? (Cost facts vs. Eco facts) Legitimacy? (Conformity with law)
Materials	**(–) Creates dependence on rare-earth and lithium-producing nations**	**(–) Creates demand for critical elements, notably Lithium and Neodymium, in kg-quantities per car** **(+) Use of Li and Nd in kg-scale components makes collection for recycling easier**	**(–) Requirement to create recycling infrastructure for lithium- and rare-earth elements**
Energy	**(+) Could reduce dependence of imported fossil fuels in oil-poor nations**	**(–) Very little contribution to carbon emissions unless national grid is decarbonized**	**(+) Creates employment in energy sector** **(–) Need for to additional power stations** **(–) Need for investment in recharging point**
Environment	**(+) Reduces emission levels in large cities**	**(+) Offers potential for clean energy for transport**	–
Legislation	**(+) Helps meet the nation's commitments to reduce emissions**	**(+) Take-back and recycling legislation reduces waste stream, contribute to a circular economy**	**(–) Meeting end-of-life regulations creates additional costs**
Economics	**(–) Need to subsidize sales of electric cars becomes a "green" tax.**		**(–) Profitability uncertain without government subsidies** **(–) Large capital investment in new electricity generating plant to provide for charging**
Society	**(+) Satisfaction in using an "emission-free" transport** **(–) Range anxiety** **(–) Paucity of charging points**		**(+) Creates employment in high-tech industry** **(+) Creates jobs, stimulates local industry**
Synthesis (the most telling facts)	**(+) Satisfaction reducing environmental impact** **(–) Dissatisfaction with green taxes used to subsidize green transport**	**(+) Ultimate success dependent on new battery technology , decarbonized grid and adaptation to range limitations – impossible in short term** **(+) But potentially possible in the long term.**	**(–) Electric cars not, at present, economic. Many issues to be resolved to make it so.**

5. Reflection on alternatives

Short term.

This is the moment to consider alternatives. Can the Prime Objective be achieved in the way assumed in the remit – by replacing petrol-driven cars by EVs that are used in the same way? It does not seem so. EVs cannot provide the range, convenience of refuelling or (at present) the economy that consumers expect. Even more tellingly: charging EVs from the national grid of most nations carries a carbon footprint larger than that of many small IC and hybrid-powered cars today.

Long term

This is where the opportunity to expose innovation potential lies. To develop these alternatives further students might return to the "society" and "economics" dimensions and explore the options and limitations for change in use and organisation, thereby escaping the idea of an electric car as a simple substitute for one with and internal combustion engine.

Electric cars are good for short journeys. Could the public be re-educated to think of electric cars in a new way, not as a simple replacement for an IC engine car, but as a vehicle well-adapted for urban use, when range is less important? Could it be made attractive to own a small electric car for daily commuting and rent a larger IC car for longer journeys, vacations or employment that required one? Or could large companies provide electric cars and on-site charge-points for staff, subsidising their commuting in a way that best used electric vehicles? A shift from private ownership to fleet ownership by municipalities, service providers and employers with provision of recharging points at supermarkets, car-parks and place of work could make better use of the strengths of electric transport.

A central issue for electric transport is that of energy density. Suppose we accept that transport is best powered by high energy-density fuels with which batteries cannot compete. Technology exists for synthesizing hydrocarbons from CO_2. Rather than using electrical power to charge batteries, could it be used to synthesize methanol or ethanol to drive efficient IC-powered cars? The infra-structure for fuel distribution and maintenance already exits, and by drawing the CO_2 from industries that emit it such as power-stations, or cement works or from the atmosphere, true carbon-neutrality might be possible.

Electric vehicles can perform another, quite different function, that of making intermittent renewable energy from wind and solar sources more practical. Most cars are in use for less than 4% of the average day. Electric vehicles can then be charged during off-peak hours at cheaper rates while helping to absorb excess night time generation. The excess rechargeable battery capacity can then provide power to the electric grid in response to peak load demands. The vehicles serve as a distributed battery storage system to buffer power.

Sustainable Development Projects

- **Projects**
  - Project 1 : Greener Beer Cans
  - Project 2 : Expanding Biopolymer Production
  - **Project 3 : Electric Cars**

- **Resources**

Students

- Problem statement
- Templates
- Assessing Sustainable Development

Educators

- Summary Presentation
- **Sample Analysis**
- Related Projects

A White Paper called Materials and Sustainable Development and a book of the same name describe this methodology and the rationale behind it in more detail.

http://teachingresources.grantadesign.com/Type/Papers/PAPSSDEN13

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