Lesson – BEV/FCV Project

Concepts

1. Internal Combustion Engines (ICE's) pollute the air and contribute to the increasing amount of carbon dioxide in the atmosphere. Battery Electric Vehicles (BEV's) and/or Fuel Cell Vehicles (FCV's) could someday replace ICE technology to help solve this problem.
2. There are many factors contributing to why we are still driving gas-powered cars today. It is important to understand the technological, economic, and social requirements for a new technology to succeed.
3. We compare energy conversions through efficiency calculations. Efficiency is (output / input) X 100%.

Activities:

- Introduce the Project Statement: *Convince GM to invest or not to invest in a Fuel Cell Car (or Battery-Electric Car).* Split the class into two groups; a fuel cell group and a battery-electric group. Each student will be responsible for a presentation which supports or doesn't support the use of their assigned technology in a new car to be designed by General Motors.
- (Note – the video – "Who Killed the Electric Car" would be a valuable supplement here)
- Brainstorm with the class. How can we compare these technologies? What do we need to find out? What do we already know?
- Show a power-point presentation (Batteries & Fuel Cells.ppt) on the histories of the gas-powered, electric, and fuel cell cars. Handout a fact sheet with the info from the presentation (Fuel Cell Car & BEV History.doc). Encourage the students to use this sheet and the references on the sheet as a starting point, but they need to find some new sources of information too.
- Have the students recall the fuel-cell car demo and battery-car demo from the previous week. Bring the models back into class and give more detail on the operation of the cars. Remind the students that potential energy is stored energy and kinetic energy is energy in motion. Ask the students what states of energy are at the different stages of car operation (ES pg. 309). Where is energy being converted into non-useful energy?
- First-law efficiency is the measure of the output/input x 100% (ES pg.310). If we say that a car is only 60% efficient, then 40% of the energy going into it is

being wasted as exhaust, heat, noise, or any other non-useful energy. Almost nothing is 100% efficient (maybe the firefly).

- Talk about car miles/gallon and how we use it to compare a car's efficiency. Why do most cars have the same shape these days? Talk a bit about aerodynamic effects.

Resource Files

Batteries & Fuel Cells.ppt

BEV vs. FC – project Statement

Botkin & Keller's "Environmental Science: 4th edition" Chapter 22. 2003, Wiley

Environmental Science Special Project

Fuel Cell and Battery Electric Cars

Currently, hybrid cars are expensive, electric cars are really expensive, and fuel cell cars are unavailable to the public. GM (General Motors) is the world's largest car manufacturer. If they were able to successfully mass produce and sell an affordable sedan that ran solely on renewable resources, not only would the company benefit, but so would the environment. If the project were to fail, GM would not likely try again anytime soon. With the uncertainty that new technology brings to the marketplace, GM has reason to hesitate.

Should they really go forward with the FCC (Fuel Cell Car) or should they manufacture a BEV (Battery Electric Vehicle)? As an advisory group to GM, it is your goal to make a convincing argument for or against one of these technologies. The class will be split into FCC and BEV research groups. Your tasks are listed below. We will work on most of these during the class period but some outside research is required. Presentations will be made on February 14^{th} and 15^{th}.

Project Tasks

How will you decide whether to promote or discourage the mass production of FCCs/BEVs? You will need to come up with criteria for making a recommendation.

What important questions need to be answered? As we learn more about Batteries and Fuel Cells, you may want to revise your criteria.

What can we learn from the past? What are the concerns of the public? of GM?

Finalize your criteria.

Make a weighted objectives table.

Individual Written Report (2-3 pages, 12pt., single-spaced)

Group Presentation: 10-15 minutes, use a slideshow or transparencies for charts and figures

United States of America Forum on Sustainable Transportation

The Kyoto Protocol shares the ultimate objective of the United Nations Framework Convention on Climate Change…to stabilize atmospheric concentrations of greenhouse gases at a level that will prevent dangerous interference with the climate system.[1]

Although the forty-third president of the United States of America has committed the United States to "work within the United Nations framework and elsewhere to develop with our friends and allies and nations throughout the world an effective and science-based response to the issue of global warming," George W. Bush has indicated that he will not submit the Kyoto Protocol for ratification by the United State congress…

> *This [global warming] is a challenge that requires a 100 percent effort; ours, and the rest of the world's. The world's second-largest emitter of greenhouse gases is China. Yet, China was entirely exempted from the requirements of the Kyoto Protocol. India and Germany are among the top emitters. Yet, India was also exempt…Kyoto also failed to address two major pollutants that have an impact on warming: black soot and tropospheric ozone. Both are proven health hazards. Reducing both would not only address climate change, but also dramatically improve people's health… Yet, America's unwillingness to embrace a flawed treaty should not be read by our friends and allies as any abdication of responsibility.*[2]
>
> *-President George W. Bush (June 11, 2001)*

In December 2007, the United Nations Framework Convention on Climate Change was held in Bali. The Conference brought representatives of over 180 countries together with observers from intergovernmental and nongovernmental organizations, and the media. The two week period included the sessions of the Conference of the Parties to the UNFCCC, its subsidiary bodies as well as the Meeting of the Parties of the Kyoto Protocol. Did the United States maintain its responsibility in 2007?

> *I am not an official and I am not bound by diplomatic niceties, so I am going to speak an inconvenient truth*[A]*: My own country, the United States, is principally responsible for obstructing progress here in Bali.You can feel anger and frustration and direct it at the United States of America. Or you can make a second choice, you can decide to move forward and do all of the difficult work that needs to be done.*[3]
>
> *- Al Gore, who narrowly lost to Bush in 2000 (Dec 14, 2007)*

[A] Shameless plug for his movie *An Inconvenient Truth*, "which offers a passionate and inspirational look at one man's fervent crusade to halt global warming's deadly progress in its tracks." - http://www.climatecrisis.net/

What is the United States' responsibility? This country emitted 6.9 billion metric tons of carbon dioxide equivalents in 2003. Compared to other high income countries, the United States is by far the worst emitter, ranking the worst out of surveyed countries.[4] Figures 1 and 2 show that although U.S. per capita greenhouse gas emissions are slightly decreasing, the country's population is growing and its total output continues to climb.

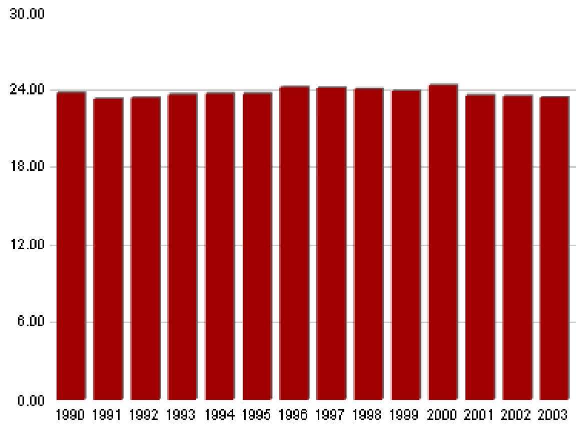

Figure 1: Total United States GHG Emissions in tons of CO2 equivalents per person.

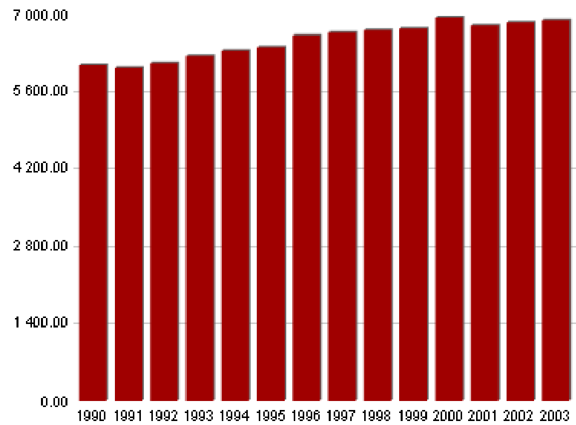

Figure 2: Total U.S. Emissions of GHG in Tg CO_2 equivalents.

Greenhouse gases are a global problem, but where are the U.S. emissions coming from? The pie charts in Figure 3 shows that transportation accounted for 27% of all U.S. greenhouse gas emissions in 2000, and 36% of those emissions came from passenger cars.

Each year Americans travel a total of 4.8 trillion person-miles, an amount nearly equivalent to a yearly trip around the world for each person. The U.S. also has the most mobile economy in the world and in 2001, 3.7 trillion ton-miles of freight were moved to make production and consumption possible.[5]

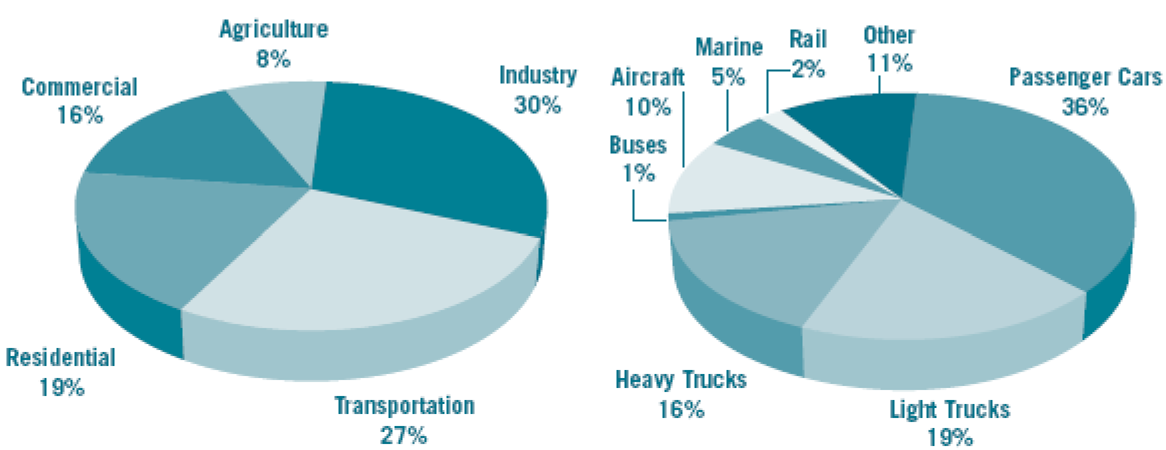

Figure 3: The pie chart on the left tells us that transportation accounts for 27% of all U.S. greenhouse gas emissions in 2000, while the pie chart on the right tells us that 36% of those emissions are coming from passenger cars (U.S. EPA 2000).[5]

An automobile may get you where you need to go, but it is a significant source of pollution and greenhouse gases. By combusting gasoline, your car or truck emits hydrocarbons, nitrogen oxides (NO_X), carbon monoxide (CO), and carbon dioxide (CO_2) from its tailpipe, but have you ever considered the emissions associated with the manufacturing, maintenance, and disposal of your vehicle?

Are there enough fossil fuels to keep you chugging happily for the rest of your life or does Hubbert have a point to his peak? In 1956, geophysicist M. King Hubbert predicted that U.S. oil production would reach its highest level in the early 1970s. Though roundly criticized by oil experts and economists, Hubbert's prediction came true in 1971.

The United States of America Forum on Sustainable Transportation will be convened on June 27, 2008 to address the issues associated with personal transportation.

What will the car of the future look like, what will power it, or will we even have personal vehicles?

The United States of America Forum on Sustainable Transportation Group Project

Potsdam High School has been awarded a great honor, choosing St. Lawrence County's representatives to the forum on sustainable transportation!

- Your class will divide into teams of three (one team of four) to create a platform for sustainable transportation. What will the car of the future look like, what will power it, or will we even have cars? What is best for your community?
- On Wednesday, Feb. 13th, each team will present their platform and the class will hold representative elections on Thursday, Feb. 14th. Presentations must be eight-ten minutes, include visuals, and each group member must speak during the presentation.

Presentations will be graded by the following rubric

Time limit (8-10 minutes)	____/10 points
All group members actively participated in the presentation	____/10 points
Team presented a clear platform for sustainable transportation	____/20 points
Team clearly explained the reasoning behind their platform	____/20 points
Team evaluated their platform for sustainably, pollution prevention , and economics (10 pts. each).	____/30 points
Peer evaluations	____/10 points

[1] *Kyoto Protocol Reference Manual on Accounting of Emissions and Assigned Amounts*, http://unfccc.int/files/national_reports/accounting_reporting_and_review_under_the_kyoto_protocol/application/pdf/rm_final.pdf (Accessed Nov. 2007).
[2] The Whitehouse. "*President Bush Discusses Global Climate Change*" Press Release June 11, 2001, http://www.whitehouse.gov/news/releases/2001/06/20010611-2.html (Accessed Nov. 2007).
[3] http://www.thebalitimes.com/2007/12/14/gore-urges-bali-talks-to-go-ahead-without-us/ (Accessed Dec. 2007).
[4] *Emissions of greenhouse gases, as reported to the United Nations Framework Convention on Climate Change*, http://globalis.gvu.unu.edu/indicator.cfm?Country=US&IndicatorID=196#rowUS (Accessed Nov. 2007).
[5] David L. Greene, Oak Ridge National Laboratory and and Andreas Schafer, Massachusetts Institute of Technology, *Reducing Greenhouse Gas Emissions from U.S. Transportation*, http://www.pewclimate.org/, (Accessed Nov. 2007).

Clarkson STEM Program
Final Project
Problem Statement


50 mpg **200 "mpg"** **∞ mpg**

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Situation: Issues surrounding our fossil fuel based transportation system, including environmental impacts, limited fuel supplies, and increased economic burden, have inspired the development of many different types of new vehicles.

Problem: Many of these new cars are powered by different types of fuels, making it difficult to compare energy use in terms of our traditional "miles per gallon" standard.

Your Task: As part of a special interest group, it is your task to develop and present a new way to compare vehicles that makes more sense in our changing society, particularly from your group's perspective.

You should consider:

- Whether to use lifecycle energy efficiency/impacts or the impacts at the vehicle use stage.
- What "Efficiency metric" or "sustainability metric" might be better than the traditional miles per gallon. Options can include total energy use, petroleum energy use, fossil energy use or emissions on a per mile basis.

Sustainability and Transportation Fuels

Group 1 – Environmental (Global Warming)

Your group is an advisory committee for an important environmental lobbying firm. The firm you work for will be critically **evaluating different options for future transportation from an environmental point of view, specifically reducing carbon footprint**. This firm is very influential in the world of politics and big business, so the results of their evaluation can have very significant effects on the future of transportation. Their influence is crucial to guiding the transportation industry in an environmentally friendly direction, by reducing the greenhouse gases emitted during transportation. While the firm executives are somewhat knowledgeable regarding vehicle and fuel efficiencies, they are not experts. The executives of the firm DO know that they cannot rely on "miles per gallon" as a measure to compare efficiencies of vehicles that run on different kinds of fuels. However, they don't understand why.

The descriptions of three vehicle types shown below were received from special interest groups. Their special interest is in the future of the industry related to these vehicles, but not necessarily in protecting the environment. It is your job to come up with a new **efficiency metric**, a way of measuring efficiency, that can be applied to all three of these vehicles. Remember that the firm's goal is to promote whatever type of vehicle would be most helpful in reducing carbon footprint and global warming, so they need to be able to objectively compare the efficiencies of the three vehicles.

Group 2 – Government (energy independence)

Your group is an advisory committee working for the US government. One of the goals of the new administration is to **reduce dependence on foreign energy (petroleum) supplies**. Keep in mind that while America produces very little crude oil these days, we do have significant coal and natural gas reserves. Since the transportation sector is responsible for a large proportion of this country's foreign oil consumption, options for increasing vehicle efficiencies or using renewable fuels are promising "weapons" in this new "war". Politicians in Washington want to promote a new vehicle type that would best help reduce American dependence on foreign energy supply. Government promotion will likely include spending lots of taxpayer money. The president's science advisors know that the metric of "miles per gallon" is not reliable for comparing vehicles that run on different fuels. However, they don't understand why.

The descriptions of three vehicle types shown below were received from special interest groups. Their special interests lie in the future of the industry related to these vehicles, but not necessarily in achieving energy independence for the US. It is your job to come up with a new **efficiency metric**, a way of measuring efficiency, which can be applied to all three of these vehicles. Remember that the government's goal is to promote whatever type of vehicle would most effectively help achieve energy independence for the US, so they need to be able to objectively compare the efficiencies of the three vehicles.

Group 3 – Sociologists (Peak Oil and dependence on non-renewable resource)
Your group is helping to advise a group of sociologists concerned with America's dependence on non-renewable fossil fuels. We have been, and continue to rely on the limited resources of oil, coal, and natural gas. Unfortunately, when crude oil production peaked in the 1970's, we did not take the lesson to heart. Now we must change our ways quickly or face a devastating blow to our social structure. The group of sociologists wants to **recommend a new type of vehicle that will greatly reduce the use of any form of fossil fuel**. This will allow us more leeway in transitioning to a sustainable energy society. The sociologists DO know that they cannot rely on "miles per gallon" as a measure to compare efficiencies and fossil fuel consumption rates of vehicles that run on different kinds of fuels. However, they don't understand why.

The descriptions of three vehicle types shown below were received from special interest groups. Their special interest is in the future of the industry related to these vehicles, but not necessarily in reducing fossil fuel consumption. It is your job to come up with a new **efficiency metric**, a way of measuring efficiency, which can be applied to all three of these vehicles. Remember that the firm's goal is to promote whatever type of vehicle would be most helpful in reducing carbon footprint and global warming, so they need to be able to objectively compare the efficiencies of the three vehicles.

Vehicle Descriptions

Develop a way to compare the efficiency and impact of these three potential future vehicles:

Gasoline/Flex-Fuel

Gasoline-powered cars have been a mainstay of American transportation since the development of the automobile. Gasoline automobiles will continue to provide a significant proportion of personal transportation into the foreseeable future. Eventually, there may be a shortage of oil as a source of transportation fuel, but this can be counteracted through the use of ethanol as a fuel. Flex-fuel vehicles are already capable of running on fuel that is up to 85% ethanol (E85), and future vehicles will be capable of running on E100.

Electric

The efficiency of power transfer in an electric motor is far greater than that of a gasoline engine, ~90% compared with ~30%. Even if coal fired power plants supply electricity at 30% efficiency, eliminating pollution from densely populated cities would be a major advantage of electric over gasoline or diesel cars. As new battery technology is developed, such as Li-polymer cells, the electric car will become the clear choice for future transportation.

Hydrogen

The hydrogen-powered car is truly the car of the future. Fuel cell technology has allowed automakers such as Honda to present a realistic future for hydrogen cars. Hydrogen itself is an energy carrier and must be produced by some means, but even if fossil fuels are used to produce hydrogen, the carbon footprint of a hydrogen car can be less than that of a gasoline powered car. Ideally, renewable sources of energy will be used to produce hydrogen, eliminating pollution and making hydrogen a truly clean alternative. Iceland and Denmark are already using renewable energy to create significant amounts of hydrogen. Once the technology is developed to make hydrogen cars affordable, they will be the obvious choice for future transportation.

<u>Advanced (optional)</u> Many different types of vehicles may be used in the future, here are a few more, some not so futuristic, that would be interesting to compare along with the first three:

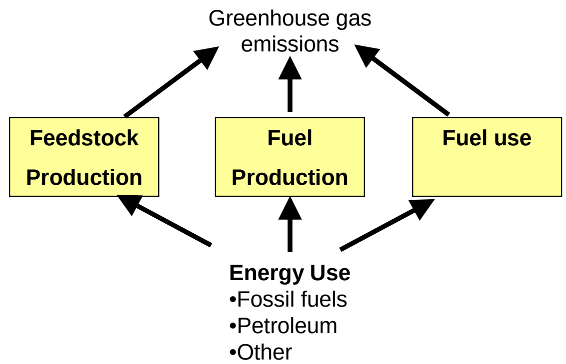
Hybrids – vehicles that can run on a combination of gasoline and electricity

High Occupancy Vehicles (like buses) – the purpose of transportation is to get people from one place to another, so why not move more people at once?

Bicycles – Free transportation energy?

Data available for the efficiency metric development

Many researchers are developing lifecycle assessment models that describe all of the energy consumption and emissions associated with transportation fuel production and use. Researchers at the Department of Energy Argonne National Laboratory developed the GREET[1] model that is used by many groups analyzing transportation impacts and policy. Results from the GREET model have been compiled for your use in this project.



The data included in the table below (and the attached spreadsheet) quantify how much energy is used in each of three lifecycle stages (Fig. 1). The life cycle stages include: feedstock production/extraction, fuel processing, and fuel use (in the vehicle). The energy consumption includes the total energy used as well as the petroleum and fossil fuel (petroleum, coal and natural gas) fractions of the total energy. Although not included in the tables, the non-fossil fuel energy used (nuclear, biomass, solar, wind etc.) can be calculated as the difference between the total energy and the fossil fuel energy consumed. The energy used includes all of the "upstream" processes. For example, the energy used to make nitrogen fertilizer is included in the feedstock (corn) production data. It is assumed that the electricity comes from the U.S. average sources of grid based electricity:

Coal-Fired Power Plants	50.7%
Natural Gas-Fired Power Plants	18.9%
Nuclear Power Plants	18.7%
Other Power Plants (hydro, wind, geothermal, etc.)	7.7%
Residual Oil-Fired Power Plants	2.7%
Biomass Power Plants	1.3%

Greenhouse gas (GHG) emissions are also included in the data table. GREET does provide estimates of all priority air pollutants (NOx, SOx, particulate mater, volatile organic carbons etc), although they are not included here.

Efficiency or sustainability metrics can include any of the following. These can be considered for the total lifecycle of the transportation system or just the vehicle use (as our present miles per gallon does). The units of your efficiency metric could include: Btus/mile, g GHG emissions/mile or their inverse. You could also consider adding # people to the denominator (e.g., Btus/mile/person) to explore the benefits of a full car.

[1] http://www.transportation.anl.gov/modeling_simulation/GREET/

Well-to-Wheels (WTW) Energy Consumption and Emissions: per Mile

(data from GREET model: SGGREET1 7.xlsm)
http://www.transportation.anl.gov/modeling_simulation/GREET/index.html

Life cycle stages include:
- feedstock production
- fuel production
- fuel consumption in an automobile

Gasoline Vehicle: Conventional Gasoline						Percentage of each stage		
Item	Units	Feed stock	Fuel	Vehicle Operation	Total	Feedst ock	Fuel	Vehicle Operation
Total Energy	Btu/mile	177	946	4631	5755	3.1%	16.4%	80.5%
Fossil Fuels	Btu/mile	171	934	4535	5639	3.0%	16.6%	80.4%
Coal	Btu/mile	33	174	0	207	15.9%	84.1%	0.0%
Natural Gas	Btu/mile	82	314	0	396	20.6%	79.4%	0.0%
Petroleum	Btu/mile	56	445	4535	5036	1.1%	8.8%	90.0%
GHGs	grams/mile	20	74	359	454	4.5%	16.4%	79.2%

Gasoline Vehicle: Low-Level EtOH Blend with Gasoline						Percentage of each stage		
Item		Feeds tock	Fuel	Vehicle Operation	Total	Feedst ock	Fuel	Vehicle Operation
Total Energy	Btu/mile	221	997	4631	5849	3.8%	17.0%	79.2%
Fossil Fuels	Btu/mile	213	983	4332	5528	3.9%	17.8%	78.4%
Coal	Btu/mile	40	199	0	239	16.8%	83.2%	0.0%
Natural Gas	Btu/mile	101	368	0	468	21.5%	78.5%	0.0%
Petroleum	Btu/mile	72	416	4332	4820	1.5%	8.6%	89.9%
GHGs	grams/mile	13	77	359	448	2.8%	17.1%	80.1%

EtOH Flex fuel vehicle (E85)						Percentage of each stage		
Item		Feed stock	Fuel	Vehicle Operation	Total	Feed stock	Fuel	Vehicle Operation
Total Energy	Btu/mile	645	2222	4410	7278	8.9%	30.5%	60.6%
Fossil Fuels	Btu/mile	624	2181	1164	3969	15.7%	54.9%	29.3%
Coal	Btu/mile	110	656	0	766	14.3%	85.7%	0.0%
Natural Gas	Btu/mile	288	1337	0	1625	17.7%	82.3%	0.0%
Petroleum	Btu/mile	226	187	1164	1578	14.3%	11.9%	73.8%
GHGs	grams/mile	-136	175	336	376	-36.2%	46.7%	89.5%

Electric Vehicle						Percentage of each stage		
Item		Feed stock	Fuel	Vehicle Operation	Total	Feed stock	Fuel	Vehicle Operation
Total Energy	Btu/mile	118	2042	1323	3483	3.4%	58.6%	38.0%
Fossil Fuels	Btu/mile	114	1772	1155	3042	3.8%	58.3%	38.0%
Coal	Btu/mile	19	1319	820	2157	0.9%	61.1%	38.0%
Natural Gas	Btu/mile	54	400	278	732	7.4%	54.6%	38.0%
Petroleum	Btu/mile	41	54	58	153	26.8%	35.2%	38.0%
GHGs	grams/mile	18	283	0	301	6.0%	94.0%	0.0%

FCV: G.H2			Fuel cell vehicle - gaseous H2			Percentage of each stage		
Item		Feedstock	Fuel	Vehicle Operation	Total	Feedstock	Fuel	Vehicle Operation
Total Energy	Btu/mile	152	1321	1996	3470	4.4%	38.1%	57.5%
Fossil Fuels	Btu/mile	151	1264	1996	3412	4.4%	37.1%	58.5%
Coal	Btu/mile	5	278	0	283	1.8%	98.2%	0.0%
Natural Gas	Btu/mile	138	963	1996	3097	4.4%	31.1%	64.5%
Petroleum	Btu/mile	9	23	0	32	27.3%	72.7%	0.0%
GHGs	grams/mile	22	214	0	236	9.2%	90.8%	0.0%

FCV: L.H2			Fuel cell vehicle - liquid H2			Percentage of each stage		
Item		Feedstock	Fuel	Vehicle Operation	Total	Feedstock	Fuel	Vehicle Operation
Total Energy	Btu/mile	154	3567	1996	5717	2.7%	62.4%	34.9%
Fossil Fuels	Btu/mile	153	3230	1996	5379	2.8%	60.0%	37.1%
Coal	Btu/mile	5	1647	0	1652	0.3%	99.7%	0.0%
Natural Gas	Btu/mile	139	1463	1996	3598	3.9%	40.7%	55.5%
Petroleum	Btu/mile	9	120	0	129	6.8%	93.2%	0.0%
GHGs	grams/mile	22	401	0	423	5.2%	94.8%	0.0%

Acronyms

FCV: fuel cell vehicle
L.H2: Hydrogen compressed for storage and transport as a liquid
G. H2: Hydrogen stored and transported as a gas
RFG: reformulated gasoline
CG: conventional gasoline
SI: spark injection
HEV: hybrid electric vehicle
CNGV: compressed natural gas vehicle
EtOH: ethanol