Sample Streamlined Life Cycle Assessment Project

Background
I chose to compare two vehicles, a battery electric vehicle (BEV), which is powered by energy stored in batteries, and a hybrid electric vehicle (HEV), which is powered by an internal combustion engine that is coupled to a battery or other energy storage device. HEV's have two drivetrains, a mechanical system, which is powered by the internal combustion engine and an electrical system, which is powered by an energy storage unit (battery). Unlike BEV's, HEV's do not have to be plugged in to recharge their batteries, instead the HEV has a regenerative braking system, which utilizes the energy usually lost to friction (heating) in order to recharge the battery. Figure 1 shows a schematic diagram of a typical HEV. In contrast, BEV's (Figure 2) derive all of their energy from batteries and must be plugged in frequently in order to recharge. I chose these products because automakers have recently begun marketing hybrid-electric vehicles and I hoped that the LCA procedure would indicate which vehicle is better for the environment. There are many different variations on the designs of each vehicle, therefore, I chose two particular models in order to perform the LCA. The first, Honda's Insight (Figure 3), is the first hybrid electric vehicle to be sold in the United States. I chose to compare this to GM's EV1 (Figure 4), an electric vehicle that is also currently for sale in the United States. The functional unit of this analysis is one car.

Figure 1: A Typical Hybrid Electric Vehicle (HEV). Source: **www.hev.doe.gov/**

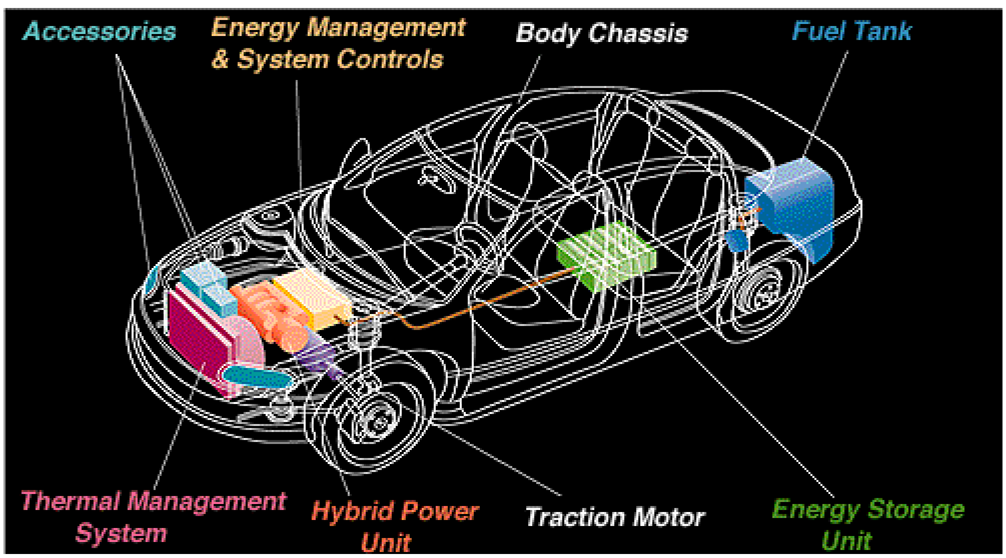


Figure 2: Ford's ECOSTAR, a battery-electric vehicle (BEV).
Source: **www.u.ford.com/electricvehicle/**

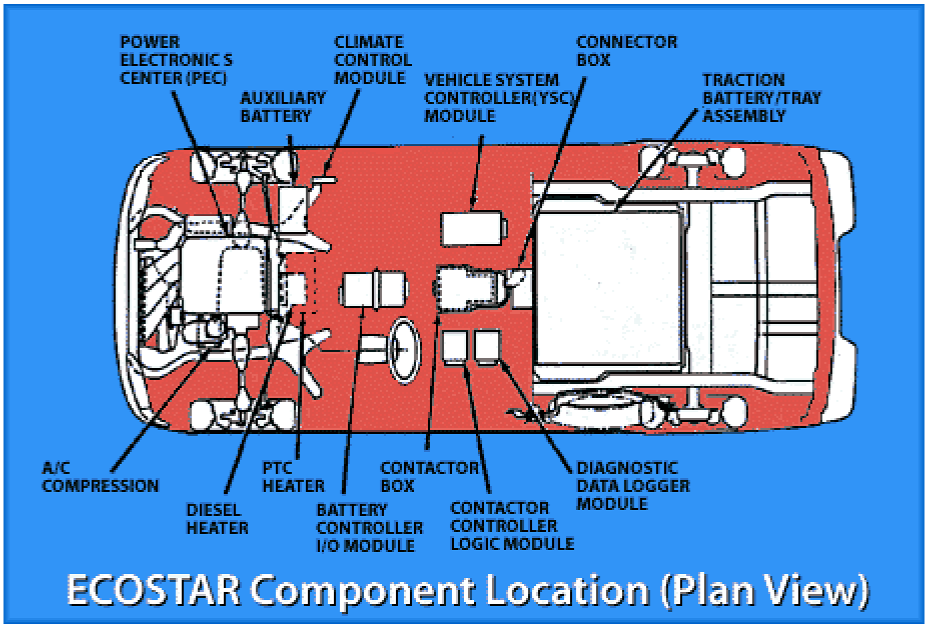
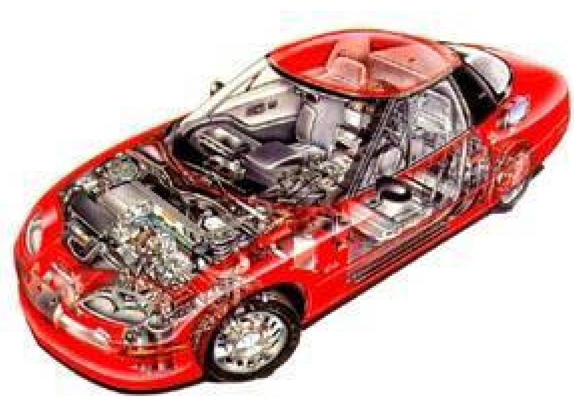


Figure 3: Honda's Insight, a hybrid electric vehicle (HEV).
Source: **www.honda2000.com**

Figure 4: GM's EV1, a BEV.
Source: **www.gmev.com**



Matrix 1: Upper numbers (in red) in each cell are scores are for a battery electric vehicle (BEV), lower numbers are for a hybrid electric vehicle (HEV)

	Material Use	Energy Use	Solid Residues	Liquid Residues	Gas Residues	**Totals**
Premanufacture	2 4	2 3	2 3	2 2	3 3	11/20 15/20
Product Manufacture	2 4	2 3	3 2	2 3	3 4	12/20 16/20
Product Delivery	3 3	2 2	3 3	4 4	3 3	15/20 15/20
Product Use	4 1	4 3	2 3	4 3	4 2	18/20 12/20
Refurbishment, recycle, disposal	3 3	2 3	4 3	4 3	2 3	15/20 15/20
Totals	14/20 15/20	12/20 14/20	14/20 14/20	16/20 15/20	15/20 15/20	**71/100** **73/100**

Justification of Matrix Scores

MATERIAL USE

Premanufacture

Battery-electric vehicles (BEV) rely on aluminum alloys for body, chassis (tires, suspension, steering mechanisms), front and rear suspension components and wheels. Batteries can be either lead-acid or nickel metal hydride. Toxics will be used (acids) to make the batteries. However, much of the material is provided from recycled sources (the lead-acid battery is made of 60% recycled lead).

Score: 2

Hybrid-electric vehicles (HEV) also rely heavily upon aluminum. Aluminum alloys are used in the body, chassis and suspension systems. Like the BEV, much of the materials used are recycled. HEV batteries are typically nickel metal hydride. However, the batteries used are much smaller than those needed for a BEV. An HEV needs a conventional engine (although small) which probably offsets the benefits of using smaller batteries. A HEV is much lighter than a BEV. Honda's Insight (HEV) weighs 1847 pounds, while the battery pack alone of the GM's EV1 weighs 1310 pounds (total weight is 2848 pounds). This indicates that fewer raw materials were needed to construct the HEV and results in an overall better score for the HEV.

Score: 4

Product Manufacture

The largest difference between the manufacture of BEV's and the manufacture of HEV's is that BEV's will require very large, heavy batteries, while HEV's will require both a small conventional engine and small batteries. The much heavier weight of BEV's

indicates that more materials will be needed to make a BEV. In addition, toxics will be used to manufacture the large batteries of BEV's.
BEV Score: 2
HEV Score: 4

Product Delivery
Product delivery techniques should be very similar for HEV's and BEV's.
BEV and HEV Score: 3

Product Use
BEV's have very little maintenance requirements other than replacing the batteries. The batteries will have to be replaced several times over the vehicles lifetime, but they are 98% recyclable.
BEV Score: 4

HEV's have many more moving parts than a BEV. As a result, an HEV will require much more maintenance over its lifetime and will require many more lubricants (oil). In addition, HEV's rely on gasoline as a power source.
HEV Score: 1

Refurbishment, Recycle, Disposal
The aluminum alloys used in BEV's are 100%recyclable. Similarly, the lead-acid batteries are 98% recyclable. HEV components are also highly recyclable. Any differences in recyclability, refurbishment and disposal between HEV and BEV components should be negligible, therefore they receive the same score.
BEV and HEV Score: 3

ENERGY USE

Premanufacture

BEV's will require the use of more raw materials than HEV's and the process is energy intensive.

BEV Score: 2

HEV Score: 3

Product Manufacture

The manufacture of large batteries required in the creation of BEV's is energy intensive.

BEV Score: 2

HEV's do not require the manufacture of large batteries, but they do require the manufacture of a small internal combustion engine. The energy requirement to make an internal combustion is probably much smaller than that required to make large batteries.

HEV Score: 3

Product Delivery

BEV and HEV deliveries should be similar and both are expected to be energy intensive, as vehicles are made in only limited locations, but are sold everywhere.

BEV and HEV Score: 2

Product Use

While the BEV no longer relies directly on fossil fuels, it does rely on the burning of coal to make power plant energy, which is then utilized when the BEV is recharged. However, this process is more energy efficient than direct burning of fossil fuels by conventional engines.

BEV Score: 4

The HEV relies on the burning of gasoline (fossil fuels) to create energy. The Insight (HEV) gets 61 to 70 miles per gallon. This can be compared to the EV1 (BEV), which only obtains 26 to 30 miles per gallon. The HEV's greatly increased fuel efficiency drastically reduces the amount of energy used.

HEV Score: 3

Refurbishment, Recycle, Disposal

BEV's will require more energy in recycling, due to the many large batteries they will produce that will need to be recycled.

BEV Score: 2

HEV's will have recycling needs that are similar to a conventional car, except that they will have a larger battery (or several small batteries) to recycle. The energy required to disassemble, recycle and dispose of parts should be moderate.

HEV Score: 3

SOLID RESIDUES

Premanufacture

Mining will be a significant source of solid residues during the premanufacturing of both BEV's and HEV's. However, again due to the heavier mass needed to construct one BEV, the impact of the BEV will be greater.

BEV Score: 2

HEV Score: 3

Product Manufacture

Solid wastes will be generated when batteries are produced and scrap metal will be produced when body, chassis, and suspension system components are produced.

BEV Score: 3

In HEV production the major source of solid waste will be scrap metal. Since the HEV has many more moving parts, it is likely to generate more solid waste than a BEV.

HEV Score: 2

Product Delivery

In delivery of both BEV's and HEV's significant amounts of packing material are generated. The amounts of wastes generated should be comparable.

BEV and HEV Score: 3

Product Use

BEV's will have significantly more solid waste produced, in the form of large batteries. Both vehicles will produce old tires as solid waste, however, the fact that the BEV is much heavier than the HEV may mean that it will produce more tires over it's lifetime.

BEV Score: 2

HEV's will also generate solid waste in the form of batteries, but this should be a much smaller amount. However, due to the many more moving parts, HEV's will also generate old parts as solid waste. Although, when compared to the very large batteries being produced for BEV's, solid waste generated by old parts from HEV's will be much smaller.

HEV Score: 3

Refurbishment, Recycle, Disposal

Although BEV's will produce significant amounts of batteries, these batteries are 98% recyclable. In addition, the aluminum structure components are 100% recyclable.

BEV Score: 4

The HEV will produce old parts, which may or may not be recyclable.

HEV Score: 3

LIQUID RESIDUES

Premanufacture

Mining of metals will be a significant source of liquid waste generation for both HEV's and BEV's.
BEV and HEV Score: 2

Product Manufacture

The manufacture of the batteries needed for BEV's will be a significant source of liquid waste. This liquid waste will be toxic and difficult to dispose of, as acid is used in the manufacture of batteries. Other liquid wastes will be generated in part cleaning and painting processes.
BEV Score: 2

Since the batteries needed in a HEV are much smaller, less liquid waste will be generated. A more significant source of waste will be the painting and cleaning of parts.
HEV Score: 3

Product Delivery

Very little liquid waste will be generated in the shipping of BEV's and HEV's.
BEV and HEV Score: 4

Product Use

A BEV will generate very little liquid waste when used, due to the fact that it has very few moving parts and will therefore require very few lubricants.
BEV Score: 4

HEV's require lubricants and these systems may leak, releasing liquid waste to the environment. In addition, used oil and other lubricants will be generated and need to be disposed of on a regular basis.
HEV Score: 3

Refurbishment, Recycle, Disposal

Since a BEV generates negligible liquid waste, there is little recycling or disposal of liquid wastes.
BEV Score: 4

Some of the wastes generated by a HEV are recyclable.
HEV Score: 3

GAS RESIDUES

Premanufacture

Metal smelting generates some gaseous wastes during BEV and HEV premanufacturing.
BEV and HEV Score: 3

Product Manufacture

Manufacturing can produce gas residues from paint aerosols. The amount produced should be comparable for BEV’s and HEV’s. However, battery production may produce significantly more gaseous waste, as plastics may be used. Therefore, BEV production may produce more gaseous waste than HEV production.
BEV Score: 3
HEV Score: 4

Product Delivery

When BEV’s and HEV’s are both delivered they will generate greenhouse gases. Both these generations should be very similar.
BEV and HEV Score: 3

Product Use

BEV’s are classified as Zero Emission Vehicles (ZEV) and produce 97% fewer emissions than a conventional car. Figure 5 depicts the emissions levels associated with ZEV’s.
BEV Score: 4

HEV’s are classified as Ultra Low Emission Vehicles (ULEV) in California and Low Emission Vehicles (LEV) in other parts of the country.   Figure 6 shows the emission levels associated with ULEV’s and LEV’s. Although HEV’s have much lower emissions than conventional cars, they are not as environmentally sound as BEV’s.
HEV Score: 3

Refurbishment, Recycle, Disposal

Recycling may involve the generation of some gaseous residues. Since BEV’s would have much more batteries to recycle, they may generate more gaseous wastes.
BEV Score: 2
HEV Score: 3

Figure 5: BEV's are classified as Zero Emissions Vehicles (ZEV). The CARB Level shows a lower emissions, because it reflects power availability within the Los Angeles Basin. Since a large portion of power used in the LA basin is imported from outside sources, there are no local emission consequences resulting from this use. In addition, LA basin has a high reliance on natural gas, which reduces emissions. The more typical mix represents the impact of ZEV's in other parts of the country, where coal is more heavily relied upon and less power is imported.
Source: www.hev.doe.gov

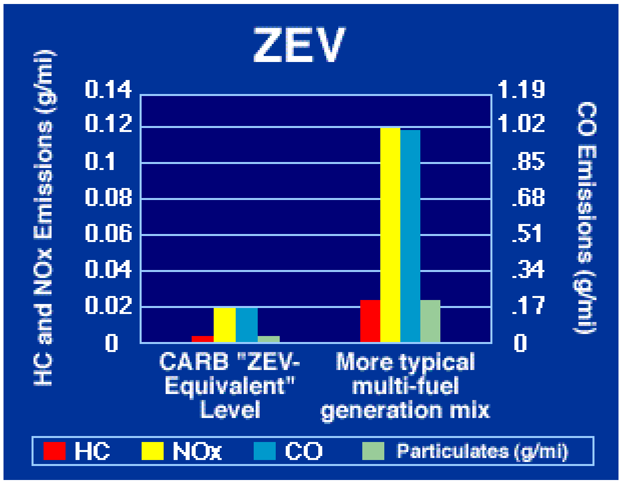
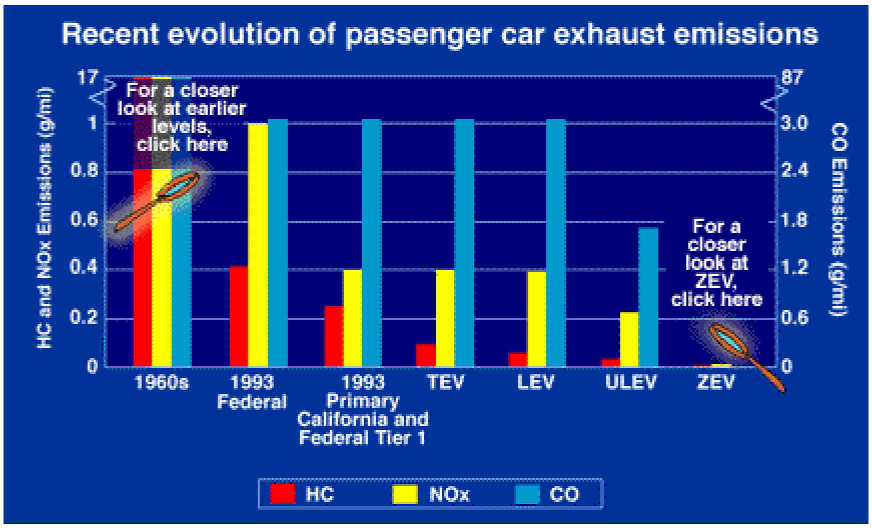


Figure 6: Emissions from LEV's and ULEV's. In California HEV's are classified as ULEV's and in other areas are classified as LEV's.
Source: www.hev.doe.gov



a. Score Weighting

I chose to weight the product use stage of the life cycle as half the total assessment value and the other four stages were weighted as one-eighth the total assessment value. The product use stage was heavily weighted because it is by far the longest of the life cycle stages and will have the largest environmental impact.

The gaseous residues environmental impact was weighted at one half the total assessment value and the other four impacts were weighted as one-eighth the total assessment value. Automobile designs are being driven by the need to decrease greenhouse gas emissions, which is why gaseous residues was heavily weighted. Another approach would be to weight the materials choice impact heavily, as new technologies are also being developed n order to decrease our reliance on fossil fuels.

Matrix 2: Weighting values used for the doubly-weighted matrix.

	Materials Choice	Energy Use	Solid Residues	Liquid Residues	Gaseous Residues
Premanufacture	0.39	0.39	0.39	0.39	1.56
Product Manufacture	0.39	0.39	0.39	0.39	1.56
Product Delivery	0.39	0.39	0.39	0.39	1.56
Product Use	1.56	1.56	1.56	1.56	6.25
Refurbishment, Recycling, Disposal	0.39	0.39	0.39	0.39	1.56

Matrix 3: The Doubly-Weighted Environmentally Responsible Product Assessment for a BEV (upper numbers) and a HEV.

	Material Use	Energy Use	Solid Residues	Liquid Residues	Gas Residues	**Totals**
Premanufacture	0.78 1.56	0.78 1.17	0.78 1.17	0.78 0.78	4.68 4.68	7.8/12.5 9.36/12.5
Product Manufacture	0.78 1.56	0.78 1.17	1.17 0.78	0.78 1.17	4.68 6.24	8.19/12.5 10.92/12.5
Product Delivery	1.17 1.17	0.78 0.78	1.17 1.17	1.56 1.56	4.68 4.68	9.36/12.5 9.36/12.5
Product Use	6.24 1.56	6.24 4.68	3.12 4.68	6.24 4.68	25 12.5	46.84/50 28.1/50
Refurbishment, recycle, disposal	1.17 1.17	0.78 1.17	1.56 1.17	1.56 1.17	3.12 4.68	8.19/12.5 9.36/12.5
Totals	10.14/12.5 7.02/12.5	9.36/12.5 8.97/12.5	7.8/12.5 8.97/12.5	10.92/12.5 9.36/12.5	42.16/50 32.78/50	**80.38/100** **67.1/100**

c. Methodology

There are several weaknesses in the streamlined LCA analysis. The scores are very subjective and finding data to support score estimates was very difficult. This was especially true for these two vehicles, as both are relatively new to the market. Also, for products like these two, which are very similar, the results of the non-weighted LCA showed no significant difference in overall score (BEV=71, HEV=73). The weighted LCA showed that BEV's are a better alternative (BEV=81, HEV=67), however, this result will vary depending on which life cycle stage and which environmental impact are weighted. Therefore, I found it very difficult to make decisions based on the results of this LCA.

In addition, this method fails to account for the effectiveness and practicability of each product. In this case, one weakness of battery electric vehicles (BEV's) is that they can only travel 50 to 100 miles before they must be recharged. This contrasts sharply with HEV's, which can travel an estimated 600 to 700 miles on only one tank of gas. Although the BEV was indicated to be a better alternative for the environment when the scores were weighted, in practice the BEV is unrealistic. In addition, the EV1 sells for $33,995, while the Insight (HEV) sells for $18,880. Therefore, large differences in price may mean that they may never occupy more than a small niche in the marketplace. Also, if a HEV and a BEV were each compared separately to a conventional car (instead of to each other), the results would probably have been very different.

One benefit of using the streamlined LCA method is that it illustrates areas where environmental improvements are needed. For example, BEV's had the lowest score in the premanufacture stage, while HEV's had the lowest score in the product manufacture stage.

The information utilized to perform this streamlined LCA was found on the following websites:

www.honda2000.com
www.hev.doe.gov/
www.hypercarcenter.org/root.html
www.gmev.com
www.rmi.org
www.u.ford.com/electricvehicle/