Educational 4-Stroke Internal Combustion Engine Model

Analysis of the Recent Growth of the Electric Vehicle Market, and the Environmental Costs of EV Battery Production vs. Carbon Emission Reduction

A Thesis Prospectus
In STS 4500
Presented to
The Faculty of the
School of Engineering and Applied Science
University of Virginia
In Partial Fulfillment of the Requirements for the Degree
Bachelor of Science in Mechanical Engineering

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November 8, 2024

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On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

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Introduction

The four-stroke internal combustion engine (ICE) is often considered the zenith of mechanical engineering. First developed in 1876 by Nikolas Otto (Ferguson 2015), this technology, which can provide significant power generation for machinery and movement, became the primary source of power for transportation vehicles in the 20th century. There have been various improvements in mechanics, components, and other aspects over the years, such as cam-controlled inlet and exhaust valves patented by Ford Motor Company in 1935 (Ford, 1935). These innovations and others similar have allowed the four-stroke ICE to be one of the most tenured, widely used, and comprehensively engineered pieces of technology in the world.

However, since the beginning of the 21st century, the automobile industry has been undergoing a shift from the ICE to electric vehicles (EV) and hybrids (HEV). In 2022 alone, electric vehicle sales in the United States increased by 55% (Pickett, 2024). This trend of significant growth has been the case for not only EV's, but also HEV variations since the year 2010 (see Fig. 1). The modern automobile industry takeover of the EV is certainly in full effect, with fully electric and hybrid vehicles forecasted to account for 30% of all vehicle sales by 2025 (J.P. Morgan, 2018). This change is not without pushbacks, as many consumers hold concerns on a variety of different aspects of the electric vehicle, including range capabilities, battery manufacturing, recyclability, and others. Despite these concerns, many experts' opinion is that the EV is well on its way to becoming the norm, rendering the ICE a thing of the past.

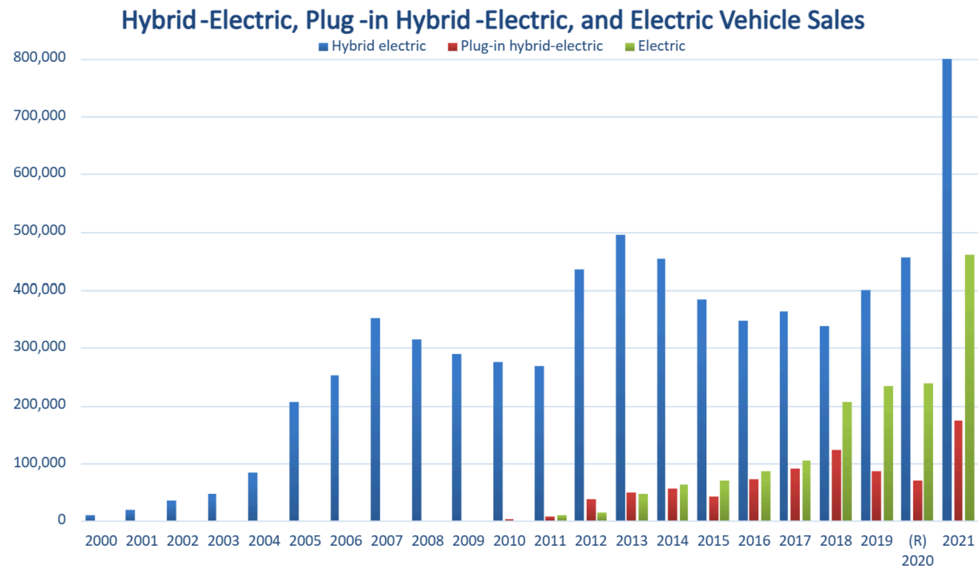

Fig. 1. Electric & Hybrid Vehicle Sales Since 2000 in the United States (BTS, 2022)

It is interesting to consider the recency of the rise of the electric vehicle, as the invention of the first practical electric vehicles was as early as the 1840's (Deal III, 2010). There are many technical and socioeconomic factors that have contributed to said rise. On the technical side, there are considerations regarding the performance and manufacturing of electric vehicles. Whereas on the socioeconomic side, other factors affect this transition, such as the economic viability of EV's and the environmental awareness initiatives gaining traction in recent years.

Although the era of the ICE is coming to an end, it is still important for engineers, mechanical or otherwise, technicians, and others in the automotive industry to be familiar with the technology of the four-stroke engine cycle. Even in the future when EV's dominate the roads, and gas-powered cars are considered antiques, the ICE will always be a significant feat of engineering and represent a time of significant innovation in the field of mechanical engineering and the automotive industry. Mechanical engineering curriculums around the world should always consist of understanding the ICE and how it works technically.

For the technical project, to promote the longevity of the ICE in the educational curriculum, the technical aspects of the technology are considered in the design and development of an educational aid or scientific museum exhibit of the ICE. For the Science, Technology and Society (STS) report, the growth of the EV market is studied from 2010 to the present from a technical and socioeconomic perspective, applying systems analysis and actor-network theory (ANT) to understand what actors, non-human or human, played a role in the significant change in the industry. Additionally, a cost-benefit analysis is conducted on the environmental effects of EV's, specifically balancing the detriments of battery production with the benefit of the reduction in carbon emissions.

Educational 4-Stroke Internal Combustion Engine Model

Although all signs point to the EV takeover, the vast majority of vehicles currently on the road, in fact 99.8% of global transport in 2020 (Leach, 2020), utilizes ICE technology. Since its birth in the 19th century, countless innovations and improvements have been made to the design of the four-stroke ICE specifically, yet the central components and thermodynamics in the operation have remained generally the same throughout its lifetime.

The integral components of ICE's start with the central structure of the engine block, which is the base for all other components, and is made up of the cylinder block and the crankcase. The cylinder block contains the cylinder bore, which is where the pistons move. The cylinder block also contains the cooling fins and valve train components, which aid with temperature control and control the flow of gases in and out of the combustion chamber, respectively. Cylinder heads attach to the cylinder block to seal the combustion chamber. The crankcase houses the crankshaft, which turns the motion of the pistons from linear to rotational. The pistons are the moveable end of the combustion chamber, and the main driving force of the engine operation. They are connected to the crankshaft by the piston rods to drive rotation and have piston rings on the heads acting as a seal between the piston and the cylinder wall. Also within the engine are bearings, which maintain the clearance and alignment of the different components of the engine, a flywheel or counterweight, which provides inertia for the rotation of the engine, smoothing power delivery, and a spark plug, for ignition. All these integral components, with some others that can vary across different models, come together in a truly marvelous feat of engineering to create the internal combustion engine (see Fig. 2).

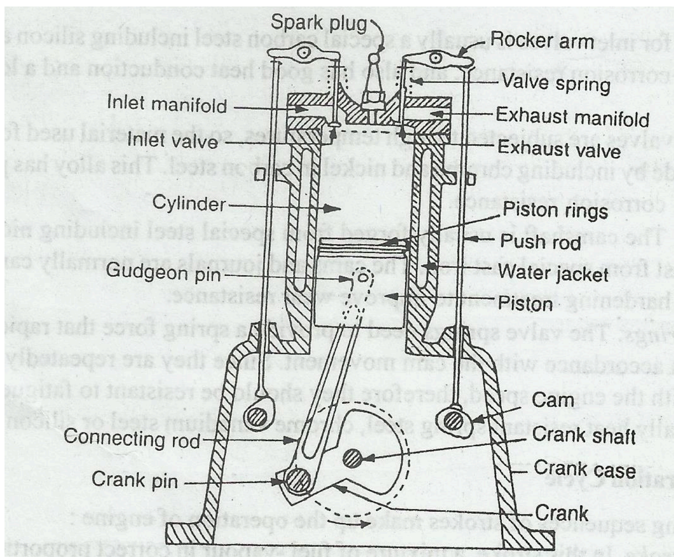

Fig. 2. Example of Internal Combustion Engine Components (Aboutmech.com, 2019)

The cycle of a four-stroke engine consists of two rotations of the system, two stages per rotation, for a total of four stages (see Fig. 3). The first stage is the intake stage, where the piston expands, air is sucked, and fuel is injected into the system for combustion. The next stage is the compression stage, in which the piston compresses the air. The third stage is the power stage, where ignition occurs and work is done on the piston, which drives crankshaft rotation. Finally, the exhaust stage is when the remaining matter is expelled from the combustion chamber post ignition.

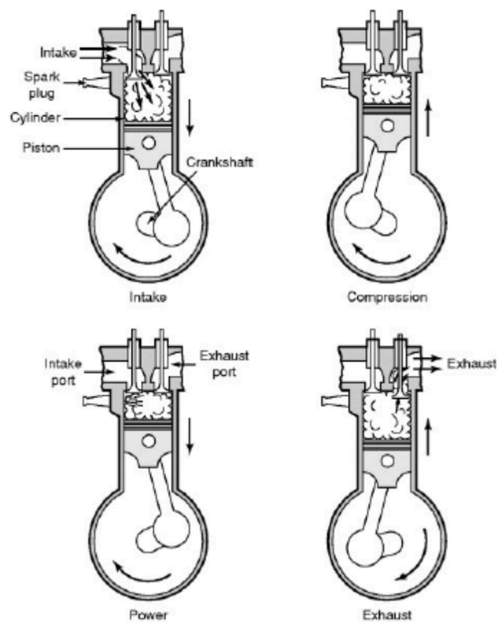

Fig. 3 Four-Stroke Engine Cycle Phases (Ferguson, 2015)

Knowledge of this technology is vital for all engineers, especially those interested in the automobile industry. This technical project is the design and development of an interactive model of a four-stroke ICE that synergistically combines mechanical, electrical, and software related components using mechatronic devices and microcontrollers. The model serves its purpose as an interactive classroom aide or museum exhibit, preserving knowledge of the four-stroke ICE in years to come.

Recent Growth of the Electric Vehicle Market and the Environmental Costs of EV Battery Production vs. Carbon Emission Reduction

While practical EV's have existed since the 1800's (Deal III, 2010), in recent years, specifically since 2010, the market for EV's has experienced rapid and drastic growth. A wide variety of technical and socioeconomic factors must have contributed to this. A definite component is the fact that EV's are catching up to ICE's in performance areas where they previously lagged. Hybrid-Electric Vehicles (HEV's) as an option only promotes the transition to electric power even further, as in most cases they match up to, if not surpass, gas-powered vehicles performance wise (see Fig. 4). Specific component developments, such as the adaptation of the lithium-ion battery, which was three times as energy dense as other batteries with lead-acid chemistry (Murray, 2022), for use in vehicles also could have contributed to this change.

	ICE			HEV		
Parameter	**Toyota Camry**	**Audi A3**	**Honda Accord Sport**	**Toyota Camry Hybrid**	**Audi A3 E-Tron**	**Honda Accord Hybrid Sport**
Fuel capacity (liters)	50	50	56	50	54.8	48.4
Fuel efficiency (Kmpl)	17.4	19.2	13.6	22.5	30	18.2

Fig. 4. Comparison of HEVs and IC Vehicles (Venugopal, 2022)

Besides technological performance, there are certainly other factors that motivate the growth of the EV market in today's day and age. One constituent is the economic side of owning an electric or hybrid vehicle tipping in the direction of the EV. Studies show that in terms of fuel costs for the average consumer, EVs cost 75% less than ICE vehicles (Venugopal, 2022). Another proponent to the change to EV from gas-power is the reduction of carbon emissions and efforts towards sustainability. Issues of global warming and sustainability affect the social network, political landscape, and other areas of day-to-day life, such as home heating/cooling and waste management, significantly.

The existence of all these factors leads me to the first part of my STS research question: What were the central technological and socio-economic factors to contribute to the swift rise of the electric vehicle market since 2010? In my analysis, I utilize both Thomas Hughes's systems analysis and Actor-Network Theory (ANT), which is employed by various authors. In Hughes's book *The Evolution of Large Technological Systems*, he details how technological systems encompass not just the technology in question, but a plethora of other elements, which I find to be very applicable to the case of the EV. In another of Hughes's books, *Networks of Power: Electrification in Western Society, 1880-1930*, he analyzes the electricity industry in the United States over a specific period of great development. This parallels what I plan on doing regarding the electric vehicle industry in recent years, so I believe taking Hughes's system approach will be quite relevant. ANT will also be valuable because of the prominence of societal and environmental factors playing a role. ANT involves analyzing all the actors, human or non-human, involved in a specific phenomenon. There are many actors involved in the EV industry. Some human actors include automotive manufacturers or sustainability activists, and some non-human actors are environmental ecosystems or lithium-ion batteries. An important part of my research will be analyzing which factors held more power than others in the EV network. Hence, I feel that the application of ANT will be beneficial.

Through preliminary research I have found that the primary support for EV is the environmental benefits, specifically emission reduction. In this paper I will argue that the environmental benefits may not be as clear cut as some believe. While it is true that carbon emissions during vehicle use are eliminated by using EVs, the production of the batteries used in EVs has significant adverse effects on the environment, some of which are not fully researched or understood. Estimates suggest that battery production is responsible for up to 70% of emissions during EV manufacturing (Lattanzio, 2020). The production of different elements used in these batteries has environmental effects as well. For example, lithium production is almost solely from brine mining, whose potential adverse effects on wildlife and ecosystems are not fully researched or understood (Lattanzio, 2020). The degradation of these batteries over time and their recyclability also remains to be seen as the EVs on the road reach the end of their lifespans and their batteries become waste. This leads me to the second portion of my STS research paper: Does the emission reduction benefits of the EV outweigh the ecological detriments of EV battery production? A cost-benefit analysis on all aspects of the environmental costs and benefits of EVs answers this question. Potential sources for this data and information include journals on the topic, emissions data, and research studies. I believe that at the conclusion of this cost-benefit analysis it will be found that, contrary to popular belief, the benefit of the environmental viability of EV's overall is marginal.

Conclusion

The technical project will produce an interactable, elegant model of a four-stroke internal combustion engine which can be used as an education aide or museum exhibit, preserving the impact of the ICE through the transition to the new technology of electric vehicles. The STS research paper will provide a socioeconomic understanding of the meteoric rise of the EV since 2010, with Hughes's system analysis and ANT applied to fully understand the actors that drove the change, as well as the network of the EV. The paper will also contain a full-scope cost-benefit analysis on the environmental costs and benefits of EVs, beyond just an emissions standpoint. The combination of the technical project and the STS research will provide an excellent basis of knowledge regarding the modern automotive industry during a time of significant change.

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