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Delphi Project -
Air Compression and Diesel Hybrid

EDSGN 100
Penn State University
December 15th 2014

Executive Summary:

Using the Delphi project guidelines, the team initially began thinking of design ideas after looking at customer needs. Each team member thought of three separate design ideas and did brief research on each concept. Afterwards, the team compared the findings and discussed which concepts were best.The team preferred the idea of a compressed air/diesel hybrid engine, but other design concepts also needed to be considered. Next, we used the Analytical Hierarchy Process (AHP) to rank key design features and the weighted numbers generated from this process were used in the Design Selection Matrix to evaluate the team's top three design ideas: The diesel/air compression hybrid, cylinder deactivation in the engine, and external airbags to protect pedestrians and other cars during accidents. Using the weighted numbers, the diesel/air compression hybrid system was the highest ranked. To finalize that this was the design focus, over 60 people were surveyed. The survey results showed that the majority of them were most interested in the hybrid system as well. This winning concept introduces a new type of hybrid engine technology into the market and has the potential for incredible fuel efficiency, which matches one of Delphi's megatrend goals for greener cars.

Introduction:

The objective of this project was to research and develop a design that would help make cars safer, greener, and more connected. The technology is required to improve on at least two of these megatrends and cannot make any of them worse. The team focused primarily on the green megatrend, as our design is almost completely about fuel efficiency. Along with being more fuel efficient, there is no pollution given off when the vehicle is running off of compressed air, making the design an even better solution to the green megatrend. This is important because Delphi utilizes its technologies to protect human health, the environment, and natural resources ("There Is Only One Planet to Support All of Us"). Since Delphi is largely focused on this and has already created technologies that support these statements, the teams' idea of an air compression/ diesel hybrid engine system fits in nicely with Delphi's objectives.

The team defined design objectives for the proposed new engine. This hybrid system must switch automatically between the compressed air engine and diesel engine, utilizing the compressed air engine when the car is starting and at slow speeds. The system also must not weigh more or cost significantly more than traditional hybrid engines. Additionally, this design has the ability to improve the safety of cars; having two engines means that a malfunction in one of them would not stop the car from running. The other power source can kick in and continue to power the vehicle. However, the compressed air engine will not be able to move the car as fast as the diesel engine.This overall design idea has the complete potential to be successful and accurately follows the Delphi project guidelines.

Research:

The team did research on the components of the proposed diesel/air compression engine to support cost estimates. Table 1 summarizes this research for the major parts.

Part	**Size**	**Cost**
Large air tank (“Goulds”)	45 Gallons	$496
Small air tank (“Viair”)	2 Gallons	$63
Battery (“Chevy Volt”)	One third of Chevy Volt’s battery	$1000
Air compressor (“Air Compressor”)	145 PSI	$120
Compressed air engine (“GAST Air Motor”)	100 horsepower	$1500*
Diesel engine (“VW Jetta”)	2.0L	$2,750
	Total-	$5929

Table 1: Cost estimates for major components of the proposed new engine

*Since 100 horsepower compressed air engines are not yet on sale to the public and the largest compressed air engine we could find was 4 horsepower, the team found the ratio between a typical compact car engine (horsepower would actually depend on vehicle weight) costing $1250 (“13 Chevy Cruze Engine”) and a 4 HP engine costing $315 (“4 HP Honda Engine”). The compact car engine was about 4 times more expensive. We then multiplied the cost of the 4 horsepower air engine which cost $390 by the factor of 4 to get approximately $1500 for the engine to be used in the vehicle.

- Estimated cost of major parts: $5929
- $5929/2.34 = $2534 [to take out supply chain effects]
  +16.4 [NRE cost per new product]
  +6.25 [Assembly and QA labor]
  = $2,556 x 2 =OEM cost=$5,113

- Cost of gas engine in an average compact car- $1,250 (“13 Chevy Cruze Engine”)
- Cost difference: $5,113-$1,250 = $3863 [Amount more that consumers would need to pay for this engine over a typical gas engine]

Calculations:

The team found cost estimates for all of the major parts that are involved with the air compression/ diesel hybrid system and the total cost came out to be $5929. This number was then used to calculate the cost for parts for the Delphi product by dividing it by 2.34 according to the costing guidelines. This was then added to the Non-Recurring Engineering costs and the Assembly and QA labor costs. The total was then multiplied by two in order to find the OEM cost. The team did not have to solve for the accessory cost because it did not quite make sense with our design idea. An engine is not an accessory, it is a necessary part of a vehicle. With the OEM cost at $5113 the team could subtract the cost of a traditional gas engine, approximately $1250, to find the cost difference between that and the hybrid system, which came out to be $3863.

To support cost comparisons, some fuel cost comparisons were developed. According to the Fuel Economy guide for 2014 the overall average miles per gallon for a tradition gas engine for city and highway driving is 27 mpg ("Fuel Economy Guide"). Assuming the car is driven 15,000 miles per year, the average fuel cost is $2.89 per gallon for unleaded gas and $3.27 for premium. Taking an average of these two prices and multiplying it by (15,000 miles per year/ 27 mpg) gives an annual fuel cost of approximately $1,950. Taking the same calculation with only the price for unleaded gas still gives an annual fuel cost of about $1,606.

Now, taking a look at the fuel economy for Diesel, the team observed that "A fuel efficient turbodiesel engine that is running properly can deliver as much as <u>30 to 35%</u> greater economy than gasoline-powered engines of comparable size" ("Better Diesel Fuel Economy"). Note that this is for just the diesel engine. It is hard to estimate how much more fuel efficient the air compression/ diesel hybrid system would be, but on average, the typical hybrid saves around 218 gallons of gas a year more than the typical gasoline engine (Rose). Multiply this by the average $2.89 per gallon and that comes out to a dollar savings of $630. Factoring the additional cost of diesel fuel into this, with diesel costing $3.30 per gallon and saving 218 gallons of fuel yields a savings of $719. Taking this price and adding it on to the $1,606 in conservative savings from the diesel engine results in $2,325 of savings a year compared to the standard gasoline engine. There is no way to determine if this is completely accurate since there are no current car models with a diesel/ air compression hybrid system like the one being suggested. However, using this number, it would take under two years to make back the $3863 more that the initial investment costed.

Customer Needs:

A list of customer statements of requirements (Table CN-1) were derived from Delphi materials, and the team created a list of customer needs and specifications that must be met in order to meet project goals. These needs were used to help determine the six requirements for the AHP matrix and Design Selection Matrix.

Table CN-1- Customer Needs

Customer statement:	**Customer need:**
Project Objective	
Identify technologies and opportunities to make cars and trucks safer, greener, and more connected.	Project design will enhance cars or trucks and make them safer, greener and more connected.
Project background	
There are up to 50 computers buried beneath the skin of the cars and trucks that you see every day on the road.	Distributed computers are an integral part of modern cars.
You wouldn't know they (the computers) were there. But each of them is making that vehicle safer, greener, and more connected.	Car computers are hidden from the user, so the users only interface with what they need to.
Many of those computers were designed and built by Delphi.	Design should be compatible with all Delphi systems.
It seems every day we're hearing in the news about "cars of the future", ones that will park themselves, drive themselves, talk to us, use fuel more efficiently, report data to insurance companies, avoid accidents, etc.	Design should be future oriented.
What does this ("cars of the future") mean in terms of the **technologies needed** to enable safer, greener, more connected cars and trucks?	Design should take into account technology to meet the Safe, Green, Connected goals.
What does this ("cars of the future") mean in terms of **societal acceptance** to enable safer, greener, more connected cars and trucks?	Design should take into account societal acceptance to meet the Safe, Green, Connected goals.
What does this ("cars of the future") mean in terms of **policies** needed to enable safer, greener, more connected cars and trucks?	Design should take into account policy to meet he Safe, Green, Connected goals.
What does this ("cars of the future") mean in terms of the **supporting systems** needed to enable safer, greener, more connected cars and trucks?	Design should take into account systems design to meet the Safe, Green, Connected goals.

Project Description	
Each design team should choose one (or a combination) of Delphi's three target areas—Safe, Green, Connected—as described below.	Design must incorporate or address one of the Megatrends.
Safe: Our ultimate goal is to help make zero fatalities, zero injuries, and zero accidents a reality	If focusing on Safe, design would drive accidents to zero
Protecting the driver and passenger is of utmost importance.	The design should protect the driver and passengers even better than current designs.
Airbags are an example of a reactive safety feature after a crash occurs.	*case example*
Safety features now being designed into cars are more proactive to avoid the crash altogether.	The design should enable the car to avoid accidents.
Sensors are used to detect dangerous situations, and can alert the driver or even take over control of the car to avoid the situation	The design may incorporate driver alters or take over control of the acr to avoid unsafe conditions.
The use of smart phones while driving is also a major safety concern.	The design must decrease the risk of danger through cell phone use.
Green: We're passionate about creating a world with zero emissions	If focusing on Green: the design should help drive emissions to zero.
Protecting the environment is also very important to the vehicles of the future.	The design can not increase the eco footprint of the vehicle or its use.
Hybrid and electric vehicles are becoming more popular as an alternative to traditional cars.	The design may incorporate hybrid or electric vehicle technology.
There are also other alternative fuels being explored.	The design can allow for alternative fuel considerations.
However, by simply reducing the weight of a vehicle or having products that make engines run smarter or more efficient can dramatically improve fuel economy.	The design should improve fuel economy by decreasing weight, or increasing fuel efficiency, or…
***Connected*:** We have the technology to allow seamless connectivity in the vehicle—it's what consumers want, and we can make it a reality.	If focusing on Connected: The design should enable the user / vehicle to be more "connected".

The vehicle of the future should be optimally connected to maximize the driver's and passengers' experience while minimizing the driver's distraction.	The connected design should maximize the driving / riding experience while minimizing distractions.
Connecting the vehicle itself and all its sensors to the outside world should not be overlooked.	All systems inputs and outputs must be considered.
The vehicle of the future will have 100s of sensors collecting data which may be very beneficial to others.	The data collected from sensors is easily interpreted and available for analysis to meet the Connected (and Safe and Green) goals.
For example, if a car is doing 5-mph on a 65-mph interstate, an algorithm would determine a traffic jam was present and alert other approaching vehicles of the situation.	*case example*
The brakes could be applied for very close vehicles, or navigation systems could re-route approaching vehicles to avoid the congestion.	*case example*
Project entries in one (or more) of these three categories should first include background research into current technologies being deployed today.	The deliverables will include appropriate background research.
The project team may then choose to modify an existing feature/function or create a new technology for enhancing the vehicle of the future.	The design may be new or a modification of a current technology as long as innovation or improvement is part of the design.
The scope of the project should include a systems diagram, an example of the user experience (i.e., a Concept of Operations), as well as the approximate cost of this new feature	Design will include a systems diagram, ConOps, and cost analysis.

Concept Generation:

The team did a brainstorming session which included online research to find new technology trends that are up-and-coming in the automotive field pertaining to the Delphi megatrends. The ideas were written down and the idea lists from each team member were shared. Then, the group voted to narrow the list down to three concepts to proceed with. The first idea of the three was a "green" concept for a diesel/air hybrid that would utilize a compressed air fueled rotary engine to power the car for short distance, "around town" (<50mph) driving, and then using a small (<2L) turbo-diesel engine to power the car for longer, higher speed driving. The second idea was a "safe" concept for an exterior airbag system that would deploy all around the car in the case of an accident in order to lessen the damage from the car hitting other vehicles and pedestrians, as well as to protect the

occupants of the vehicle from harm by softening the impact of a crash. The third concept was another “green” idea for an advanced cylinder deactivation system that would electronically control the engine to deactivate cylinders in order to use the optimum amount of cylinders at each time in order to maintain peak efficiency from the engine to increase fuel economy while still providing the required amount of power. The team created a survey that can be found in Appendix A. The survey first gathered some background demographic information about each participant, and then asked which design concept people thought to be the most interesting and applicable, and why they thought this way. In addition, the survey asked for any concepts that they would feel uncomfortable with and why. Sixty-one people completed the survey, with 54% of them choosing the diesel/air hybrid concept, so that concept was the winner in the survey.

Concept Selection:

The team created an AHP matrix (Table CS-1) in order to determine weights of importance of different features and requirements that need to be met as determined by the customer needs list. The first requirement is simplicity, which means that the system needs to be very straight-forward and easy for any customer to use with little to no training in its use. The second requirement is ease of maintenance which entails that the system must be very easy to maintain in proper working order, and requiring minimal to no periodic adjustments and maintenance. The third feature is that the system must not add additional weight to the vehicle as this would be counterproductive and would fuel efficiency. The next requirement is that the system is “green”, being that is helps to save fuel and conserve energy, as well as putting out relatively low exhaust emissions. The fifth requirement of the concept is that it must be cost effective; the system should not add too much initial extra cost to the vehicle that would make it less desirable for a customer to purchase, and any price increase must be justified by a significant reduction in operating costs. The final requirement of the concept system is that the system must be reliable and fail-safe; it must be designed in a way such that it cannot easily fail and stop working, and should be reliable. If the system was to fail, there should be some sort of back-up so that the vehicle or system would not be entirely inoperable.

The AHP matrix (Table CS-1) was used to compare and rate each feature against each other, and the results of this produced a weight of importance for each requirement to be used in the Design Selection Matrix, with the Green megatrend being the most important, and Fail-safe/reliability following closely in second. A Design Selection Matrix (Table CS-2) was then completed by the team using the AHP weights and rating each requirement per design concept, and the Diesel/Air Hybrid concept was the clear winner.

Table CS-1- AHP Matrix (doing pair-wise comparison of desired design features)

	Simplicity	Ease of maintenance	Relatively light	Green (Main megatrend)	Cost effective	Fail-safe modes/reliability	Total	Weights
Simplicity	1	1	0.33	0.25	3	0.33	5.91	0.109
Ease of maintenance	1	1	3	0.5	3	1	9.5	0.176
Relatively light	3	0.33	1	0.33	1	0.33	5.99	0.11
Green (Main megatrend)	4	2	3	1	5	0.5	15.5	0.287
Cost effective	0.33	0.33	1	0.2	1	0.25	3.11	0.058
Fail-safe modes/reliability	3	1	3	2	4	1	14	0.259
						Grand Total:	54.01	0.999

Table CS-2- Design Selection Matrix (using AHP-weighted design features to down-select to final design concept)

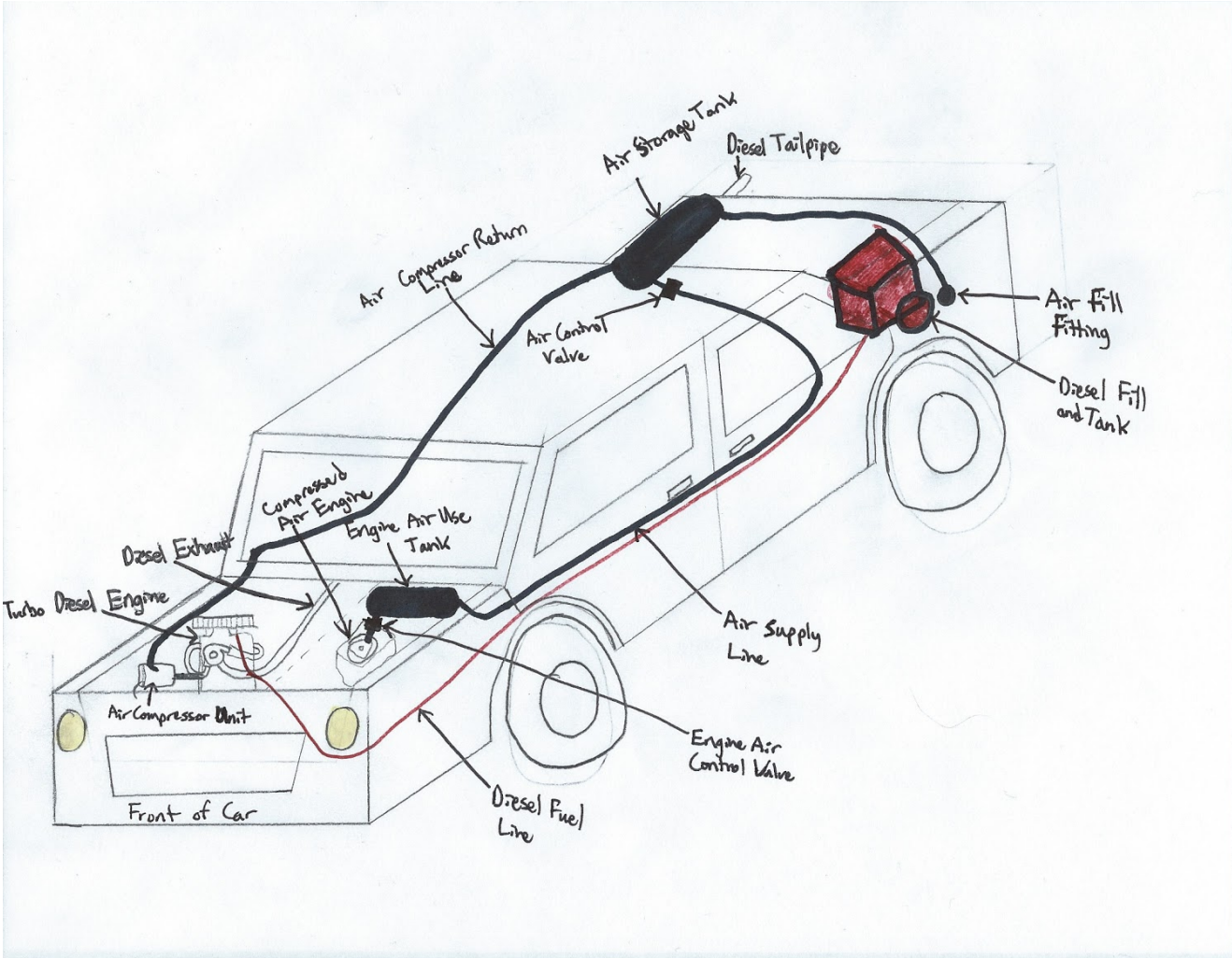
	AHP	Air compression/diesel hybrid system	External Airbags	Cylinder deactivation
Simplicity	0.109	3/0.327	2/0.218	4/0.436
Ease of maintenance	0.176	4/0.704	5/0.88	4/0.704
Relatively light	0.11	4/0.44	2/0.22	4/0.44
Green (Main megatrend)	0.287	5/1.435	1/0.287	4/1.148
Cost effective	0.058	5/0.29	3/0.174	4/0.232

Fail-safe modes/reliability	0.259	4.5/1.16	4/1.036	4/1.036
Total/weighted total:		**25.5/4.356**	17/2.815	24/3.996

Final Description:

The Diesel/Air Hybrid concept is something new to the world of hybrid vehicles, and its goal is efficiency upon efficiency. The compressed air engine system is the primary power source for the vehicle. The system will consist of a compressed air engine, most likely a rotary style engine, and a tank system that will hold the compressed air similarly to how a standard fuel tank does. This compressed air system will include a series of computer controlled valves and fed to the engine via air hose lines. This compressed air system will be used for short distance driving at low speeds, because large amounts of air compared to the size of the car would be needed to support a long range while driving with the compressed air system. High speed driving cuts down on engine efficiency and would deplete the air supply very quickly. The compressed air engine can be used up to about 50 mph, and could provide a range of up to about 125 miles (Nedelea) using a 45 gallon tank and a 100 horsepower air engine. The compressed air tank can be filled by a compressed air system installed at the owner's home, at a gas station, and even by an on board compressor system that could be driven by electricity from the battery or from the diesel engine. The diesel engine would be a small (≤2L) turbocharged, direct injected diesel engine that will be set up just like a traditional car today using a small turbo diesel system, with the fuel tank located to the rear of the vehicle. The diesel engine will be used to power the car at speeds above about 45 mph, as well as when going up hills and in other situations that would demand a high amount of compressed air to be used, and on longer trips once the compressed air supply runs out in the tanks and the air engine is no longer able to be used. As stated previously, the diesel engine would also be able to power a small onboard air compressor that can refill the air tanks, which could be done while driving, or while parked, such as in a remote area with no compressed air supply. The purpose of using compressed air as the primary fuel source is that compressed air is clean: nothing is being burned in the engine, and no pollutants whatsoever are being given off except when the diesel engine is running to drive the on-board air compressor. The air at the owner's home would be compressed by an electrically powered air compressor, which uses electricity that is most likely made at a fossil-fuel burning generation plant, so there are not zero emissions involved with the compressed air, but the emissions are significantly lower than if a standard internal combustion were to be used in the car. Using compressed air generated by electricity from solar or wind power would be even more ideal as this would drive the emissions for the entire process to very near zero.

Systems Diagram:



Scenario:

In a typical day in the life of an automobile using the diesel-compressed air hybrid, an owner would arrive at his or her car in the morning to find the compressed air tank full. An internal compressor will have run overnight and shut off when the tank is full. In a typical drive to work, the vehicle will run mostly on compressed air. When going up hills, the diesel engine will engage to assist the compressed air system to avoid exhausting the tanks too quickly.

When arriving at work, the owner would be able to plug in the car's internal compressor into a regular wall outlet. This would replenish at least some of the tank throughout the work day.

Since the average American commute takes about 50 minutes both ways or ~30 miles at 35 mph (Plumer) and existing compressed-air only automobiles such as the MDI MiniFlowAir have a range of about 60 miles, running on compressed air alone should be sufficient for getting to work and back for most Americans (Yvkoff). This range may even be extended because of the hybrid system's engine-assist when going up hills. If a vehicle owner chooses to drive farther than just back home to, for example, run errands, an already-efficient diesel engine can take over for when the compressed air tank runs out or even refill the air tank. Since the Chevy Cruze Diesel, a compact car that provides a good base of comparison for the diesel component of this concept, gets an estimated 46 MPG, an owner can go a great distance without burning too much fuel (Cruze).

After coming home from wherever the owner chooses, he or she would connect his or her in-home compressor to their vehicle so the tank will be full for nearly zero-emission driving the next day or let the diesel-compressed air hybrid system refill the vehicle's tanks on its own.

Feasibility Analysis:

From the previous section on calculation, the price of implementing a compressed air/diesel hybrid would be $4,250 as compared to a $1,250 gasoline engine in a typical compact car. For a second survey (shown in Appendix B), the team asked 13 people what they would pay in addition to the price of a compact car to include the diesel-compressed air hybrid system. The 13 surveyed claimed they would pay anywhere from $1,000 to $10,000 with the average being $6,083. Since people said they would pay an average of around $6000, they should have little problem with paying around $3,863 more.

Another factor affecting feasibility is the cost of refilling the air tanks. As the design for a compressed air-diesel hybrid incorporates an internal air compressor that can be plugged into a wall, an external charging apparatus is not required like an electric vehicle would need. While there will be some cost for electricity in refilling the vehicle overnight, it would be much cheaper than charging a full electric car battery.

Additionally, air tanks could potentially create a safety hazard if they fail and explode. However, there are government regulations related to air tanks fifty pounds per square-inch. For instance, in the state of Massachusetts, air tanks must be inspected after installation and then once every other year. While this may cost the owner a few extra dollars for every air tank inspection, the process will ensure the tanks will not fail and become a safety hazard ("Air Tanks"). Overall, the compressed air-diesel hybrid system would be affordable and all potential feasibility setbacks would be minimized by its design as well as government regulation and inspection.

Life Cycle Analysis:

To ensure the most efficient operation for a diesel/ compressed air hybrid, one must consider the effects of material and energy use across all phases of the vehicle's life. In production, the choice of materials determines how many resources are expended and how many emissions are created during production. While some materials such as carbon fiber reinforced polymer or aluminum cost more and create more emissions in the factory, they are lighter and may contribute to a vehicle's efficiency when replacing steel. Additionally, this choice of materials will affect a vehicle later in the life cycle when parts are recycled.

One particular element of the vehicle's design which may be changed to improve efficiency would be the vehicle's air tanks. The tank the team chose in the costing portion of the report is made from steel and weighs in around 68 pounds ("Goulds"). To save some weight, one may consider changing the large steel tank to a lighter, composite tank (Note that aluminum tanks are typically not considered strong enough for sizes larger than a few gallons). Changing to a composite tank would bring the tank weight down to 47 pounds which is 21 pounds or 30% lighter than the steel tank ("Price List"). While this minor change in weight may make some difference, one must carefully examine the drawbacks of this switch. First, the composite tank costs about $536 more than the steel tank. Second, producing the composite tank emits around 5-6 times more greenhouse than steel would according to Audi. Lastly, composite is much more difficult to recycle than steel. While using lighter materials often helps conserve energy in the long run, in this case it is unlikely that a 21-pound reduction would be worth the trade-offs in the long run ("Life Cycle Assessment").

Conclusion:

After completing several phases of product development, a final design for a diesel-compressed air hybrid was created. During this process, the team learned that collaboration and communication are necessary to achieve design goals throughout the entire process. By surveying a wide variety of people and applying engineering design skills to generate concepts, the team was able to successfully choose an idea that would be both effective and marketable. The team then took the final idea, a compressed-air diesel hybrid, and analyzed the cost of implementing this hybrid technology. The team again surveyed a sample of people to decide if the generated price was reasonable. Altogether, these steps led to a final design which could later continue through the development stage with the construction of prototypes to undergo road tests and eventually become a final product. This product provided insight into the team customer driven design, and could be a new product in Delphi's line.

Appendices:

Appendix A

Concept Selection Survey

We are working on a project with Delphi, one of the largest automotive technology corporations in the world. Our challenge is to develop innovative new technologies to meet Dephi's three "megatrends"; Green, Safe, and Connected. We have three different ideas in consideration as follow:

1. Diesel & Air-Compression Hybrid Technology - Compressed air will be used to power the car on short drives at low speeds, and a small diesel engine will be used for longer drives in order to maintain vehicle range. With this technology it is possible to achieve efficiency of over 100 mpg.
2. External Protection Airbag Technology - Airbags are deployed around the exterior of the vehicle in case of an accident to help protect pedestrians, the car itself, and other cars on the road.
3. Real-Time Cylinder Deactivation Technology - The amount of cylinders that are used in the engine is constantly monitored and changed in order to maintain maximum efficiency while supplying required power, and saving large amounts of fuel, especially on highways.

* Required

1. What is your age? *
    - 16-21
    - 22-26
    - 27-34
    - 35-55
    - >55
2. Gender? *
    - Male
    - Female
    - Other
3. Do you own/operate a car? *
    - Yes
    - No
4. Have you ever been involved in an accident? *
    - Never
    - Once
    - 2-3 times
    - More than 3 times
5. Which of the three topics listed above do you find to the most interesting and applicable? *
    - 1
    - 2
    - 3
6. Why did you choose that topic? *
7. Would you feel uncomfortable trusting any of these technologies? *

Please check off the ones you feel uncomfortable using

- Topic 1 (Diesel/compressed air technology)
- Topic 2 (External Airbags)
- Topic 3 (Cylinder Deactivation)
- I would feel comfortable with all of these

8. If one does make you uncomfortable, what are your concerns?

Appendix B

Pricing Survey
*** Required**

What is your age? *

- **16-21**
- **22-26**
- **27-34**
- **35-55**
- **>55**

Gender?

- **Male**
- **Female**
- **Other**

Do you own/operate a car? *

- **Yes**
- **No**

If you were purchasing a new car, how much extra would you be willing to pay to have a compressed air and diesel-powered hybrid drivechain? *

- **-The compressed air/diesel hybrid drivechain is a system our group is developing to maximize fuel efficiency in real-world driving scenarios.**

What is your reasoning behind this pricing? *

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