# Case Study: Diesel Excavators Compared to Hybrid Excavators

**Corey McGrillen**
California Polytechnic State University
San Luis Obispo, California

The construction industry is constantly evolving and developing equipment that is more efficient, materials that promote sustainability and practices that emphasize lean construction principles to enhance productivity on projects. Modern day construction projects have become highly reliant on these ideals due to the highly competitive nature of the industry. In regards to heavy civil construction, specifically the underground utilities market, equipment costs count for a large percentage of overall project costs. Reducing these costs allows a contractor to be more competitive. As the focus on infrastructure construction continues to grow and expand, many heavy civil contractors are turning to alternative fuel option for heavy equipment to reduce operating costs and emissions. As a result, many heavy equipment manufacturers have invested into the production of hybrid heavy equipment for these purposes. Conversions from conventional diesel equipment to hybrid equipment have proven savings in operating costs, but for some contractors the more expensive ownership costs do not result in a more efficient machine.

**Keywords:** Hybrid Excavators, Fuel Alternatives, Underground Construction

## History of Heavy Equipment in Construction

The implementation of heavy equipment to the construction industry revolutionized how work would be performed, especially in the heavy civil sector. Before this, the task of moving mass amounts of earth required a significant labor force and a much longer schedule. To resolve this problem, William S. Otis invented the steam shovel in 1838 changing heavy civil construction from that point on. (Haycraft, 2011) The steam shovel was the earliest form of heavy equipment, and set the foundation for a lot of the pieces of heavy machinery that we see today on construction sites. Otis's steam shovel was originally designed for railroad construction, which explains why it was mounted on a rail car. (Haycraft, 2011)

One of the main obstacles when using the steam shovel was its lack of mobility. An early advancement that was implemented to the basic steam shovel design was the incorporation of an upper unit that allowed for a full 360 degree swing of the shovel and superior utilization. These steam shovels played a massive role in the construction of the Panama Canal, from 1904 to 1914. However, that was not the only modification to allow for great mobility. The next major advancement, about 65 years after Otis's creation, was Benjamin Holt's combination of steam traction engines and combines. Holt had the idea to manufacture a steam shovel with a track-type or crawler base. From this idea, Holt continued to develop his own type of internal combustion engine, and as a result of this, the "Caterpillar" company was created. (Haycraft, 2011)

The concept of the crawler type tractor became increasingly popular during World War I, when Holt began supplying to Great Britain, France and later the U.S. Army. While Holt was busy manufacturing machinery for the war, C.L. Best was working on developing a machine that was, "…. superior to anything in the Holt Line at the time." (Haycraft, 2011) The project that Best was working on became the foundation for Caterpillar's first diesel tractor, after the merger of Caterpillar and Best in 1925. (Haycraft, 2011)

Since the incorporation of track type mounting and the internal combustion engine, the steam shovel evolved in to the cable-operated power shovel. This machine became a key player in the heavy earthmoving and mining industry post World War II. (Haycraft, 2011) During this era, technological advancements were being applied to this machine starting with introduction of the hydraulic cylinder to the boom, stick and bucket.

In 1954, a German manufacturer, known as Demag, applied hydraulic motors to the swing and rotation functions of the machine to develop the first fully hydraulic excavator. This machine became incredible popular in Europe, and

shortly the trend travelled to Japanese. It wasn't until the 1970s, that the United States adopted the state of the art development. (Haycraft, 2011) Since then manufacturers all over the globe have updated and upgraded machinery with the latest technologies.

A current example is the development of alternative fuel options which are becoming more popular in the industry, with the fairly recent introduction of hybrid hydraulic excavators. Komatsu became the first company to mass produce the commercial hybrid hydraulic excavator in 2008, and since then many other manufacturers have been engineering and producing similarly powered machines. (Wang, J., Yang Z., Liu S., Zhang Q., & Han Y., 2016) Now a days, manufacturers from all over the globe are producing and distributing excavators of all shapes and sizes to the construction, mining, logging, marine and other industries.

## The Hydraulic Excavator

The hydraulic excavator is a piece of heavy equipment that is primarily used for excavation and demolition purposes, but is seen across multiple industries. The major components of an excavator are the tracks or wheel, the body, and the arm. Hydraulic excavators are usually mounted on either wheels or tracks. Track mounted or crawler type excavators are usually used in areas where there is less traction on the terrain.

The next major section of the machine is the body, which contains the main components such as the cab and the engine. The body of modern hydraulic excavators have the ability to swing a full 360 degrees, allowing for a lot better mobility. The engine is the power source for the machine, where the motor, transmission and other mechanical components are housed. On the other hand, the cab is where the operator sits to maneuver and make the machine perform work.

Depending on the machine, the cab contains a series of joysticks or levers to control the functions of the boom, stick, bucket, tracks, and other attachments. The cab also contains all the gauges and computers to show how the equipment and operators are performing. Finally, within the arm of the machine there are three major components, the boom, the stick and the bucket or attachment. The boom of the machine moves in the up and down direction, while the stick and bucket move back and forward.

The hydraulic excavator as a whole is a very powerful and versatile piece of machinery that has drastically change the heavy civil construction industry. As one of the most popular earthmoving pieces of equipment, the hydraulic excavator can be adapted with a wide variety of attachments to perform a plethora of construction tasks.

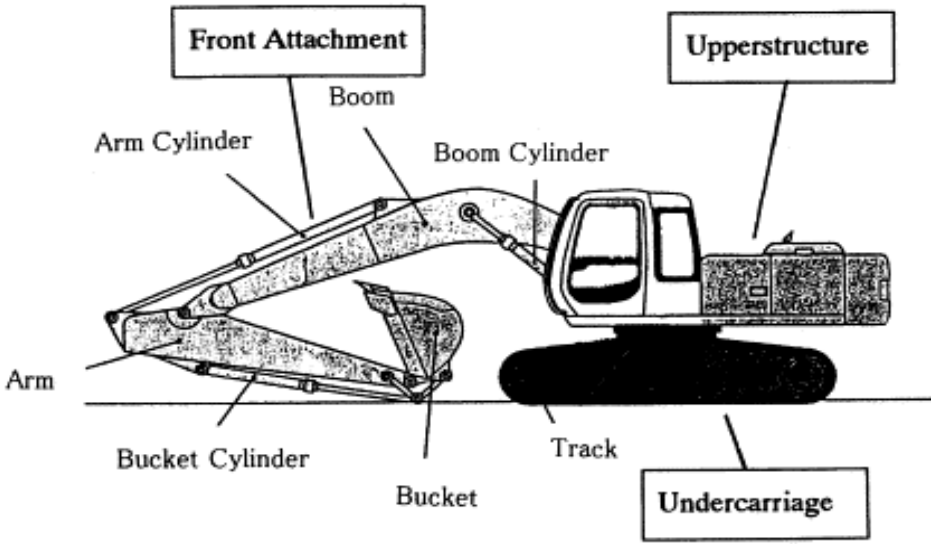


*Figure 1*-Hydraulic Excavator Constitution
*Source:* Haga M., Hiroshi W., & Fujishima K.(2001)

## *Hybrid Technology in Hydraulic Excavators*

The implementation of hybrid technology in the heavy equipment industry has been a popular topic in recent years. Following the success of the automotive industry, heavy equipment manufacturers decided to produce more fuel and cost efficient machines through these technologies. Hybrid heavy equipment also limits pollutants and meets certain air quality regulations. Still due to the sheer size difference of a modern day hybrid car compared to a 23 ton excavator, there are some differences on the way the electric motor integrates with the diesel engine in a hybrid hydraulic excavator.

For example, a modern day hybrid car is powered by an internal combustion engine that is wired in parallel or series to an electric motor. This system works through the engine providing the base power for the system, and then the electric motor regenerates energy and stores it for later use. This differs from the system in some hybrid hydraulic excavators in many ways. Due to the expectations and power required of excavators, this system is more difficult to apply directly. As a result, some manufacturers have split the system, where the diesel engine powers the tracks, boom, arm and bucket of the machine while the electric motor is solely responsible for powering the 360 degree swing of the upper portion of the machine. Other manufactures, such as Komatsu, have developed a system where the electric motor assist the diesel motors, after being charged through multiple rotations or swings of the upper units of the machine. (America Corp., Komatsu 2011) This system is shown in the figure below.

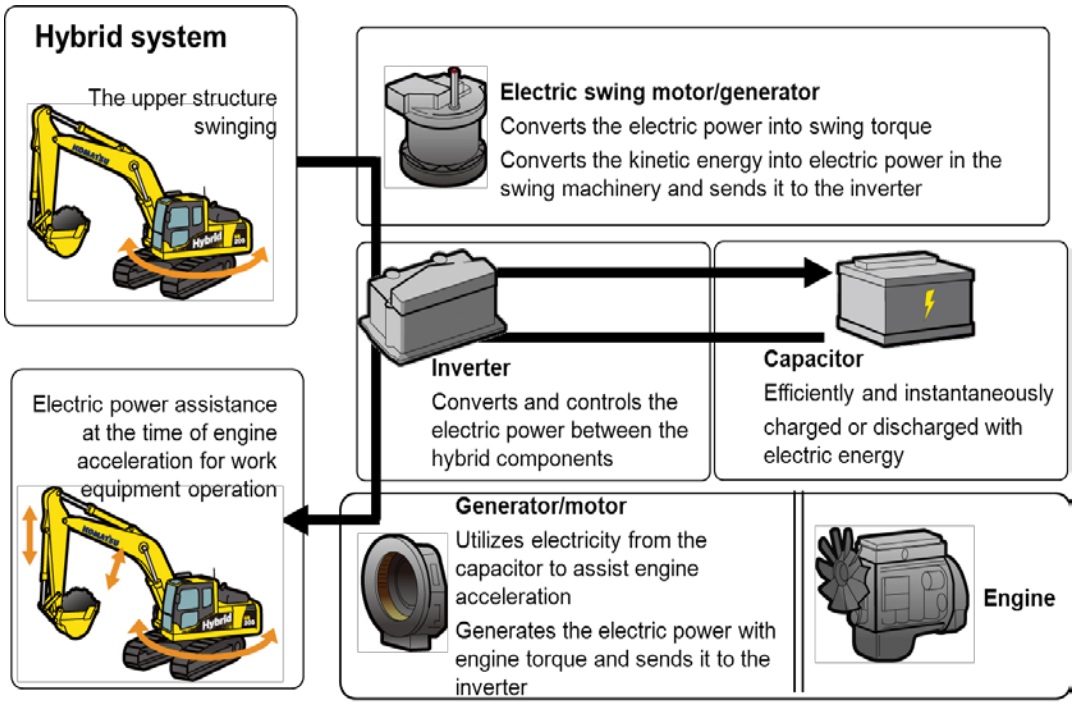


*Figure 2*- Komatsu's HB215-LC1 Hybrid Excavator Sales Presentation
*Source:* America Corp., Komatsu (2011)

Engineers and manufacturers have developed a way to have a diesel powered engine and an electric motor that is coupled to the driveshaft to jointly power the machine. Having this configuration in the machine allows for the excavator to be powered by the engine alone or in a combined mode with the electric motor. This generation of power is stored in the generator or motor and assists the engine with acceleration, while generating electric power to send to the inverter. (Wang, J., Yang Z., Liu S., Zhang Q., & Han Y., 2016)

Another key difference between the hybrid systems that we see in cars compared to hydraulic excavators is how the systems use the energy generated in the electric motor. In a car, initial start-up and acceleration requires a lot of energy, but it can run very stable while the engine is maintaining constant revolutions per minute. On the other hand, construction equipment have to accommodate a lot more change in revolutions while in operation. Because of this the accumulator that charges the electric motors is required to switch off and on in a matter of seconds rather than minutes, which you usually see in an automobile. (Lin T., Wang Q., Hu B., & Gong W., 2010)

### *Benefits of Hybridization*

Conventional diesel powered heavy equipment has been ridiculed by environmentalists for years about the amount of natural resources they are using up and their output of emissions. To combat this problem, some heavy equipment manufacturers have aimed their focus on hybrid equipment, and have tested the results in the work field. The hybridization of heavy equipment can lead to a series of benefits to the owner, but the main driving factors of using this type of equipment are higher fuel efficiency, fewer emissions and conform to emissions regulations.

Achieving better fuel efficiency for heavy equipment can result in money saved for the owner and less consumption of natural resources. Tests have indicated fuel savings of 18-30% of regular fuel consumption, when compared to a similar piece of equipment back in 2011. This study compared the systems of two excavators, the HB215LC-1 model and the PC200LC-8. These figures are based on a 100% working day, with no idle time, in a mass production working environment analyzing a power mode and economy mode of each machine. (America Corp., Komatsu 2011)

The implementation of hybrid equipment into a company's fleet helps to meet the demanding environmental regulations set by the Environmental Protection Agency. Recent findings from the Clean Air Task Force have shown that off-road equipment, trucks buses, trains and ships emit pollutants that are responsible for about 21,000 premature deaths. (Lyon J. 2012) Due to facts like this and others, the Environmental Protection Agency has increased fleet regulations in recent years to combat this problem. Seeing that the hybrid equipment can omit much less emissions than the most environmental diesel equipment, some models have allow for a much lower average emission output as a fleet, making emissions standards much easier to comply with. Standards set by the Environmental Protection Agency have defined the qualification for meeting the respective tiers for offered diesel power equipment. Tier 4 final is the most desired tier for heavy equipment owners, and required substantial reductions in nitrous oxide, sulfur and particle matter. (Lyon J. 2012)

## Methodology

The methodology that I have chosen in this case study is to analyze the ownerships and operating costs of a hybrid hydraulic excavator compared to a similar sized diesel hydraulic excavator in the pipeline sector of heavy civil construction. I will explore into the rate of return for purchasing each piece of equipment as well as conducting a complete life cycle cost analyze. This information will be relevant for companies in the heavy civil construction field, but seeing that my focus is in the pipeline and underground utilities portion of construction, the information will be targeted towards contractors performing that work.

My objective for this case study is to….

- Provide new knowledge to pipeline and underground utility contractors in regards to purchasing hydraulic excavators.
- Analyze the financial and environmental aspects of purchasing either type of equipment, hybrid powered verse diesel powered.
- Provide information about the feasibility of implementing a hybrid powered hydraulic excavator into the fleet of a pipeline and underground utility contractor.
- Analyze factors and provide reasoning for choice of either type of hydraulic excavator.

## Case Study

Casey Construction Inc. is a general engineering contractors located in Redwood City, CA. The services that they provide to the greater San Francisco Bay Area is in both the residential as well as heavy civil sectors of construction. For the purpose of this case study, I plan on focusing on the work performed in the heavy civil branch of the company, regarding projects such as water, sewer, electrical conduit, gas and storm drain pipeline construction and rehabilitation. As the company continues to expand, investments in field assets, specifically a new excavator, seems essential to match the company's growth. With this in mind, I will be comparing the Komatsu PC210-LC11 diesel powered hydraulic excavator to the Komatsu HB215 LC-1 hybrid powered hydraulic excavator.

## Data Collection

To further my research on the topic of implementing a hybrid excavator to Casey Construction's company fleet, I conducted multiple interviews with company employees as well as a local salesperson for Komatsu. Throughout this data collection, I grasped a better idea of the feasibility of the purchasing a Komatsu HB215 LC-1 or a Komatsu PC210-LC.

The first interview that I conducted was with James McGrillen, general manager of Casey Construction Inc. While conducting this interview, I was able to extrapolate data to assist my calculations of ownership costs and operating costs for both the Komatsu HB215 LC-1 and Komatsu PC210-LC. Some of the information that I was able to receive, was the estimated salvage value of the potential excavator, lifetime expectancy of the machine, estimated track life, maintenance requirements, hours of operation a year, as well as other useful information for conducting a lifecycle cost analyzes for each machine. While talking to James, I also found out that the company would prefer to purchase a used excavator, within a specific hour range as well as age. After receiving this information, I began to look into the used excavator market to find two excavators to meet these qualifications.

The next interview I conducted was with Dennis Belli, from Road Machinery LLC. Dennis is a sale representative for the company and has a lot experience with the heavy equipment market in the San Francisco Bay Area. He was able to provide me with a lot of great information on both the HB215 LC-1 as well as the Komatsu PC210-LC. The information Dennis provided me is used by Komatsu to educated customers on the capabilities and performance of each piece of equipment. Dennis was also able to educate me based on personal experience in selling both of these pieces of equipment throughout his career as well.

### *Ownership and Operating Costs*

Using the information through research as well as data collection, I was able to conduct a lifecycle cost analyst for each type of excavator and compare them in regards to ownership and operating costs. To accurately compare the two pieces of equipment, I used a constant formula and method for calculating each of these costs, using the information I extrapolated through the data collection process. In order to evaluate the ownership cost of each machine per hour and year, I used the Average Annual Investment Method, taking the time value of money and depreciation of the machine into consideration

The two pieces of equipment that I found in the current market to evaluate for potential purchase was a 2014 Komatsu HB215-LC1 and a 2014 Komatsu PC-210- LC10. Both pieces of equipment are within the company's parameters for age as well as number of hours. The asking price for the HB215-LC1 is $193,000, after considering transportation costs, which is a 3 year old model with 697 hours. Seeing that this piece of equipment has been lightly used over the past three years compared to the PC210-LC10 that has 2,548 hours, I have shortened the life expectancy for the PC210-LC10 to a year less than the HB215-LC1. While conducting the calculations for both excavators, I kept the working conditions constant, in order to create controlled variables. Other controlled variables that were held constant throughout the study were, insurance rate, work hours per year, cost of capital percentage, fuel cost, time between oil changes, track life expectancy, operating efficiency and throttle factor. Results from these calculations are shown below.

2014 Komatsu HB215-LC1

Ownership Costs
- Depreciation: $8.78/hr
- Cost of Capitol: $6.52/hr
- Insurance: $1.30/hr

Total: $16.60/hr

Operating Costs
- Repairs: $3.48/hr
- Fuel: $9.65/hr
- Lube: $0.67/hr
- Track Repairs: $0.23/hr
- Track Deprecation: $1.11/hr

Total: $ 15.12/hr

Total Ownership & Operating Cost: $31.72/hr

2014 Komatsu PC210-LC10

Ownership Costs
- Depreciation: $5.42/hr
- Cost of Capitol: $4.41/hr
- Insurance: $0.88/hr

Total: $10.71/hr

Operating Costs
- Repairs: $2.10/hr
- Fuel: $14.43/hr
- Lube: $0.76/hr
- Track Repairs: $0.23/hr
- Track Deprecation: $1.23/hr

Total: $ 18.75/hr

Total Ownership & Operating Cost: $29.46/hr

After calculating the lifetime ownership and operating cost for each excavator, we find that the high up front cost of the HB215-LC1 does not justify the savings in operating costs. Therefore utilizing the PC210-LC10 can lead to a savings of $2.26 per hour. Over the lifetime of either of these machines, this difference in price can result in thousands of dollars saved in equipment costs. The HB215-LC1 did perform up to expectation when considering operating costs, only costing $15.12 per hour compared to the PC210-LC10's $18.75 per hour.

The most significant difference in this category was the savings in fuel. The PC210-LC10 costs an estimated $14.43 per hour, while the hybrid powered HB215-LC1 only cost $9.65. This cost could have been even lower for the HB215-LC1 in a production setting, but due to the fact that the hybrid motor is powered through full swing rotations, excavating trenches does not allow for as much swing of the upper body as mass earthmoving or mining would. In a trench excavation setting, the operator usually unloads the bucket anywhere from 45 to 90 degrees from where the dirt is excavated. Under these conditions, it would take the excavator anywhere from two to four cycles, in order to reach a full 360 degree rotation to power the hybrid motor. Therefore under these working conditions, the HB215-LC1 would not be able to perform to its full capabilities.

## *Financial Calculations*

Now that we are aware of the cost each excavator will inquire throughout its working lifetime, we can analyze this data against what the anticipated hourly rate these machines will be charged to a job, using the total lifetime ownership and operating costs. Ordinarily, the cost of an excavator to a job is associated with the wages of the operating as well. After taking away the wages of the operator, I was able to determine the rate at which each of these excavators would be charged to a project. Seeing as these two machine are very similar in size and output, they would in turn be charged at the same rate per hour. After evaluating the time value of money and using a standard inflation rate, I was able to determine the payback period, rate of return, and return on investment for each excavator. The results from my calculations are shown below.

2014 Komatsu HB215-LC1

**Payback Period:** 7137 hrs or 3.965 years

**Rate of Return:** 152%

**Return on Investment:** $869,040

2014 Komatsu PC210-LC10

**Payback Period:** 5966 hrs or 3.31 years

**Rate of Return:** 172%

**Return on Investment:** $818,748

## Conclusion and Future Research

After conducting this case study, I would recommend for Casey Construction Inc. to invest in the conventional diesel powered, Komatsu PC210-LC10 excavator over the hybrid Komatsu HB215-LC1. After analyzing both types of excavators in terms of qualitative and quantitative information, the PC210-LC10 would be a much better fit for the company considering the tasks it would be required for and company circumstances. Despite the fact that the HB215-LC1 has a larger overall return on investment, the obstacles that are associated with the purchase of this machine has a larger burden. For example, with the purchase of the HB215-LC1, this would require Casey Construction either to invest in a larger trailer to transport the excavator or to subcontract transportation between project rather than using their existing trailer, which can transport the PC210-LC11. Seeing as the company takes on a lot projects all over the San Francisco Bay Area, there would be thousands of dollars for additional transportation costs each year. Another reason why the HB215-LC1 would not be suited to the company, would be, ironically, due to the EPA emissions tier that it is placed. The PC210-LC11 is a Tier 4 qualified excavator, while the HB215-LC1 is only Tier 3, which would result in additional savings for the company each year. In conclusion, the Komatsu HB215-LC1 may be more advantageous in a production environment, but for a medium sized underground utility contractor, it does not seem to be a feasible or beneficial option.

As the construction industry continues to evolve, so does the machinery and methods used in the process. Each year more cost, energy and fuel efficient equipment are produced by major manufactures to stay competitive in the sale of heavy equipment. Due to this fact, it would not be a surprise if in the near future there was a hybrid excavator manufactured to fit the needs of an excavator in the underground utility construction market. But until then, comparing the HB215-LC1 and the PC210-LC10 under the circumstances of the company, the conventional diesel powered hydraulic excavator is the superior option.

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