CALIFORNIA ENERGY COMMISSION

California Energy Commission

Clean Transportation Program

FINAL PROJECT REPORT

Zero Motorcycles' Advanced Electric Vehicle Powertrain Development and Pilot Manufacturing in California

Prepared for: California Energy Commission

Prepared by: Zero Motorcycles, Inc.

Gavin Newsom, Governor

January 2020 | CEC-600-2020-037

California Energy Commission

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ACKNOWLEDGEMENTS

The Zero Motorcycles team would like to thank the following people and organizations for their support throughout the project:

Alan Romero, David Fairchild, and Richard Stedman, Monterey Bay Unified Air Pollution Control District

Peter Koht and Bonnie Lipscomb, City of Santa Cruz, California

Corrie Kates and Steve Ando, City of Scotts Valley, California

William Ow, 100 Pioneer Street Facility

Miles Roberts, Kevyn Piper, Linda Schrupp, and Jared Cacho, California Energy Commission Project Managers and Staff

Sharon Sarris, Monterey Bay Electric Vehicle Alliance

Stefan Unnasch, Life Cycle Associates

The staff and executives of Zero Motorcycles, Inc. for all of their hard work and dedication.

PREFACE

Assembly Bill 118 (Núñez, Chapter 750, Statutes of 2007) created the Clean Transportation Program, formerly known as the Alternative and Renewable Fuel and Vehicle Technology Program. The statute authorizes the California Energy Commission (CEC) to develop and deploy alternative and renewable fuels and advanced transportation technologies to help attain the state's climate change policies. Assembly Bill 8 (Perea, Chapter 401, Statutes of 2013) reauthorizes the Clean Transportation Program through January 1, 2024, and specifies that the CEC allocate up to $20 million per year (or up to 20 percent of each fiscal year's funds) in funding for hydrogen station development until at least 100 stations are operational.

The Clean Transportation Program has an annual budget of about $100 million and provides financial support for projects that:

- Reduce California's use and dependence on petroleum transportation fuels and increase the use of alternative and renewable fuels and advanced vehicle technologies.
- Produce sustainable alternative and renewable low-carbon fuels in California.
- Expand alternative fueling infrastructure and fueling stations.
- Improve the efficiency, performance and market viability of alternative light-, medium-, and heavy-duty vehicle technologies.
- Retrofit medium- and heavy-duty on-road and nonroad vehicle fleets to alternative technologies or fuel use.
- Expand the alternative fueling infrastructure available to existing fleets, public transit, and transportation corridors.
- Establish workforce-training programs and conduct public outreach on the benefits of alternative transportation fuels and vehicle technologies.

To be eligible for funding under the Clean Transportation Program, a project must be consistent with the CEC's annual Clean Transportation Program Investment Plan Update. The CEC issued solicitation PON-09-605 to provide funding opportunities under the Clean Transportation Program for the development and expansion of manufacturing and assembly plants in California that produce electric vehicles, batteries, and component parts for alternative fuel vehicles. In response to PON-09-605, the recipient submitted an application, which was proposed for funding in the CEC's Notice of Proposed Awards on July 30, 2010. The agreement was executed as ARV-10-018 in the amount of $900,272 on February 17, 2011.

ABSTRACT

Zero Motorcycles, Inc., a California-based company that designs, manufactures, and sells high performance electric motorcycles, identified a market opportunity for more powerful and efficient electric vehicle powertrains. Under California Energy Commission Grant ARV-10-013, Zero Motorcycles evaluated the technical and economic feasibility of this advanced electric vehicle powertrain, developed and prototyped the most promising powertrain (electric motor and integrated controller), and brought the final prototype to pilot manufacturing verification.

The project was a success in all technical areas, producing an advanced electric vehicle powertrain that not only exceeded the target motor constant (Km) by 132 percent over the baseline goal, but also advanced the overall state of the market. More challenging was cost: Zero designed a manufacturable motor, but without significant additional investment in process automation, the powertrain costs still exceeded the target cost from the original grant proposal. Three primary reasons drove the cost variance - increased performance specifications, the motor controller, and the labor content of the motor.

The technology developed under this grant resulted in a powertrain that exceeds 35 kilowatts in peak performance and costs less than those used in Zero Motorcycles' 2012 product line. Zero will leverage the newly designed advanced electric vehicle powertrain's performance to manufacture higher volumes of electric motorcycles in California, exceeding consumer expectations, while displacing internal combustion vehicles in both California and worldwide fleets.

Keywords: California Energy Commission, Zero Motorcycles, electric vehicle, electric motorcycle, electric powertrain, electric motor, AEVP, motor constant, motor controller, electric motor pilot manufacturing.

Please use the following citation for this report:

Friedland, Jay, Sylvie Denuit, John Borofka. 2020. *Zero Motorcycles' Advanced Electric Vehicle Powertrain Development and Pilot Manufacturing in California.* California Energy Commission. Publication number: CEC-600-2020-037.

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EXECUTIVE SUMMARY

Zero Motorcycles, a California-based electric vehicle company that designs, manufactures, and sells high performance electric motorcycles, has successfully completed the Advanced Electric Vehicle Powertrain Project (AEVP) under CEC Grant ARV-10-013.

In 2008, Zero identified a market opportunity for more powerful and efficient powertrains for electric vehicles. Early research identified the feasibility of significantly improving the performance, efficiency, and power-to-weight ratio, while maintaining low manufacturing costs for a new, advanced generation of electric power trains. A key design consideration of the advanced electric vehicle powertrain was to enable California manufacturing to be competitive with Asian manufacturing.

With CEC funding of $900,272 and matching support of $1,331,449, Zero Motorcycles was able to evaluate the technical and economic feasibility of this advanced powertrain, develop and prototype the most promising versions, and bring the final prototypes to pilot manufacturing readiness. A total project investment of $2,231,721 allowed the development of the AEVP powertrain, which is now being incorporated into Zero Motorcycles' 2013 product line. It will also be marketed to provide a platform for the next generation of other efficient, practical electric vehicles.

The Zero Motorcycles' AEVP Development Program has advanced the state of powertrain technology used on electric vehicles. Traditional electric vehicle motor designs have been derived directly from technologies developed for industrial motor applications. They typically have been stationary, where weight and size are not a significant issue, and they have used cheap and plentiful power from the electric power grid, a very different set of constraints than those faced by electric vehicles. Even motors used in mobile applications, like golf carts or forklifts, have not had the range of performance needs required of an on-road electric vehicle.

Project Objectives and Tasks

In order to tackle these issues and advance electric vehicle powertrain technology, Zero completed the following AEVP project tasks:

- Benchmarking a representative sample of currently available electric motors in the three to ten kilowatt space, to define the existing performance envelope;
- Developing the proof of concept of an AEVP motor and controller that exceeded the performance envelope defined by the above activities, particularly a 20 percent increase in K_M, a comprehensive gauge of motor performance;
- Manufacturing and testing advanced prototypes, and creating an early pre-production pilot manufacturing total of 30 motors; and
- Securing a space for the development, testing, prototyping, and pilot manufacturing of the advanced motors

The specific AEVP Project Objectives were:

- Achieving a 20 percent improvement in K_M over the currently available electric motors by developing the next generation of purpose-built electric powertrains;

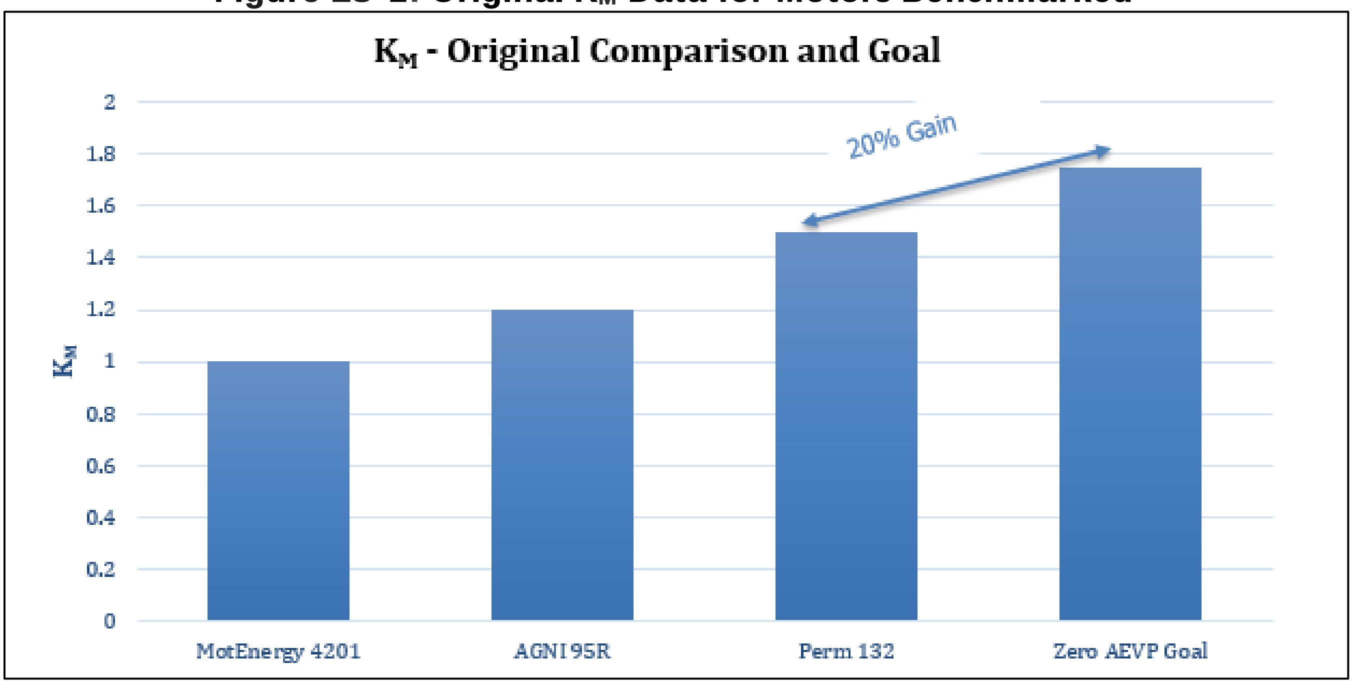
- Designing manufacturing processes for the scalable production of the advanced powertrains in Santa Cruz, California; and
- Proving the economics of fully scalable manufacturability within a financial envelope of $450 per electric powertrain.

Zero Motorcycles' AEVP Project addressed these key goals, including:

- Completing the design of an electric powertrain with a 20 percent increase in K_M performance over currently available DC motors (see Figure ES-1);
- Moving from proof of concept to advanced prototypes with a production ready design of the electric power train, completing the manufacturing of 30 early production motors; and
- Proving scalable manufacturability within a known financial envelope for each electric powertrain.

The supporting goals of the project included: 1) securing and building out space in Santa Cruz, California to base the AEVP operation; and 2) defining the performance envelope of currently available electric motors by benchmarking Agni, Perm, Mars and other motors in terms of KM and overall efficiency.

Figure ES-1: Original K_M Data for Motors Benchmarked



Source: Zero Motorcycles

Market Requirements

Since Zero proposed the project in 2008, the power requirements of the AEVP powertrain have increased significantly. Originally, the goal was to build a 10-12 kilowatt (kW) power train with 25 kW peak performance. While the market for this product has moved substantially upward in performance, Zero Motorcycles now believes that a powertrain delivering a minimum continuous performance of 20 kW and 30-50 kW of peak performance is required to meet market expectations.

Figure ES-2: Final ZF75-7 Motor As Used in the 2013 Zero S

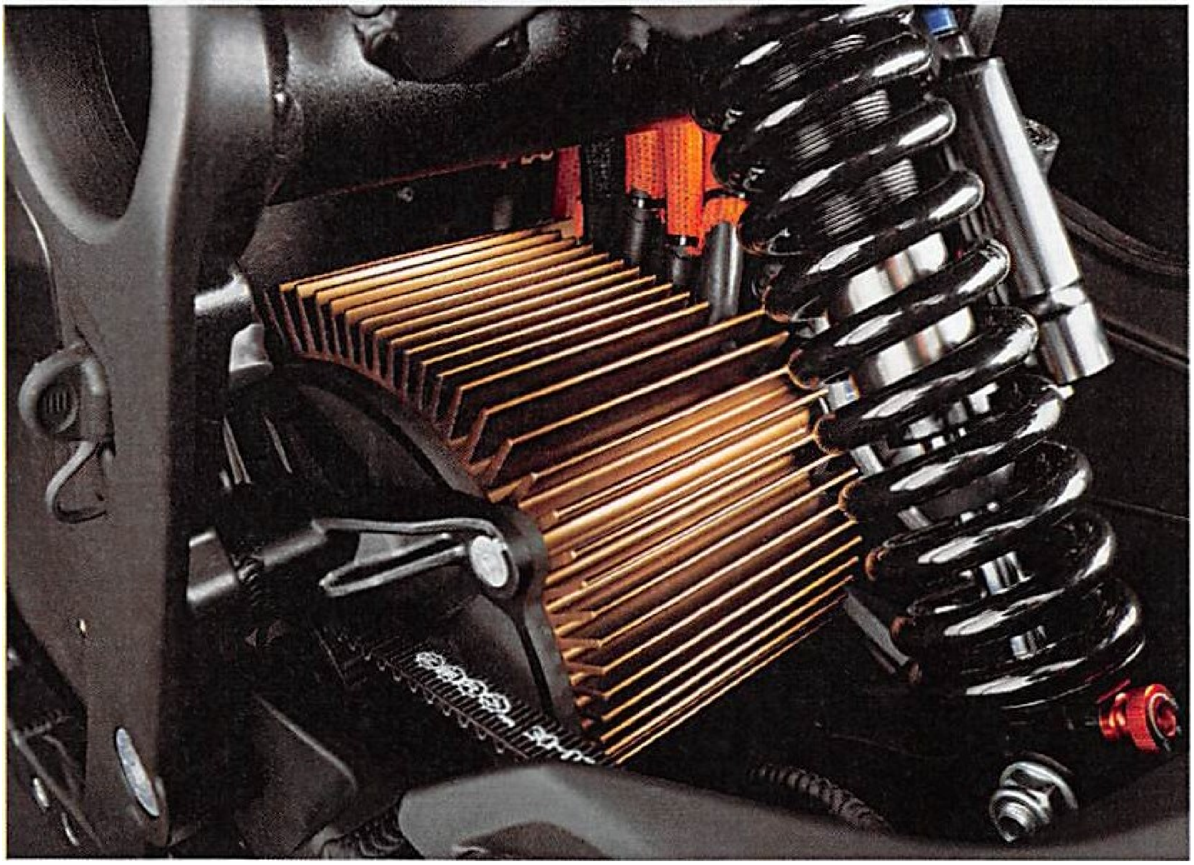


Photo Credit: Zero Motorcycles

The motor / controller combination developed as a complete powertrain for this project has dramatically higher performance than originally envisioned. This higher performance level meets anticipated market requirements as Zero Motorcycles looks forward in its powertrain development. The original baseline performance goal was a KM of 1.8 (a 20 percent increase compared to the KM of 1.5 of the best motor (Perm 132) benchmarked during the beginning of the project). The final AEVP Motor (Zero's ZF75-7) has a KM of 3.48, representing a 132 percent increase compared to the KM of the baseline Perm 132 motor.

Investment and Cost Challenges

The AEVP Project met or exceeded all technical goals and objectives. Without further investment however, Zero could not meet the final cost target. Zero was still able to create an AEVP powertrain at a lower cost than the powertrain used in Zero's 2012-product line. Three primary reasons drove the cost variance; increased performance specifications, the motor controller cost, and the labor content of the motor itself. Initially, Zero's engineers thought that the motor alone might suffice as being the key powertrain component. The motor cost is approximately 55 percent of the total powertrain cost. While the final overall powertrain cost is significantly higher than the initial cost target, Zero realized that in order for the powertrain to be marketable it had to be fully integrated with the motor, motor controller, and battery interface as a complete package.

During the process, Zero ran into obstacles with project siting, suppliers, and production issues, and overcame each challenge to complete the project within the revised timeframe.

Working closely with CEC project management and keeping strong lines of communication open was a significant part of the success of the project.

Leveraging the CEC's support, Zero Motorcycles was able to develop the AEVP and bring the final prototypes to pilot manufacturing readiness. Zero completed a pilot production run manufacturing 30 pre-production powertrain prototypes, focusing on refining the design for performance and manufacturability of the motor and fully examined production, supplier, and integration issues.

Zero is actively exploring sources of capital that will allow it to manufacture the AEVP in California. When Zero applied for the CEC grant program, the company planned to apply for both a grant to complete the pilot production, and a loan to provide the capital needed to build the full manufacturing facility. As the CEC manufacturing program evolved, it was clear that an application for the R&D and pilot production made the most sense.

Looking forward, the company determined it can more efficiently use the knowledge gained from the AEVP project to accelerate the overall manufacturing of complete electric motorcycles, and continue to partner with suppliers on powertrain components such as the AEVP motor, motor controller and battery interface. Zero will create more jobs in California by manufacturing complete vehicles rather than components; however, the company will continue to seek additional capital and efficiencies with the goal of manufacturing additional components of these vehicles in California.

By initially targeting electric motorcycles, Zero can take advantage of consumer interest and desire for a fun means of transportation at a price point significantly lower than other electric vehicles. Zero also plans to capture a market segment that has been traditionally more polluting and has generated more greenhouse gas emissions (GHG) due to lower standards for the engines in this class. Zero Motorcycles' advanced electric powertrains will have zero tailpipe emissions and a minimum 89 percent reduction in carbon intensity as compared to similar gasoline engines.

Emissions and Petroleum Reductions

Based on Zero's analysis, the project reduced petroleum use by nearly 2,700 gallons of gasoline and 27 metric tons of GHG. More importantly, over the next five years, the cumulative reduction from powertrains created under this grant and deployed into service will be 3.2 million gallons of gasoline and 33,000 metric tons of GHG. These reduction estimates are based on estimated sales of Zero Motorcycles' product line alone. If additional powertrain sales occur into the broader electric vehicle industry, the impact could triple to the reduction of 10.8 million gallons of gasoline and 110,000 metric tons of GHG.

Manufacturing and Employment

As Zero completes the development of its advanced electric powertrain, it believes they can scale the overall electric motorcycle manufacturing to achieve significant volume, changing the manufacturing dynamics, and expanding California employment.

This project created eight additional jobs at Zero Motorcycles. In addition, during the grant timeframe, Zero has grown from 55 employees to 80 employees, with much of the growth attributable to product improvements directly or indirectly related to the grant project.

Zero will continue to create California jobs by focusing its capital and human resources on full vehicle electric motorcycle production in California. This effort will lead to the creation of dozens of new cleantech jobs. Leveraging the performance of the AEVP powertrain, Zero will be able to produce more electric motorcycles, exceeding consumer expectations as we replace internal combustion vehicles in the California fleet, simultaneously achieving broad gasoline and GHG reductions.

The innovative AEVP powertrain has the potential to serve as a platform for a wide variety of efficient, practical electric vehicles, especially electric motorcycles beginning with the Zero Motorcycles 2013 model line.

Figure ES-3: Zero Motorcycles 2013 Model Line

Photo Credit: Zero Motorcycles

CHAPTER 1: Project Goals and Objectives

Project Goals

The Zero Motorcycles' AEVP Project had multiple principal and supporting goals.

Principal goals:

- Complete the design of an electric powertrain with a 20 percent increase in K_M performance over currently available DC motors;
- Move from proof of concept, to advanced prototypes, to production-ready design of the electric powertrain;
- Complete manufacturing of 30 early production motors; and
- Finalize production activities to prove scalable manufacturability within a financial envelope of $450 per electric powertrain

Supporting Goals:

- Secure and construct research and manufacturing space in Santa Cruz, California to base the AEVP operation; and
- Define the performance envelope of currently available electric motors by benchmarking Agni, Perm, Mars and other motors in terms of K_M and overall efficiency.

Project Objectives

The AEVP Project Objectives were:

- Achieve a 20 percent improvement in K_M over currently available electric motor powertrains;
- Design manufacturing processes for the scalable production of advanced powertrains in Santa Cruz; and
- Prove the economics of fully scalable manufacturability within a financial envelope of $450 per electric powertrain.

A complete discussion of how Zero Motorcycles met these Project Goals and Objectives can be found in the Project Task Summaries and Technical Details covered in Chapters 4 and 5 of this Final Project Report.

CHAPTER 2: Project Overview

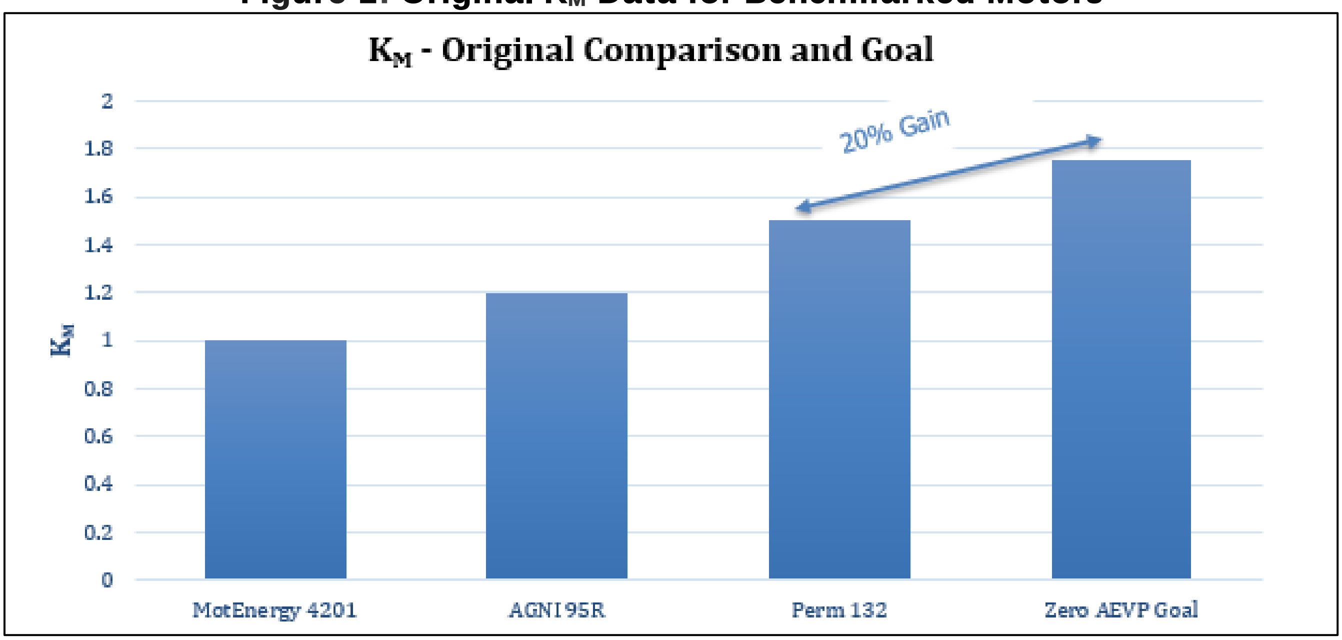
At the beginning of the AEVP project, Zero Motorcycles identified a market opportunity for designing and manufacturing more powerful and efficient electric vehicle powertrains. As it developed, the project was able to demonstrate the feasibility of improving performance, efficiency, and power-to-weight ratios while managing manufacturing costs for a new generation of advanced electric vehicle powertrains.

The goals of Zero Motorcycles' AEVP Development Program were already advanced as compared to the current state of EV powertrains. Electric vehicle motor designs have been derived directly from technologies developed for industrial motor applications. Industrial-scale electric motors tend to be stationary, where weight and size are not an issue. They also used cheap and plentiful power from the electric grid, a very different set of constraints than those faced by electric vehicles. Even motors used in mobile applications, like golf carts or forklifts, have not had the range of performance characteristics required of an on road electric vehicle.

One of the key AEVP project objectives was to achieve a 20 percent improvement in the motor constant, or K_M, a comprehensive gauge of motor performance, over currently available electric motors.

To tackle these issues and further advance electric vehicles, the AEVP project first benchmarked a representative sample of currently available 3-10 kW direct current electric motors, defining their performance envelope. See Figure 1. The Zero team then developed and built a set of prototype motors that greatly exceeded the benchmarked performance envelope in KM, efficiency, and power density.

Figure 1: Original K_M Data for Benchmarked Motors

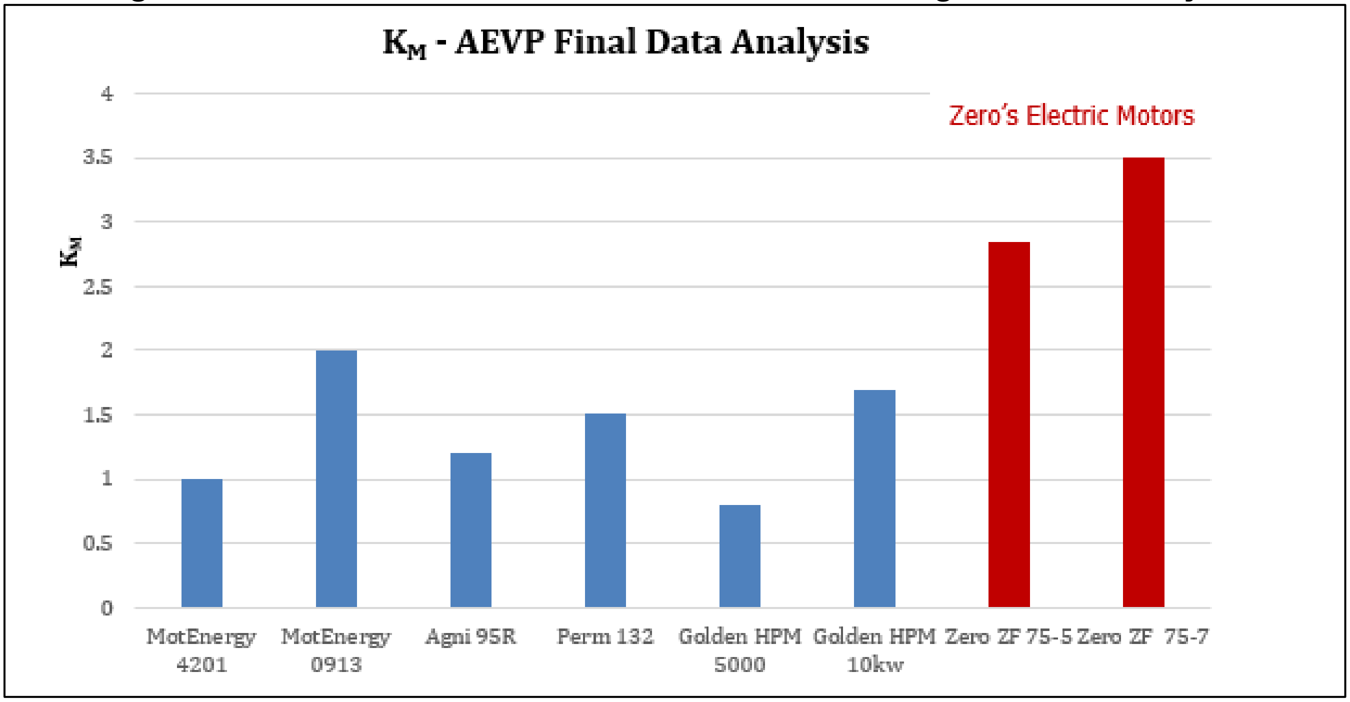


Source: Zero Motorcycles

After the initial setbacks during Task 3 with the Sevcon controller, as discussed in the Task 3 Feasibility Report and the Task 3 Technical Details in Chapter 5, Zero was able to successfully redesign the AEVP Motor to a 10-pole configuration and build working prototypes. During Task 4, Zero refined the design and performed numerous performance tests. Figure 1 above shows the set of electric motors reviewed to define the original performance goal for Zero AEVP program. The original performance target was a 20 percent increase in K_M over the Perm 132 motor, the best motor benchmarked during the beginning of the project. Zero therefore aimed to reach a K_M of 1.8 for its newly developed motor and powertrain.

Figure 2 shows the final K_M performance for the various motors and powertrains tested during the project, including the final AEVP Motor performance (ZF75 motor). Zero actually designed two versions of the ZF75 Motor Assembly, a larger motor, the ZF75-7, which has a rotor length of 7cm, and a smaller motor, the ZF75-5 with a 5 cm rotor length. As shown in Figure 2, the ZF75-5 has a K_M of 2.85, exceeding the original baseline Perm 132 motor by 90 percent while the ZF75-7 shows a K_M of 3.48, exceeding the original baseline motor by 132 percent. Both Zero motors exceeded the AEVP K_M goal of 1.8 by a significant amount.

Figure 2: Final K_M Data for all Motors Tested during the AEVP Project



Source: Zero Motorcycles

Note that the above motor efficiencies were calculated from the difference in the electric power entering the motor to the mechanical power measured by the dynamometer. K_M was calculated with the following formula from the measured resistance of the motor and motor torque constant K_T determined from the dynamometer.

$$K_M = \frac{K_T}{\sqrt{R}}$$

To achieve the AEVP project goals, Zero altered the overall timeline of the ARV-10-013 CEC grant project to match the production of Zero's manufacturing year (MY) 2013 product line.

Zero received the first prototypes of the new 10-pole motor design during that same month and began a new prototype testing cycle. Over the next few months, Zero refined the design and worked to determine the optimal suppliers and manufacturing processes.

The original Task 4 pilot manufacturing goals were revised to produce five powertrain prototypes for the 2013 Zero product line (MY 2013). The durability and refinement phase started in January 2012 and additional pilot production prototypes were completed in June 2012. Thirty pilot-production prototype powertrains were completed for the project. This schedule allowed for the additional testing necessary to meet the powertrain performance goals and aligned the pilot production goals with Zero Motorcycle's MY 2013 build schedule.

The motor / controller combination developed as a complete powertrain for this project has dramatically more performance than those origin ally envisioned for the project. This higher level of performance meets the anticipated market requirements as Zero Motorcycles looks forward in its powertrain development.

Since Zero proposed the project in 2008, power requirements for the AEVP powertrain have increased significantly. Originally, the goal was to build a 10-12 kW powertrain (with 25 kW peak performance); the market for this product has since moved substantially upward in performance. Zero Motorcycles now believes that a powertrain delivering a minimum of 20 kW continuous performance and 30-50 kW peak performance is required to meet market expectations.

Zero Motorcycles planned to reduce costs for both the motor controller and the motor magnet components. Unfortunately, neither of these cost reductions occurred. Even with increasing volumes, the cost of the Sevco motor controller did not decrease. The cost of rare-earth permanent magnets also continues to fluctuate and Zero has not been able to achieve cost reductions in this area. As Zero continues the powertrain development, it has learned that creating its own integrated motor controller or establishing a stronger relationship with its motor controller partner would allow for additional technical improvements and cost reductions. A complete discussion of the cost implications of the project is included in the Task 4 Technical Details in Chapter 5.

The project succeeded in all technical areas, producing an AEVP powertrain which exceeded the target motor constant K_M by 132 percent over the nearest competitive offering. Zero designed the motor component itself to be manufacturable, durable, and scalable. While the cost is higher than the original goal, the technology meets the market requirements.

Figure 3: Final Zero AEVP Prototypes during Bench Testing

Source: Zero Motorcycles

CHAPTER 3: Project Task Summaries

The AEVP project was broken up into five separate tasks, with Tasks 2-4 being the primary technical tasks. Task 1 included all of the grant administrative and reporting work, while Task 5 was used for final project data collection.

Task 1

The primary goals of Task 1 were to manage the project administration and reporting, including meetings with Commission staff, Monthly Reports, Critical Project Reviews, Contract Administration, and Final Reporting. Zero stayed up to date and on time with its reporting throughout the project.

A summary of the Task 1 deliverables and their completion status is included below:

Table 1: Task 1 Goals and Status

Scope of Work – Task 1	Final Status Recommendations and Conclusions
Attend Kick-Off meeting with Energy Commission Project Staff. The Recipient shall bring appropriate staff members. The CEC Project Manager will provide the agenda. Meeting will review requirements for all administrative tasks. (Task 1.1)	Kickoff Meeting held on 2/17/11.
Meet for 3 Critical Project Reviews (CPRs) to determine if project should continue to receive CEC funding and to identify any needed modifications to the tasks, products, schedule or budget. (Task 1.2)	CPR No.1 Meeting held 6/8/11. CPR No. 2 Meeting held 9/16/11. CPR No. 3 Meeting held 3/13112.
Provide Monthly Progress Reports to periodically verify that satisfactory and continued progress is made towards achieving the research objectives of this Agreement on time and within budget. (Task 1.4)	Provided 16 Monthly Progress Reports to CEC staff.
Create a Final Report assessing the project's success in achieving its goals and objectives, advancing science and technology, and providing energy-related and other benefits to California. (Task 1.5)	Final Report sent to Energy Commission staff on 8/31/12.
Identify and obtain matching funds, ensuring that the match funds are received and applied during the term of this Agreement. (Task 1.6)	All Matching Funds were obtained and deployed: $79,118 from City of Santa Cruz, $177,906 from MBUAPCD, $102,746 from Facility Landlord, $971,619 from Zero Motorcycles.
Identify and obtain required permits necessary for work completed under this Agreement in advance of the date needed to keep the Agreement schedule on track. (Task1.7)	Permits obtained and completed by 12/7/11.

Scope of Work – Task 1	Final Status Recommendations and Conclusions
Obtain and Execute Subcontracts required to carry out the tasks under this Agreement, and to procure them consistent with the terms and conditions of this Agreement. (Task 1.8)	All Subcontracts were executed and completed by 11/3/11.

Source: Zero Motorcycles

Task 2

The goal of Task 2 was to locate, outfit and populate an appropriate facility for the Advanced Electric Powertrain Development Program. Zero Motorcycles was able to recover from a significant delay caused when the original property owner withdrew from lease negotiations, which delayed completion of Task 2 until June 20, 2011. The overall project objectives continued to be met in temporary space provided at Zero Motorcycles' Scotts Valley Facility during construction. Zero actually used both facilities throughout the project since the primary testbeds for the AEVP powertrain were pre-production and developmental motorcycles. The final deliverable for Task 2, the Facility Report, was delivered to Energy Commission staff on June 20, 2011.

Table 2: Task 2 Goals and Status

Task 2 Scope of Work	Final Status, Recommendations and Conclusions
Complete all associated administrative work for the facility, including legal agreements between the property owner, government agencies and Zero Motorcycles.	Completed: Lease signed for 100 Pioneer Street in Santa Cruz on 5/13/11. City of Santa Cruz Redevelopment Agency agreement for Improvement Matching Funds signed 6/23/11. Zero used Scotts Valley and Santa Cruz sites during the project to mitigate early delays.
Construct interiors to accommodate engineering and administrative personnel.	Completed: Construction complete on 6/15/11.
Construct interior space to accommodate development and testing activities, including laboratory benches, testing areas and shop space.	Completed: 6/15/11
Locate AEVP personnel, equipment and supplies to new facility.	Completed: Began occupancy 6/17/11
Prepare Facility Report	Completed: Sent to CEC staff on 6/20/11

Source: Zero Motorcycles

Task 3

The goal of Task 3 was to design a next generation DC electric motor with a 20 percent increase in K_M over existing 3-10 kW motors and prove the concept both analytically and physically with a working prototype. The first step of this task was to benchmark the performance envelope of existing 3-10 kW DC motors and create a Performance Report, which was delivered to the Energy Commission July 29, 2011. The second deliverable of this task was a Feasibility Report delivered to the CEC on September 7, 2011, which reviewed the electrical and mechanical feasibility of alternative designs. Zero ran into a number of setbacks during this Task (discussed in detail in Chapter 5). Finally Zero delivered a Letter of Confirmation to Energy Commission staff on November 30, 2011 to complete Task 3.

Table 3: Task 3 Goals and Status

Task 3 Scope of Work	Final Status, Recommendations and Conclusions
Benchmark current performance envelope for 3 to 10 kW direct current electric motors. Calculate K_M, weight, power and efficiency ratios for the motors.	Completed: Benchmarking of existing motors complete 6/30/11.
Conduct Proof of Concept for an improved electric motor design and associated motor controller.	Completed: Motor design and powertrain components subjected to multiple iterations and test phases. Additional iteration required to resolve Sevcon motor controller performance issue. Completed 11/21/11
Conduct physical Proof of Concept for an improved electric motor design and associated motor controller. Construct early working prototypes Verify that performance specifications achieve design requirements of 20% increase in K_M.	Completed: 7 prototypes constructed and subjected to extensive testing. Performance of prototypes exceeded initial design goals. Motor controller limited maximum RPMs below acceptable levels. Final prototype exceeded design goals by 132% with a K_M of 3.48.
Prepare a Feasibility Report that reviews the electric and mechanical feasibility of multiple designs.	Completed: Submitted to CEC staff on 9/7/11.
Confirm a working prototype to document achievement of K_M target. Document with letter of confirmation.	Completed: All prototypes met or exceeded K_M target. Letter of Confirmation submitted to CEC staff on 11/30/11.

Source: Zero Motorcycles

Task 4

The goals of Task 4 were to finalize the prototype design, complete 30 late-stage, working prototype motors, and assess the manufacturability of the powertrain. One of the major steps of this task was to complete the design and create this Engineering Report, including the Final Design Documentation Package, which was delivered to the Energy Commission on August 16, 2012. The other key deliverable of this task was a Powertrain

Cost and Manufacturability Report that reviewed the final powertrain costs and assessed the manufacturability of the AEVP Powertrain. Zero also submitted a Certificate of Completion on July 6, 2012 that certified that all 30 AEVP powertrains had been completed for the project.

Table 4: Task 4 Goals and Status

Task 4 Scope of Work	Final Status, Recommendations and Conclusions
Finalize design for pilot production of 30 powertrains.	Completed: Design work completed and sent to parts suppliers for bids on 2/15/12. Some suppliers provided critical feedback, which resulted in design revisions. Design revisions completed 5/15/12.
Manufacture 30 powertrains, review manufacturability, and conduct durability and longevity tests.	Completed: Manufacture, design review and durability tests completed on 6/30/12.
Conduct a powertrain cost and manufacturability assessment. Include: A Bill of Materials for the advanced electric vehicle powertrain A description of each item Test protocols and codes applicable to each item Cost estimates or bids for each item Assessment of facility and space requirements for manufacturing, including physical space, equipment and human resources.	Completed: Cost assessments complete. Manufacturing assessment and Bill of Materials included in Task 4 Powertrain, Cost and Manufacturing Report.
Prepare final design documentation package for powertrains, including engineering drawings and standard operating procedures for construction.	Completed: Diagrams showing working design documentation provided in Task 4 Engineering Report on 8/15/12.
Write confirmation letter confirming that 30 working powertrains have been produced. Include photographs.	Completed: Provided to CEC staff on 7/16/12. Zero constructed 30 powertrains.
Prepare Engineering Report that addresses performance, durability and longevity analyses of the 30 powertrains.	Completed: Task 4 Engineering Report submitted to CEC staff on 8/15/12.

Source: Zero Motorcycles

Task 5

The primary goal of Task 5 was to perform final analyses of all project data and to present final reports to the Energy Commission. The analyses include an estimate of the project's

GHG and petroleum reduction benefits and an extrapolation of this data based on market acceptance of the AEVP powertrain. Data from Task 5 is included in this Final Report.

Table 5: Task 5 Goals and Status

Task 5 Scope of Work	Final Status, Recommendations and Conclusions
Define data analysis parameters and begin data collection.	Completed: Data analysis initiated with completion of first prototype in May 2011.
Task 3 data collection.	Completed: Data collection continued throughout Task 3 as each prototype was completed. Data was also collected to allow for a comparison of new prototypes with MY 2012 powertrains. Completed 11/30/11.
Task 4 data collection.	Completed: Most of the Task 4 data was collected between December 2011 and July 2012. Over 2,500 hours of motor data was collected. Completed 7/31/12.
Summarize data for Final Report	Completed: Final data analysis was conducted in July and August 2012. Over 2,200 test miles were logged on 4 MY 2013 motorcycles equipped with the new powertrains.

Source: Zero Motorcycles

CHAPTER 4: Project Task and Technical Details

The AEVP project was broken up into five separate tasks, with Tasks 2-4 being the primary technical tasks. Task 1 included the grant administrative and reporting while Task 5 was the final data collection for the project.

Task 1

The primary goals of Task 1 were to manage project administration and reporting, including meetings with Commission staff, Monthly Reports, Critical Project Reviews, Contract Administration, and Final Reporting. Zero stayed up to date and on time with its reporting throughout the project. A total of 14 monthly reports were submitted along with three Critical Project Review presentations. Since Task 1 was an administrative and reporting task, the Task 1 Summary in Chapter 3 provides a complete assessment of the task completion.

Task 2

The goal of Task 2 was to locate, outfit and populate an appropriate facility for the AEVP development program. Zero Motorcycles was able to recover from a significant delay caused by the original property owner withdrawing from lease negotiations. While changing facility locations delayed completion of Task 2 until June 2011, overall progress on project objectives continued to be met in temporary space at Zero Motorcycles' Scotts Valley Facility.

Zero successfully completed all the associated administrative work for the facility, including legal agreements between the new real estate owner, Zero and appropriate government agencies. Zero signed the lease for 100 Pioneer Street, Santa Cruz, on May 13, 2011.

Zero's contractors began construction of the interior facility to accommodate the engineering and administrative personnel for the electric powertrain program immediately upon occupancy. Zero began using the completed facility on June 11, 2011. Finally, Zero prepared the Task 2 Facility Report to complete Task 2, meeting the revised deadline on time. Figures 4-13 provide photographs of the interior and exterior of the facility.

Figure 4: Front View of 100 Pioneer Facility - Zero AEVP Location

Photo Credit: Zero Motorcycles

Figure 5: Interior of Warehouse/Manufacturing Area at 100 Pioneer Street Site

Photo Credit: Zero Motorcycles

Figure 6: Workbench Area for Powertrain Testing

Photo Credit: Zero Motorcycles

Figure 7: Test Motors Ready for Benchmarking

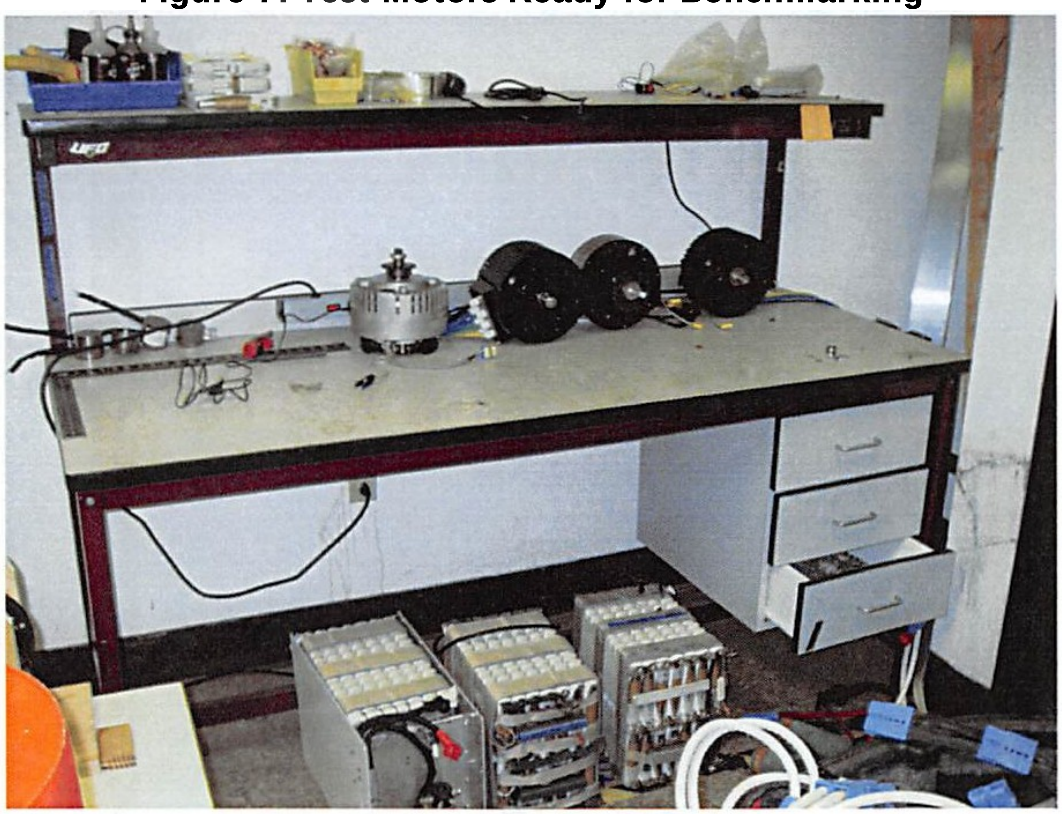


Photo Credit: Zero Motorcycles

Figure 8: Power Dissipation Water Bath

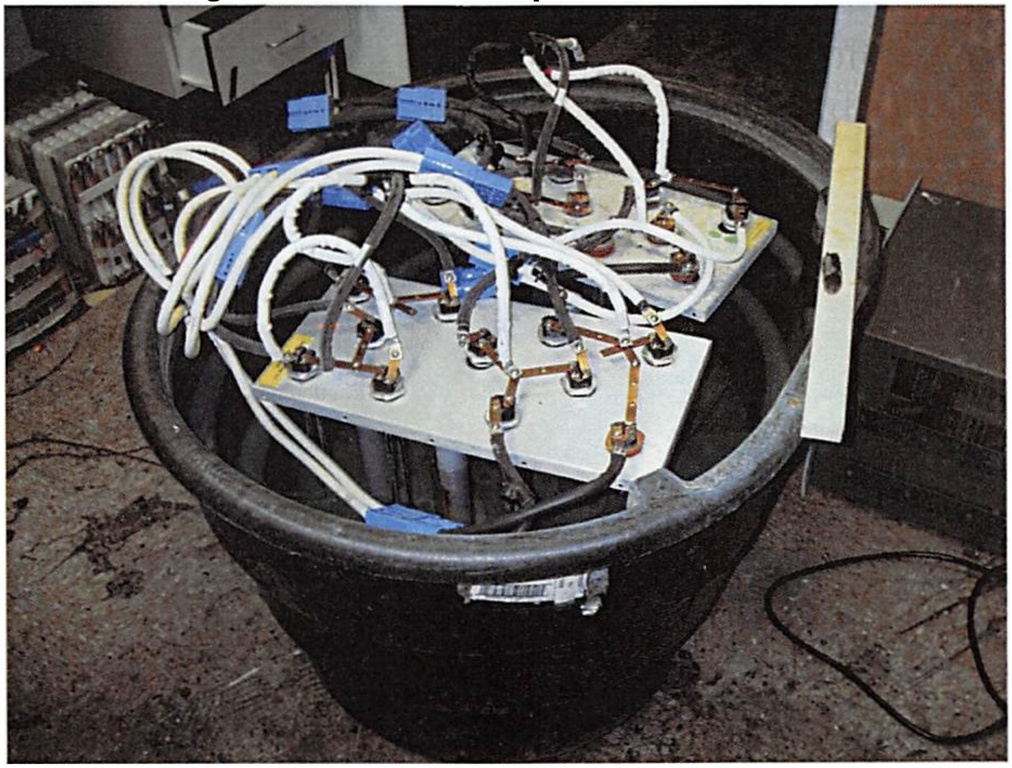


Photo Credit: Zero Motorcycles

Figure 9: Motor Dynamometer

Photo Credit: Zero Motorcycles

Figure 10: AEVP Prototype I Motor Mounted on Motorcycle Test Mule

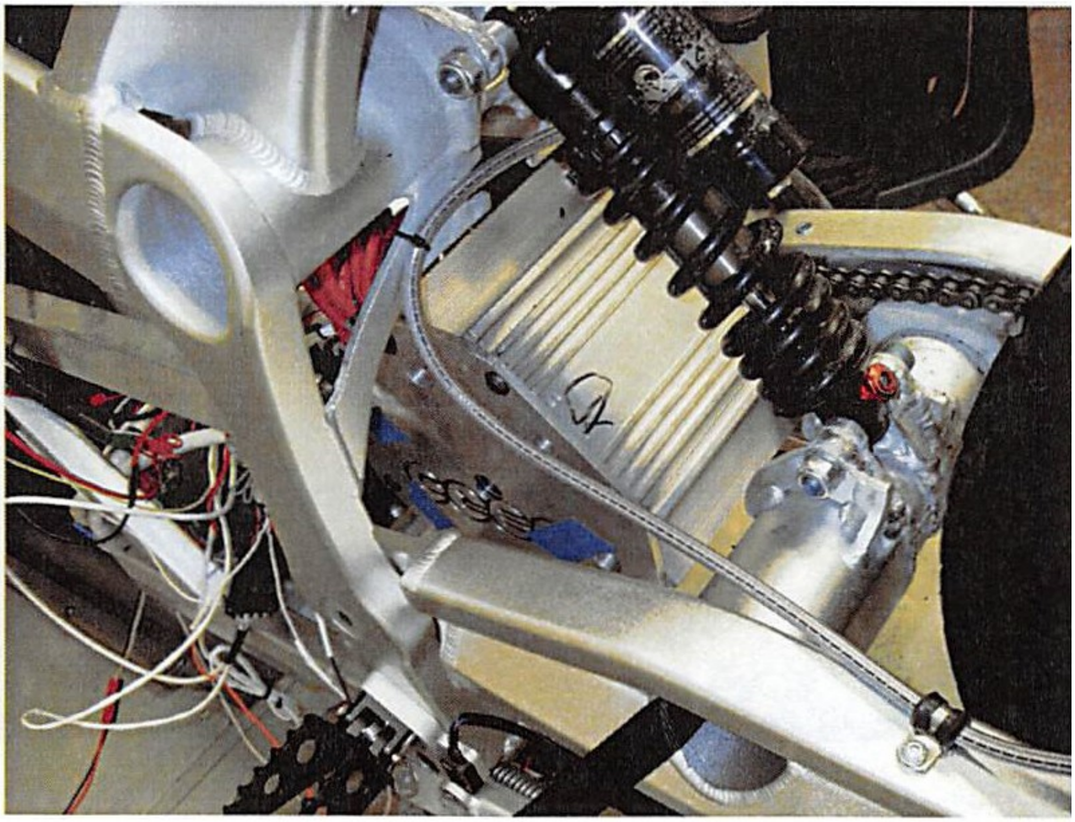


Photo Credit: Zero Motorcycles

Figure 11: Chassis Dynamometer Run with AEVP Motorcycle Test Mule

Photo Credit: Zero Motorcycles

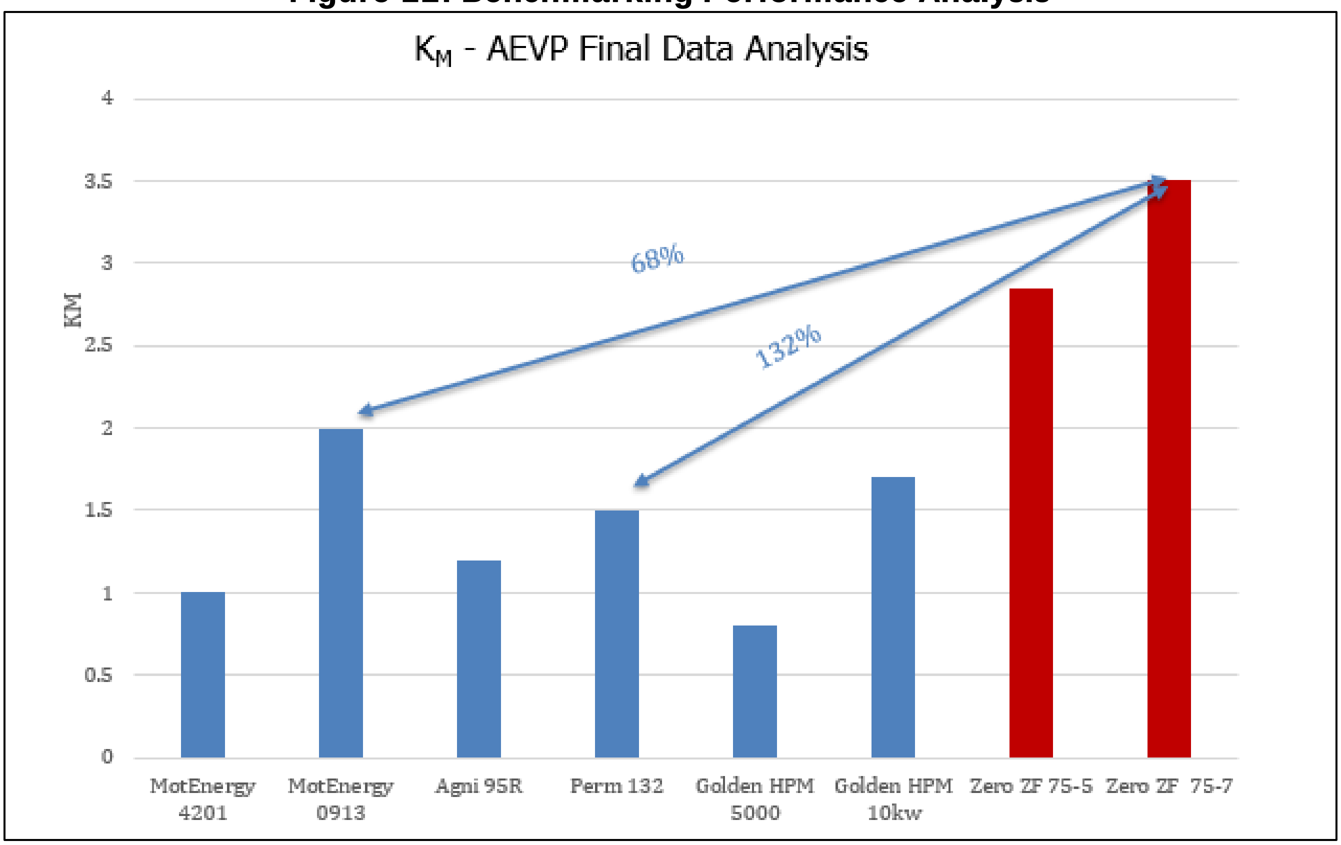
Task 3

The goal of Task 3 was to design the next generation DC electric motor with a 20 percent increase in KM over existing 3-10 kW motors and prove the concept both analytically and physically with a working prototype. The first step of this task was to benchmark the performance envelope of existing 3-10 kW DC motors and create a Performance Report, which was delivered to the Energy Commission July 29, 2011. The second deliverable was a Feasibility Report delivered to the CEC on September 7, 2011, which reviewed the electrical and mechanical feasibility of alternative designs. Zero encountered a number of setbacks during this Task. Finally, Zero delivered a Letter of Confirmation to Energy Commission staff on November 30, 2011 to complete Task 3.

Zero completed the first milestone of Task 3 with the submission of a Performance Report. The report summarized the benchmarking and performance envelope for currently available 3-10 kW DC motors and compared them to the performance of the initial Zero AEVP motor/powertrain.

Zero designed the advanced motor and constructed prototypes that outperformed the best currently available 3-10 kW DC electric motors by 68 percent in the performance metric K_M and made significant improvements in power density. Figure 14 shows the initial benchmarking performance results, measured by K_M.

Figure 12: Benchmarking Performance Analysis



Source: Zero Motorcycles

Table 6: Motor Performance Characteristics

Performance Parameter	Perm 132	Agni 95R	Golden HPM 5000	Golden HPM 10kW	Mars 4201	Mars 0913	Zero LD 70-7	Zero LD 70-5
K_M	1.5	1.29	0.9	1.7	1.0	2.0	3.35	3.45
Weight (lbs)	25	24	24	38	25	35	33	30
Continuous Power (HP)	9	13	9	13	8	16	26	20
Continuous Power (kW)	7	10	7	10	6	12	20	15
Peak Efficiency (%)	93	93	90	90	90	90	95	95
Power Density (Hp/lb)	0.36	0.54	0.38	0.34	0.32	0.46	0.79	0.67

Source: Zero Motorcycles

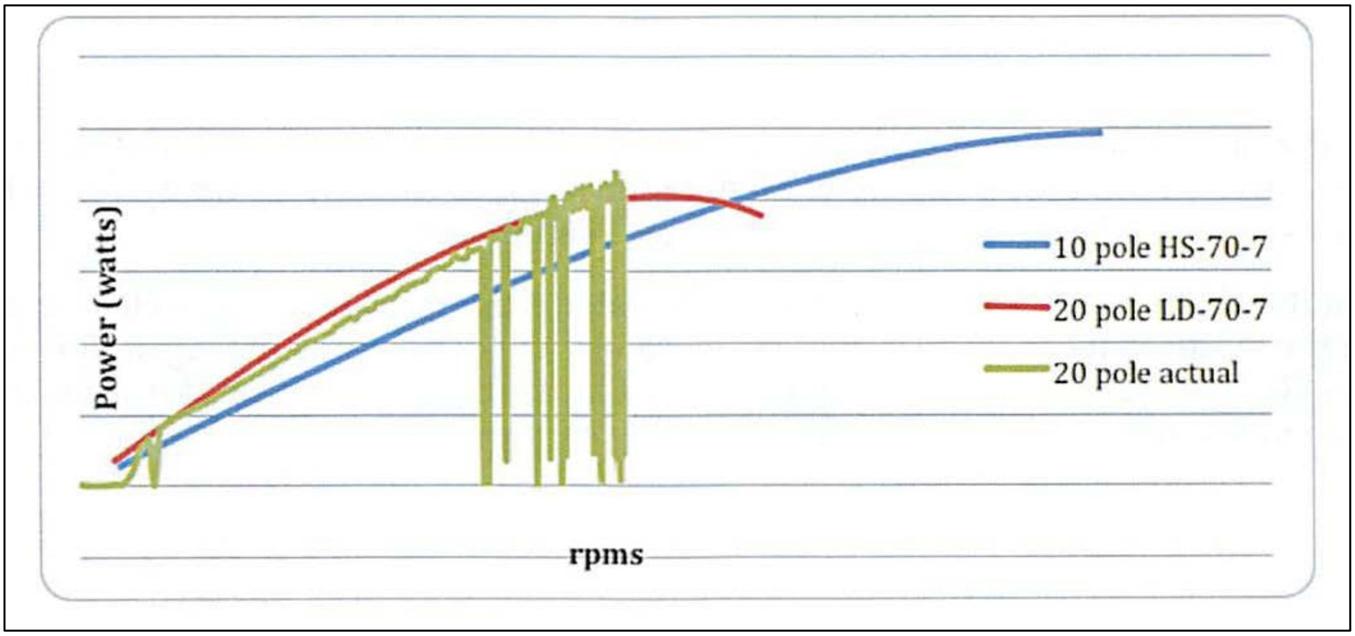
During Task 3, the Zero-designed motor and initial prototypes clearly outperformed the best currently available 3-10 kW DC electric motors. Table 6 indicates performance parameters for the benchmarked motors.

After completion of the motor prototypes, Zero discovered limitations in the motor controller produced by project partner Sevcon. This made the optimal design for the Zero AEVP motor uncontrollable above 2000 RPM, significantly decreasing its peak power output. Working with Sevcon, the controller was modified to increase controllable speed up to 3000 RPM. However, this still fell short of the performance (especially for top speed) required for Zero's product line. To meet Zero's MY 2012 product schedule, they selected the second highest performance motor from the benchmark testing and worked with Motenergy (formerly Mars Electric) to further increase its overall performance. The Zero team was motivated and worked aggressively to deliver the AEVP powertrain on schedule for Zero's MY 2012 electric motorcycle production, but were unable to achieve this aggressive schedule due to issues with the initial controller supplier.

The Zero AEVP motor design worked correctly. The motor was powered by EIG Lithium Polymer batteries and a Kelly motor controller that was substituted for the Sevcon controller. This version of the AEVP powertrain attained 102 mph and 39 HP on the dynamometer and a top speed of 94 mph on the track. Unfortunately, the Kelly controller is significantly more expensive and not suitable for Zero's production intent electric motorcycles from a cost perspective.

Based on feedback from Sevcon, Zero initiated a redesign of the AEVP motor to make it compatible with the Sevcon controller without sacrificing targeted performance or cost. This required moving from a 20-pole motor design to a 10-pole motor design, effectively lowering the operating frequency of the motor. Using simulation software, Zero significantly reduced harmonic distortion in the motor design. The 10-pole design enabled Zero to reach the initial project design goals with respect to K_M without sacrificing performance. The 10-pole design reached a higher overall RPM, satisfying the top end speed requirements, while meeting the compatibility requirements of the Sevcon motor controller.

Figure 13: Powertrain Performance Modeling/Actual Data for 10 and 20 Pole AEVP Motors



Source: Zero Motorcycles

In order to achieve the AEVP project goals, Zero modified the overall timeline of the CEC grant to match the production of Zero's MY 2013 product line. Zero received the first prototypes of the new 10-pole motor design during September 2011 and began a new prototype testing cycle.

The original Task 4 pilot manufacturing goals were re-targeted to produce five powertrain prototypes for the Zero MY 2013 product line durability and refinement phase, and 25 additional pilot production prototypes for the Zero MY 2013 validation build. This revised schedule allowed time for the testing needed to meet the powertrain performance and pilot production goals for Zero's MY 2013 production schedule.

Task 4

The goals of Task 4 were to finalize the prototype design, complete 30 late-stage, working prototypes, and assess the manufacturability of the powertrain. Part of this task was to complete the Engineering Report and Final Design Documentation Package, which was delivered to the CEC on August 16, 2012. The other key deliverable for this task was the Powertrain Cost and Manufacturability Report, which reviewed the final powertrain costs and assessed the manufacturability of the AEVP Powertrain. Zero also submitted a Certificate of Completion on July 6, 2012 certifying that all 30 AEVP powertrains were completed.

After the initial setbacks during Task 3 with the Sevcon controller, Zero was able to successfully redesign the AEVP Motor to a 10-pole configuration and build working prototypes. Zero refined the design and performed numerous performance tests. The original performance target was a 20 percent increase in K_M over the Perm 132 motor, the best motor benchmarked during the project. Zero therefore aimed to reach a K_M of 1.8 for its newly developed motor.

Figure 14 above shows the overall final K_M performance for the various motors/powertrains tested during the project and illustrates the final AEVP Motor performance (ZF75 motor). Zero actually designed two versions of the ZF75 Motor Assembly, a larger motor, the ZF75-7 that has a rotor length of 7 cm, and a smaller motor, the ZF75-5 with a 5-cm rotor length. The ZF75-5 has a K_M of 2.85, exceeding the original baseline Perm 132 motor by 90 percent. The ZF75-7 shows a K_M of 3.48, exceeding the original baseline motor by 132 percent. Both motors exceed the Zero AEVP K_M goal of 1.8 by a significant amount.

Note that the above motor efficiencies were calculated from the difference in the electric power entering the motor to the mechanical power measured by the dynamometer. K_M was calculated with the following formula from the measured resistance of the motor and motor torque constant K_T determined from the dynamometer.

$$K_M = \frac{K_T}{\sqrt{R}}$$

Test Procedures

Each of the prototype motors was tested on one of Zero Motorcycles' motor dynamometers to verify performance specifications.

Figure 14: Zero Motorcycles' Dynamometers and Bench Setup

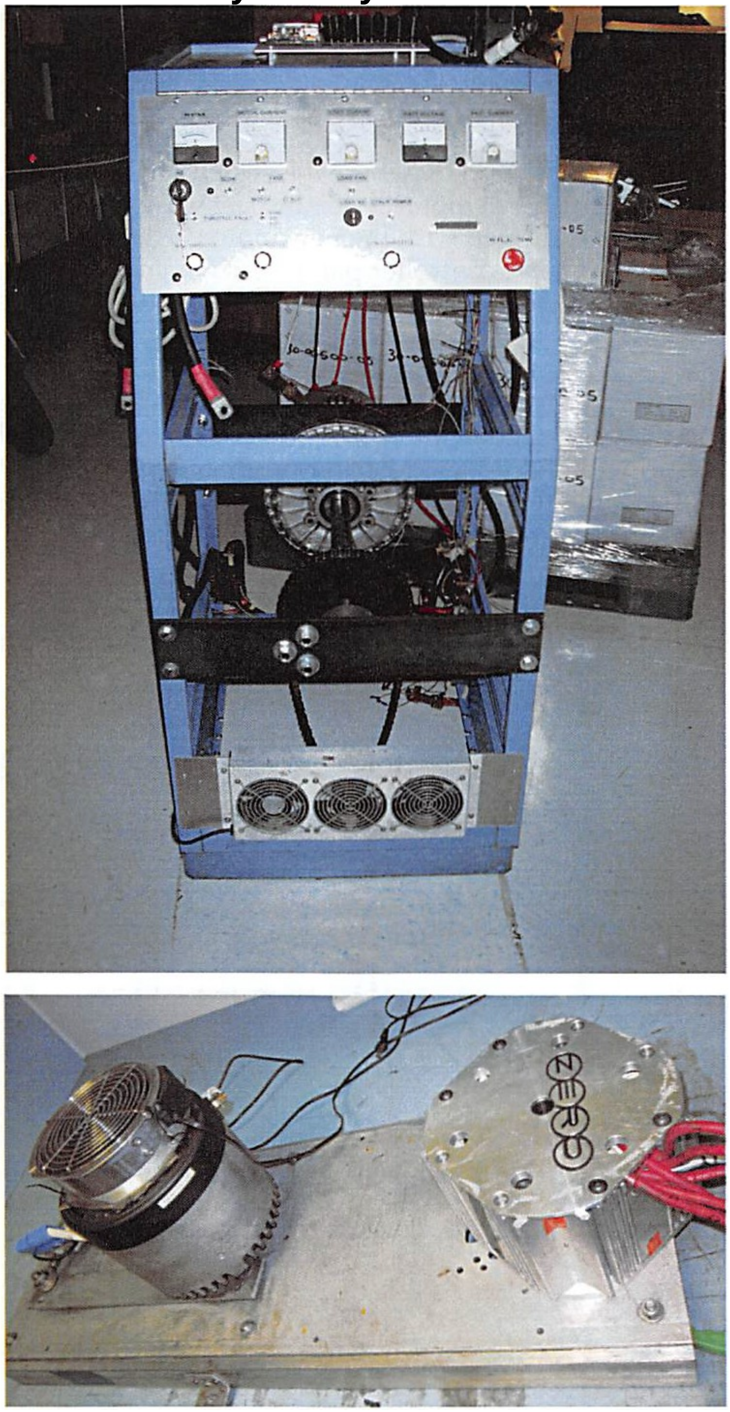


Photo Credits: Zero Motorcycles

Dynamometer Procedures

For the continuous power rating, performance testing is completed by running the motor at a fixed speed and adjusting the torque to maintain 10 degrees C below maximum operating temperature. Speed is increased by 250 RPM and the new operating torque is determined. Zero uses these torque and RPM (torque * RPM = power) values to produce a continuous power curve. The maximum point on that curve is then selected to determine the maximum continuous power.

The typical test protocol is to validate the motor integrity and performance on a bench, then install the motor in a motorcycle for power and ride testing. The bench test involves spinning the motor with an external force while measuring the motors' BEMF waveform to verify that the coils and magnets are operating as expected. Further bench tests involve a no-load loss profile to ensure there is no mechanical friction or faults in the wiring or the position sensor.

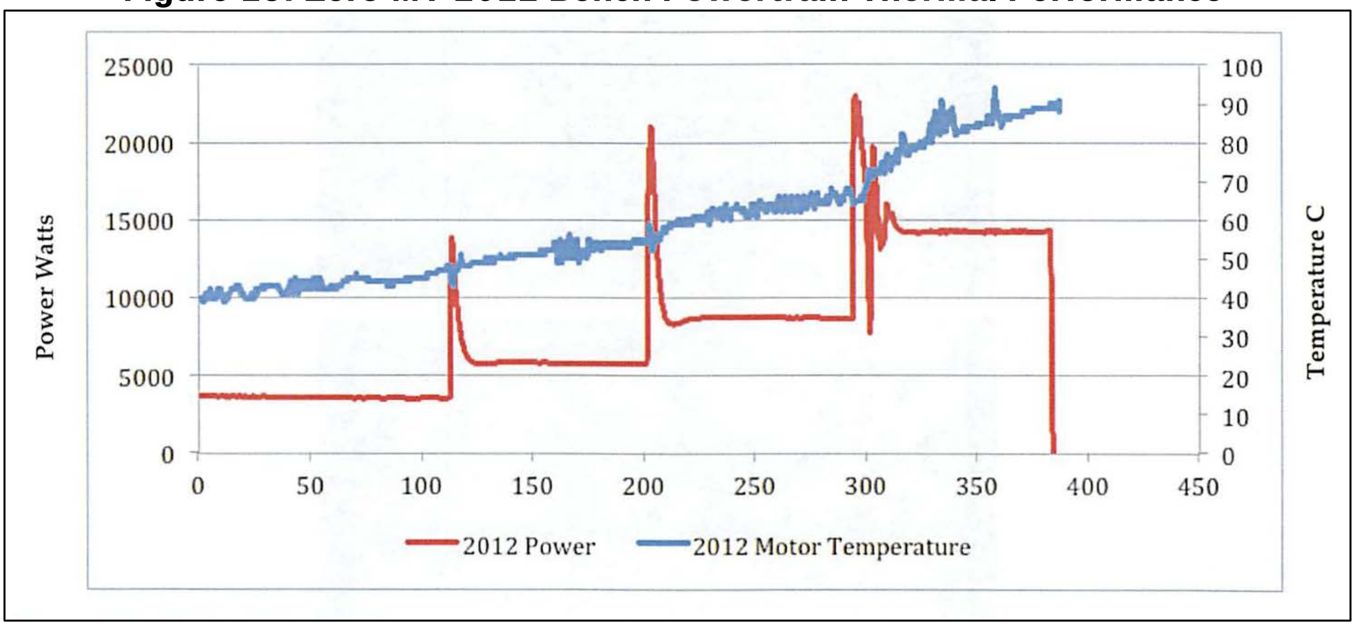
Road Testing

The motor is installed in a motorcycle and tested on the chassis. Since the primary application of the motor is for use in a motorcycle, the best way to test its performance is through road testing. The motorcycle, equipped with the new motor, is then ridden on a standard set of routes while a number of motor and controller parameters (such as temperature) are being logged in order to analyze the performance of the motor in "real conditions".

Durability

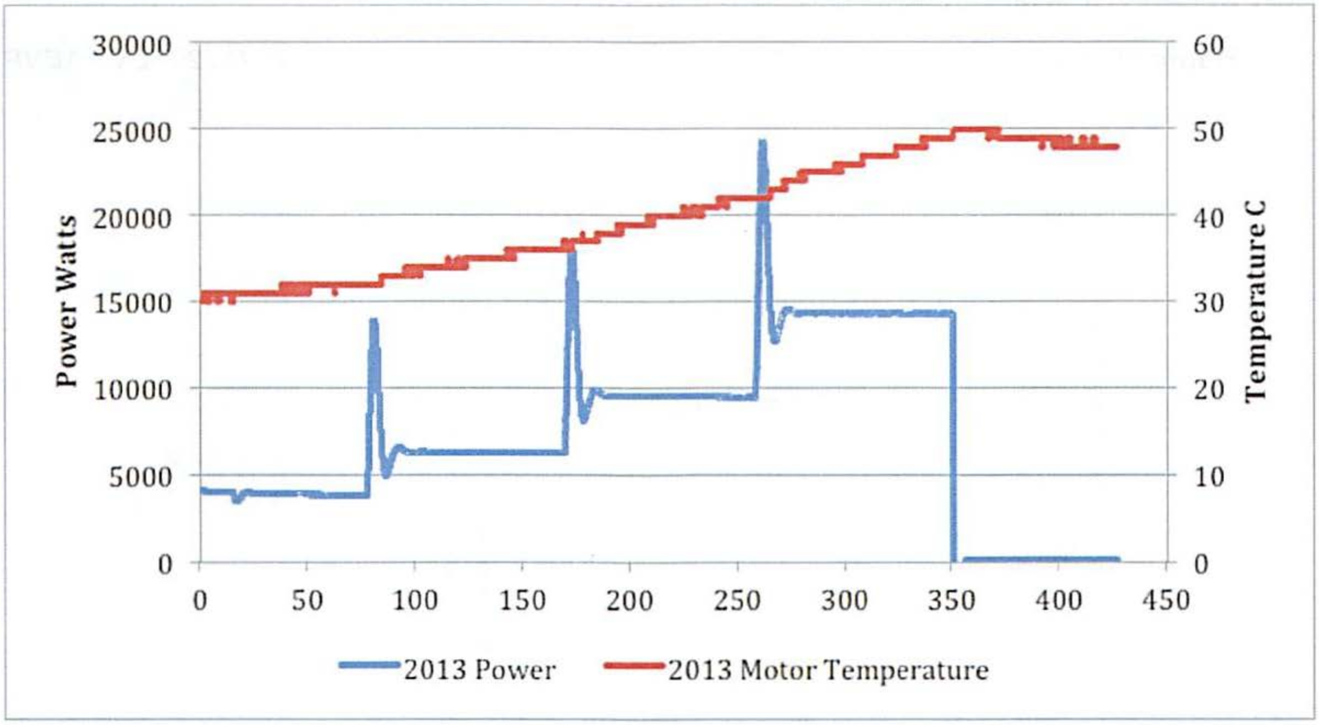
One of the key durability issues with high performance electric vehicle motors is overheating. Zero specifically designed the AEVP powertrain to be more thermally stable. Below are the data plots measuring both the Zero MY2012 production powertrain (based on the enhanced Mars/Motoenergy motor) and the preproduction Zero MY 2013 powertrain using the ZF75-7 motor and updated Sevcon controller.

Figure 15: Zero MY 2012 Bench Powertrain Thermal Performance



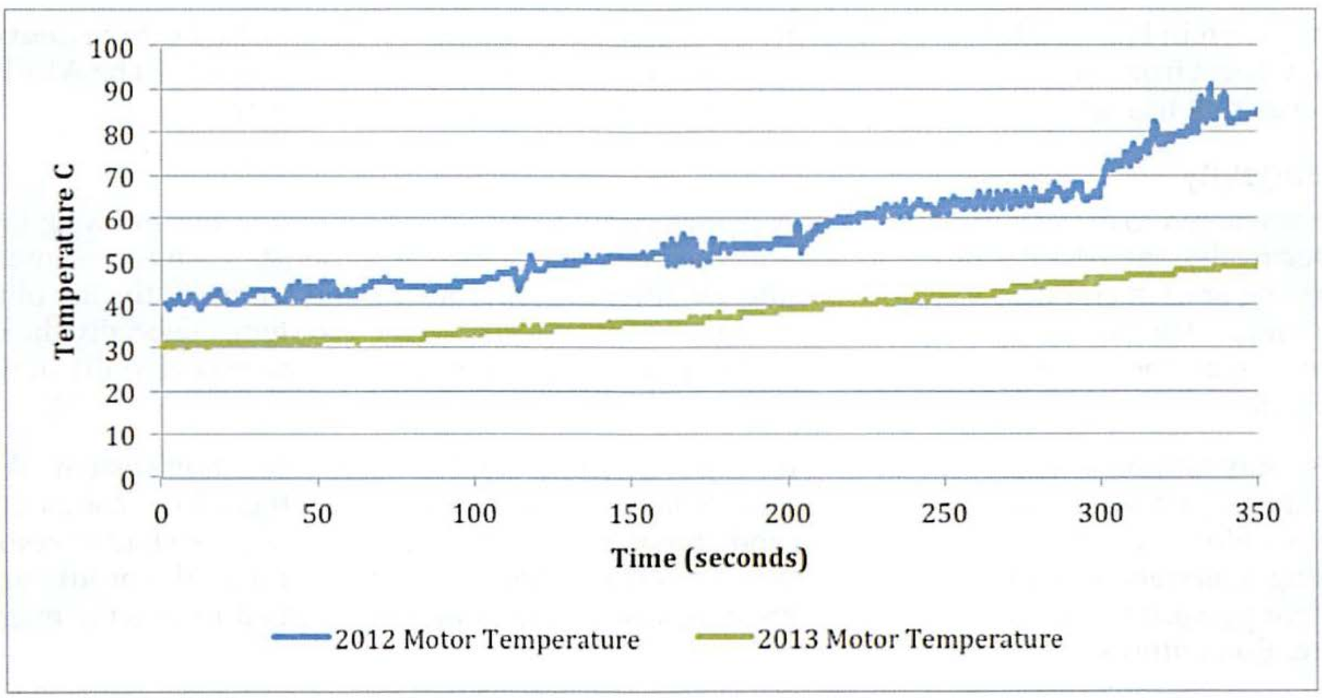
Source: Zero Motorcycles

Figure 16: Zero AEVP Bench Powertrain Thermal Performance



Source: Zero Motorcycles

Figure 17: Thermal Performance Comparison of MY 2012 vs Zero AEVP Powertrain

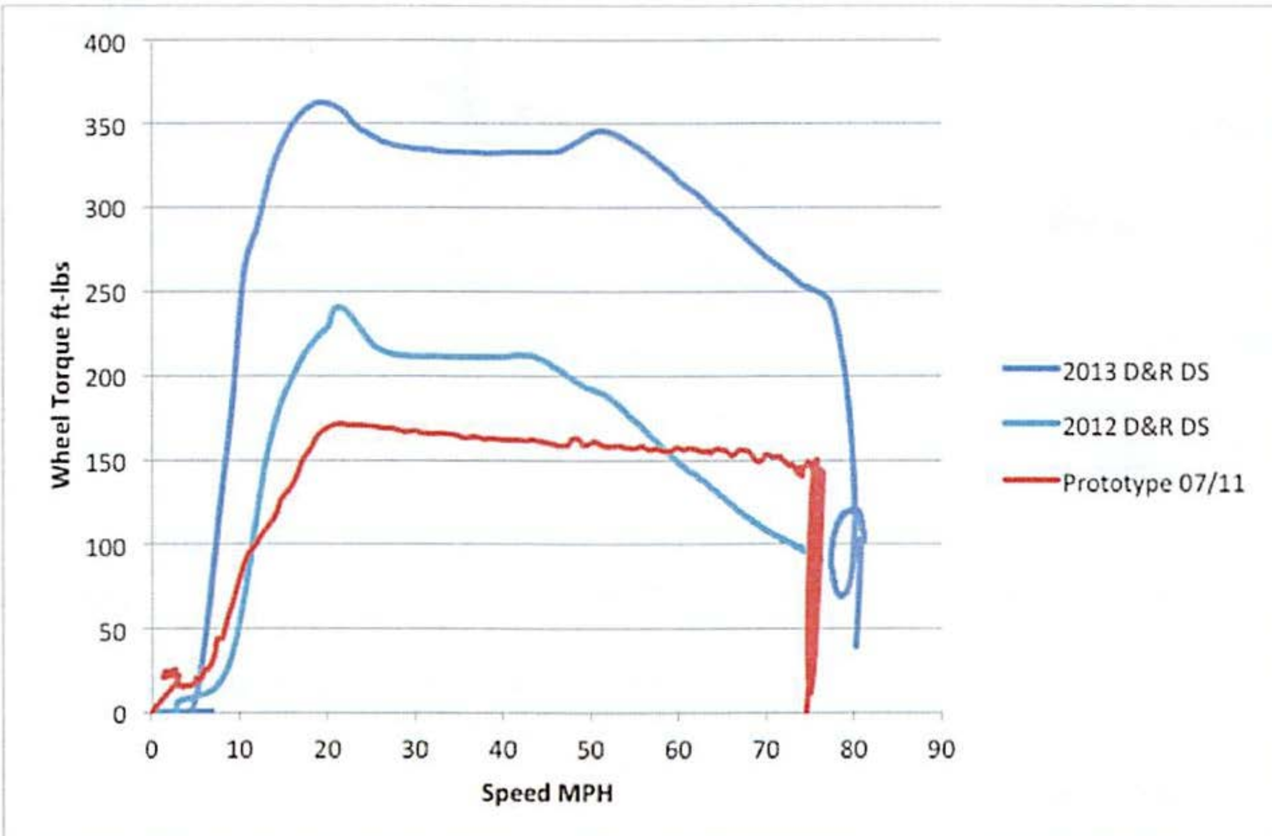


Source: Zero Motorcycles

As shown in Figure 17, the AEVP Powertrain is more thermally stable than the previous configuration. This will allow the power train to be much more durable and provide longer sustained performance at higher RPM. The AEVP power train, when geared correctly in an electric motorcycle, will be able to exceed 100 MPH.

The graph in Figure 18 shows one of the other key performance factors - actual torque delivered to the wheels from the powertrain. This is truly where the "rubber meets the road." The AEVP powertrain has 50 percent more delivered torque than its Zero MY 2012 equivalent.

Figure 18: Comparison Data of Wheel Torque - Original Prototype vs MY 2012 vs AEVP



Source: Zero Motorcycles

Longevity

Zero wanted to make sure that the AEVP powertrain would prove both durable and long lasting. Specifically, the AEVP motor was designed to be both low-cost and robust. Using the same large bearing at each end decreased the number of different components and increases the life of the bearings. The motor should survive the rigors of any electric vehicle system, especially the more severe e-motorcycle environment and not require any maintenance for the expected life of the vehicle.

The only failures experienced during testing were linked to the magnet retention system. A fiberglass / epoxy matrix was used to encapsulate the magnets and keep them from contacting the rotor. However, the proper fiberglass and epoxy were difficult to obtain and the team had to use materials available in the shop. Although this was a viable prototype option, the production intent powertrain has a more robust retaining system than fiberglass that addresses the magnet retention failures.

In terms of longevity, Zero has over 3,000 total miles and 250 riding hours on the AEVP prototype powertrains during in-vehicle testing. This is in addition to the 1,900 hours logged on the motor dynamometer. Most of those miles are on the ZF-75-7 motors, which are also used on the motorcycles with larger batteries. The two main durability and refinement Zero S/DS motorcycles have 714 and 758 miles on them respectively, while the two Zero XU/FX motorcycles with ZF-75-5 based powertrains have 328 and 437 miles respectively. Images of the ZF75-7 motor and Sevcon Gen 4 Size 4 controller are shown below in Figures 20 and 21. The engineering drawings that were used as the final design package for construction are included in Appendix A and a copy of the Sevcon motor controller datasheet is included in Appendix B.

Figure 19: Sevcon Gen4 Size 4 Motor Controller

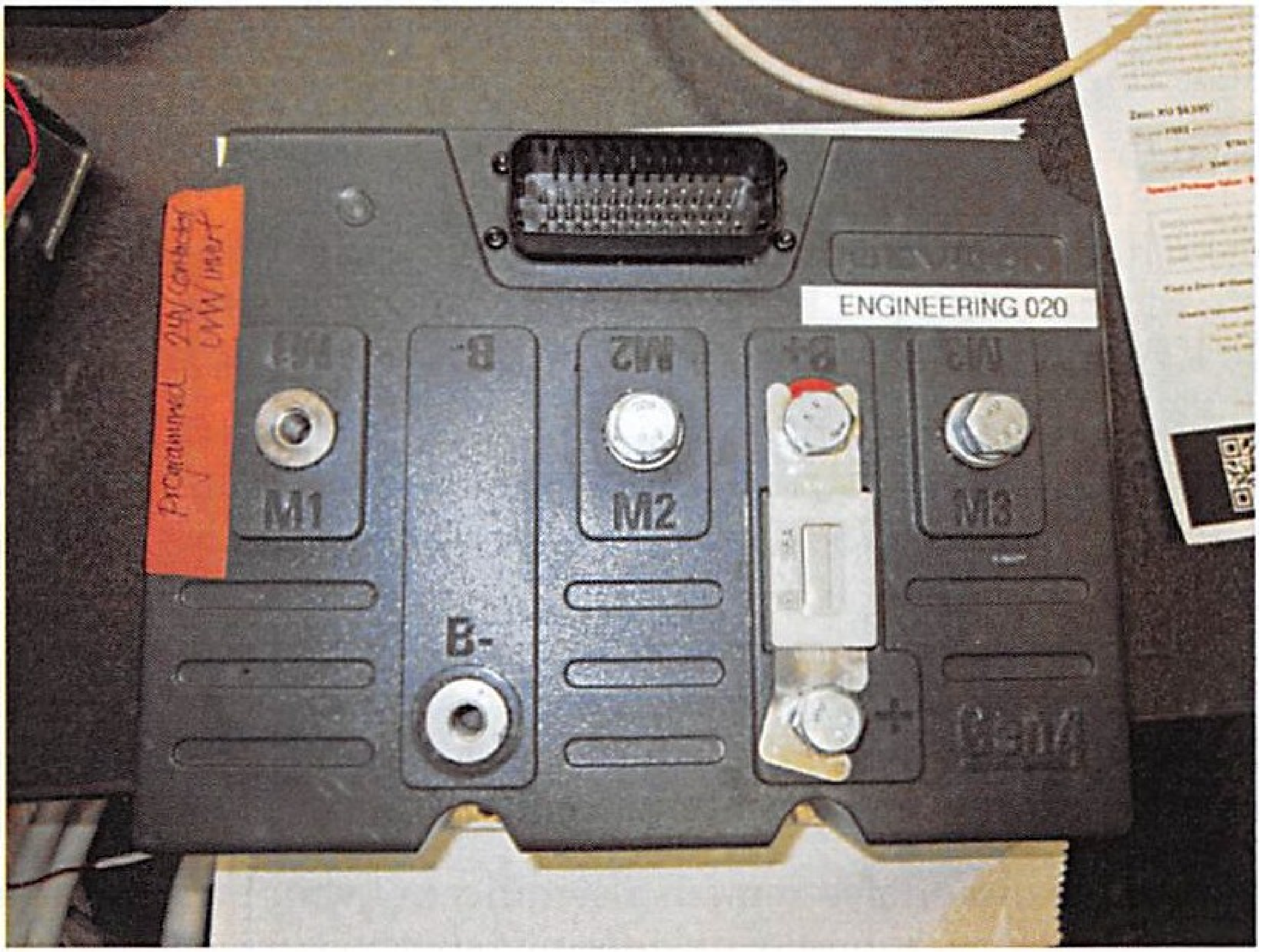


Photo Credit: Zero Motorcycles

There are several unique aspects to this design, including the 10-pole stator which is heat-shrink pressed in the outside case of the motor to enhance thermal stability, and a high performance rotor with long-life bearings.

Figure 20: ZF75-7 AEVP Production Intent Motor

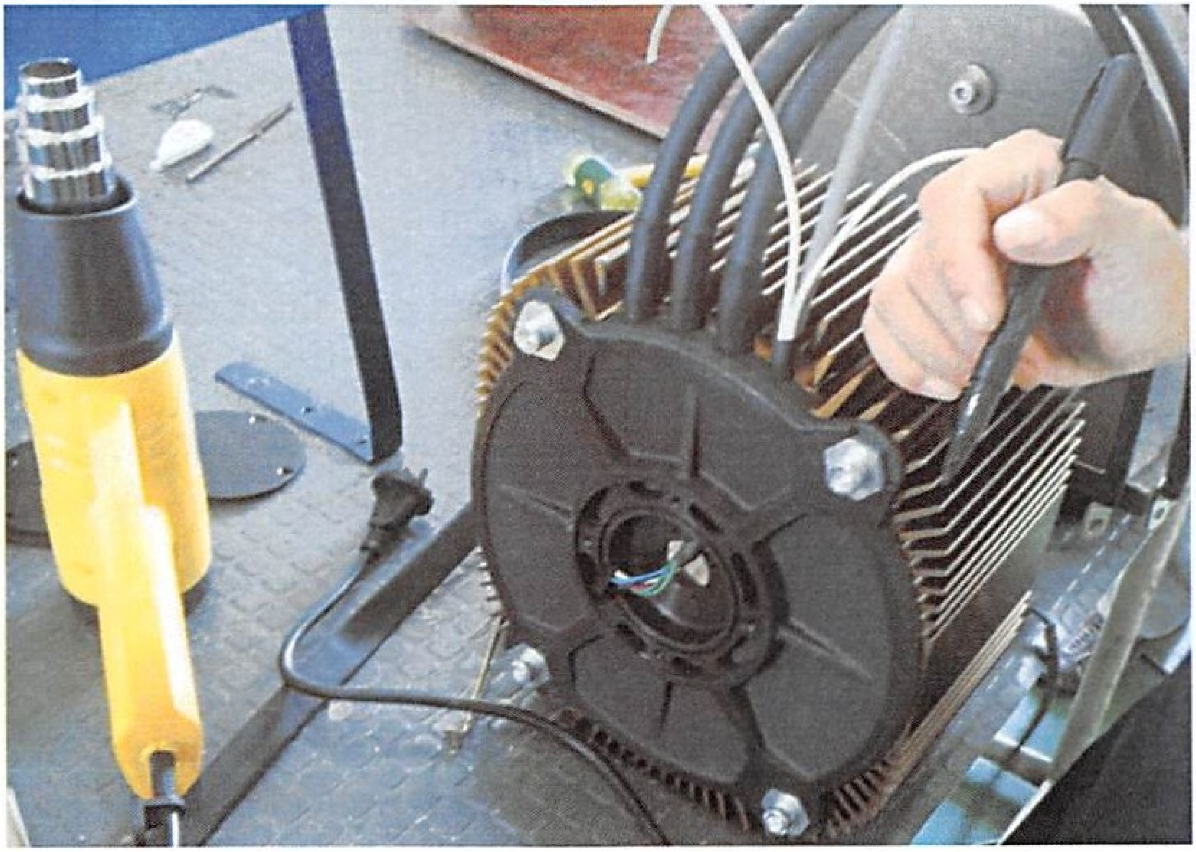


Photo Credit: Zero Motorcycles

Cost and Manufacturability

As part of Task 4, Zero initiated a comprehensive cost and manufacturing analysis to determine if the AEVP powertrain could be manufactured competitively in California. In May 2010, at the time of submission of the PON-09-605 grant application, Zero targeted a final powertrain cost of $450. From a cost perspective, the AEVP powertrain is significantly more expensive that the original target goal set in the grant application. This is due to three primary reasons - increased performance specifications, cost of the motor controller, and the labor content of the motor itself.

Since Zero proposed the project in 2008, the power requirements of the AEVP powertrain have increased significantly. Originally the goal was to build a 10-12 KW powertrain (with 25 KW peak performance) while the market for this product has moved substantially upward in performance. Zero Motorcycles now believes that a powertrain delivering a minimum continuous performance of 20 KW and 30-50 KW peak performance is required to meet market expectations.

Zero anticipated that there would be cost reductions in both the motor controller and the motor magnet components. Unfortunately, these cost reductions did not occur. The cost of the Sevcon motor controller did not decrease either, even with increasing volumes. The cost of rare-earth permanent magnets also continues to fluctuate and Zero has not been able to achieve cost reductions in this area. As Zero continues the powertrain development, it has realized that creating its own integrated motor controller or establishing a stronger relationship with the motor controller partner would allow for additional performance improvements and cost reductions.

Labor costs to produce the motor also remain a significant factor in the overall cost, requiring about 12 hours of labor per motor. Considering the labor intensive nature of the manufacturing process and the high labor cost for manual labor in the US (about $25/hr), this motor cannot be competitively produced at Zero Motorcycles in California at this time without changes in the manufacturing process. If Zero ultimately decides to manufacture the AEVP motor in California, it would have to make major investments in capital equipment that allows for robotic automation of the motor winding process to move away from the current labor intensive, manual winding procedure.

After significant analysis, Zero believes it will create more California jobs and add more value by focusing its capital and human resources on full vehicle electric motorcycle production in California. This effort will lead to the creation of dozens of jobs. Zero will continue to explore cost reductions and evaluate opportunities to invest capital in the AEVP powertrain so that these key components can be manufactured in California.

Figure 21: Zero's AEVP Final Prototypes and Test Motorcycles

Source: Zero Motorcycles

Task 5

The purpose of Task 5 was to perform the final analyses of all project data. The analysis includes an estimate of GHG and petroleum reduction and an extrapolation of this data that assumes a favorable market acceptance of the AEVP powertrain. Data from Task 5 is included below in this Final Project Report.

Zero Motorcycles collected data on the performance and reliability of the AEVP powertrain during the project. While data was sampled for a wide variety of performance characteristics, the most important data comes from the actual miles ridden on test motorcycles and the cumulative number of test hours on the powertrain prototypes. Table 7 below summarizes this data.

Table 7: Actual and Projected Petroleum and GHG Reductions

Measurement Metric	Motor Dyno Hours on Prototype Motors	Miles Driven on Powertrain Test	Totals
Actual Results			
Project Results	1,940	2,237	
Equiv. Petroleum Consumption (Gal)	2,622	50	2,672
Petroleum Reduction (Gal)	2,622	50	2,672
GHG Output (metric tons)	3.3	0.1	3.3
GHG Reduction (metric tons)	26.6	0.5	27.2
Projected Results			
Impact of 18,000 e-motorcycles (mi/yr)			57,510,000
Five Year Potential Impact (miles)			143,775,000
Equiv. Petroleum Consumption (Gal)			3,238,18
Petroleum Reduction (Gal)			3,238,18
GHG Output (metric tons)			4,026
GHG Reduction (metric tons)			32,924
Impact of 60,000 powertrains (mi/yr)			191,700,000
Five Year Potential Impact (miles)			479,250,000
Equiv. Petroleum Consumption (Gal)			10,793,919
Petroleum Reduction (Gal)			10,793,919
GHG Output (metric tons)			13,419
GHG Reduction (metric tons)			109,748

Source: Life Cycle Associates and Zero Motorcycles

Based on an analysis performed by Life Cycle Associates (See Appendix C), Zero Motorcycles' Zero Emissions Vehicles (ZEVs) achieve an 89 percent reduction using the electricity resource mix for the Low Carbon Fuel Standard. The energy economy ratio (EER) for these vehicles is equal to 10.1.[1] This EER is considerably higher than the 3.5 to 4 estimated for battery-

1 The EER for a gasoline vehicle is 1.0. More efficient vehicles fueled with an alternative fuel have EERs > 1.0.

powered electric cars because motorcycle engines must achieve very high power outputs and two-stroke or four-stroke engines of a comparable size are not as efficient or as highly developed as passenger car engines.

The Wells-to-Wheels (WTW) results are consistent with the approach used by ARB for the Low Carbon Fuel Standard. ARB reports an adjusted carbon intensity (CI) for electric transportation, taking into account improvements in electric vehicle (EV) fuel efficiency, which is expressed as an EER, or the ratio of the fuel consumption (MJ/ mi) of an alternative-fueled vehicle compared to a comparable gasoline-powered vehicle. With an all-renewable resource mix, the GHG emissions from this option will be zero and the lower power consumption from the electric motorcycle can enable operation on resources such as home solar power.

This analysis shows that this advanced electric powertrain can be truly transformative from both the perspective of innovation and sustainability.

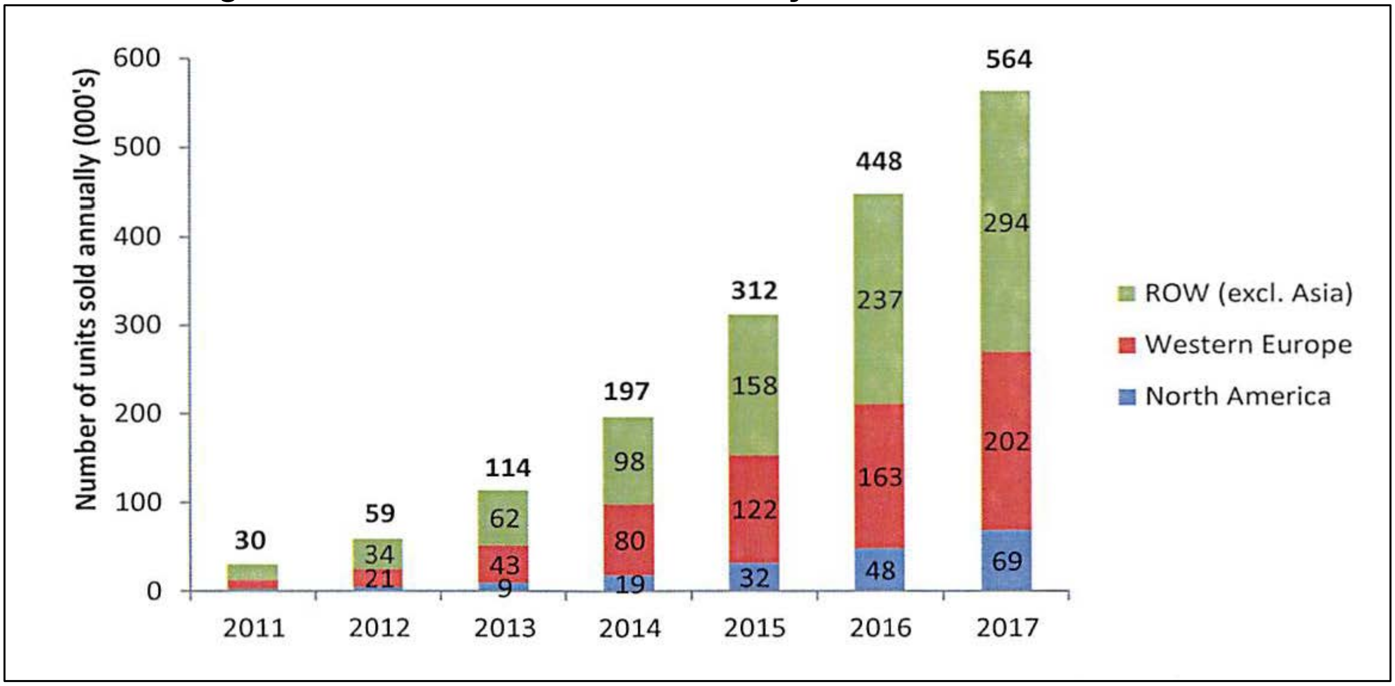
The immediate and direct impact during the AEVP powertrain project was a reduction of 2,672 gallons of gasoline and 27 metric tons of CO_2 abated.

The longer-term impact is much more important. Estimating the cost efficiency of reducing petroleum consumption and greenhouse gas emissions from CEC's funding reveals a significant impact per dollar of investment. This analysis estimates the impact over the five-year period of 2013 to 2018, assuming the AEVP is responsible for 60,000 cumulative new powertrain applications (very conservative estimate based on Zero Motorcycles business forecast as well as external market research from Pike's Research).

According to the Pike Pulse Report[2] on the future of electric motorcycles and scooters, more than 1.7 million electric motorcycles and scooters will be sold globally between now and 2017. According to Figure 24, which represents the annual expected sales per region, as predicted by the Pike Pulse Report, 197,000 electric motorcycles and scooters will be sold globally (excluding the Asia Pacific region where the sales are predominantly scooters) in 2014. Of those, 99,000 vehicles (19,000 in the US and 80,000 in Western Europe) are predicted to be sold in regions where Zero Motorcycles has an active presence.

2 Pike Pulse Report "Assessment of Strategy and Execution for 12 Leading Electric Motorcycle and Scooter Manufacturers," Hurst, 2012.

Figure 22: Pike's Research E-Motorcycle Market Estimates



Source: Pike's Research

Zero Motorcycles is well positioned to become the undisputed leader in the industry, as shown by Pike Pulse's conclusion: "Zero Motorcycles achieved the highest ranking in this Pike Pulse thanks to a combination of strong strategic planning and good execution of that plan. With a product lineup well-suited to the less cost-conscious early adopter market, the company has put together a strong management team and continues to build a robust dealer network in the kea; regions of Western Europe, Asia Pacific, Latin America, and North America."[2]

Using the input of 60,000 new powertrains during that five year time period, approximately 150,000 vehicle years will occur during the 2013-2018 time period. Standard assumptions of 3,195 miles per vehicle year[3] and an efficiency of 45 miles per gallon for each motorcycle yield a 10.8 million gallon reduction in gasoline consumption. This equates to $0.08 of CEC funding per gallon of gasoline avoided.

Life Cycle Associates calculated a carbon emissions factor of 257g CO2 per mile for a gasoline-fueled motorcycle using California reformulated gasoline. They calculated a carbon emissions factor of 28g CO2 per mile for a Zero S Motorcycle. The introduction of Zero's advanced electric powertrain will reduce carbon emissions by 109,750 metric tons of CO2 during the 2013 to 2018 time period. This equates to $8.20 of CEC funding per metric ton of CO2 abated.

3 Motorcycle Industry Council 2008, Average Annual On-Highway Miles.

CHAPTER 6: Conclusions

A Better Drivetrain

Zero targeted the market opportunity for more powerful and efficient electric drivetrains and set out to make an AEVP motor/powertrain that outperformed the 3-10 kW DC electric motors by at least 20 percent. In the early part of the project, the performance envelope for 3-10 kW DC motors was benchmarked by analyzing the currently available DC electric motors. Next, Zero designed a motor and constructed prototypes to outperform the best available 3-10 kW DC electric motors by improving the overall power density. When serious issues with the Sevcon motor controller were discovered, Zero redesigned the ZF75-7 motor so that it outperformed the Perm 132 motor by 132 percent in K_M, which far exceeded the original AEVP project goal of 20 percent. This new motor also outperforms the best currently available motor, the Motenergy 0913 by 68 percent. This is the motor Zero used in its 2012 S and OS models.

The original pilot manufacturing goals were revised to produce five powertrain prototypes for the Zero MY 2013 product line. This allowed for the additional testing necessary to meet the powertrain performance goals and aligned the pilot production goals with Zero Motorcycle's MY 2013 build schedule.

Zero successfully completed the pilot production run of 30 pre-production powertrain prototypes, focusing on refining the design for performance and manufacturability of the motor and evaluating production, supplier, and integration issues.

Power Requirements

Since Zero proposed the project in 2008, the power requirements of the AEVP powertrain have increased significantly. Originally, the goal was to build a 10-12 kW powertrain (with 25 kW peak performance). Zero Motorcycles now believes that a powertrain delivering a minimum continuous performance of 20 kW and 30-50 kW of peak performance is required to meet market expectations.

The motor/ controller combination developed for this project has dramatically better performance than those originally envisioned. This higher level of performance meets the anticipated market requirements as Zero Motorcycles looks forward in its powertrain development. The original baseline performance goal was a K_M of 1.8 (a 20 percent increase compared to the K_M of 1.5 of the best motor (Perm 132) benchmarked during the beginning of the project). The final AEVP Motor (Zero's ZF75-7) has a KM of 3.48, representing a 132 percent increase compared to the K_M of the baseline Perm 132 motor.

Cost Challenges

Zero anticipated cost reductions in both the motor controller and the motor magnet components during the course of the project. Unfortunately, neither of these cost reductions occurred, and the cost of the Sevcon motor controller has not declined, even with increasing volumes of orders. The cost of rare-earth permanent magnets used in these powertrains continues to fluctuate, and Zero has not been able to achieve planned cost reductions.

Labor costs to produce the motor also remain a significant factor in Zero's overall cost structure. Considering the labor intensive nature of the manufacturing process and the high cost for manual labor in the US (about $25/ hr), this motor cannot be competitively produced by Zero Motorcycles in California without pushing down labor costs with process automation.

Zero is seriously investigating the next steps toward manufacturing the powertrain components, especially the AEVP motor. If Zero does decide to manufacture the AEVP motor in California, it would have to make major investments in capital equipment that allows for robotic automation of the motor winding process to move away from the current labor intensive, manual winding procedure.

Focus on Motorcycle Manufacturing

Based on timing constraints for Zero's MY 2013 production runs and its higher labor costs, Zero will continue to partner with one of its key suppliers for the 2013 AEVP production. After significant analysis, Zero believes it will create more California jobs and add more value by focusing its capital and human resources on full electric motorcycle production in California. This effort will lead to the creation of dozens of jobs vs. just a few for the manufacturing of the AEVP motor. Zero will continue to explore cost reductions and evaluate opportunities to invest capital in the AEVP powertrain so that these key components can be on-shored as well.

AEVP Project Success

The project succeeded in all technical areas. Zero developed an AEVP powertrain that exceeds the K_M of the baseline Perm 132 motor by 132 percent. Zero helped advance the state of the market by introducing a motor with a K_M 68 percent higher than the current best available DC motor in the 3-10 kW range. With respect to cost and pilot production, Zero designed the motor component to be manufacturable, durable, and scalable. While costs are higher than the original goal and do not meet the original cost target, the technology does meet the market requirements. Zero will leverage this effort and focus on scaling the manufacturing of complete electric motorcycles in California, resulting in a more significant employment impact.

The AEVP project directly accounted for the reduction of 2,672 gallons of gasoline use and 27 metric tons of GHG emissions. More importantly, the cumulative reduction in petroleum use and carbon emissions over the next five years from powertrains developed under this grant could total 3.24 million gallons of gasoline and 32,900 metric tons of GHG. These estimates are based on anticipated sales of Zero Motorcycles' product line. Should additional powertrain sales occur in the broader electric vehicle industry, the reduction benefits could triple to 10.8 million gallons of gasoline and 109,750 metric tons of GHG.

Scientific and Technology Advancements

In order to meet California's GHG reduction goals of 20 percent by 2020 and 80 percent by 2050, non-carbon based fuels must displace transportation petroleum. According to ARB, the only long-term fuel solution that will achieve the required reduction is electricity. Based on the "2050 Greenhouse Gas Emissions Analysis: Staff Modeling in Support of the Zero Emission

Vehicle Regulation,"[4] ARB estimates that 100 percent of all vehicles sold by 2040 must be zero emission vehicles using electric drivetrains.

The ARB report states, "Because it takes decades for a new propulsion system to capture a large fraction of the passenger vehicle market due to vehicle fleet tum-over rates, it is important to accelerate the introduction of low-carbon vehicle alternatives to ensure markets enter into pre- commercial volumes (10,000s) between 2015 and 2020." Zero's advanced electric powertrain project does exactly this; volume manufacturing will be achieved within 12 months of full project funding. The vehicles using Zero's electric powertrain will also be affordable and accessible, further expanding market penetration.

Leveraging the results of this project, along with significant anticipated advances in battery technology, Zero expects continuous improvements in electric powertrain technology that will drive both increased capability and further cost reductions. Zero expects that within the next 10 years, this advanced electric powertrain technology will reach parity with internal combustion engines, and then surpass it on many metrics. Today, hybrids represent about 3 percent of all vehicle sales. In the near future, electric drive technology will penetrate the marketplace more quickly and then transform broad sectors of the transportation industry.

Zero Motorcycles' AEVP Development Program has advanced the current state of powertrains used on electric vehicles today. As previously outlined, traditional electric vehicle motor designs have been derived directly from technology developed for industrial motor applications. They typically have been stationary, where weight and size are not a significant issue, and they have used cheap and plentiful power from the electric power grid, a very different set of constraints than those faced by electric vehicles. Even motors used in mobile applications, like golf carts or forklifts, have not had the range of performance characteristics required of an on-road electric vehicle.

Benefits to the State of California

California relies excessively on one fuel type to meet 96 percent of its transportation needs. Clearly, the need for fuel diversity is paramount, and this program has opened up new areas of the transportation and recreational motor market to alternative fuels, specifically ubiquitous electricity.

Electric Motorcycles Reduce Emissions and Petroleum Consumption

Zero Motorcycles believes that transportation electrification represents the single greatest opportunity to positively affect the dynamics of climate change. By shifting as many vehicles as possible to electric drive and changing vehicle miles traveled (VMT) to electricity, Zero can help achieve the critical GHG reductions targeted by the state of California. This project approached the challenge in several ways.

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4 2050 Greenhouse Gas Emissions Analysis

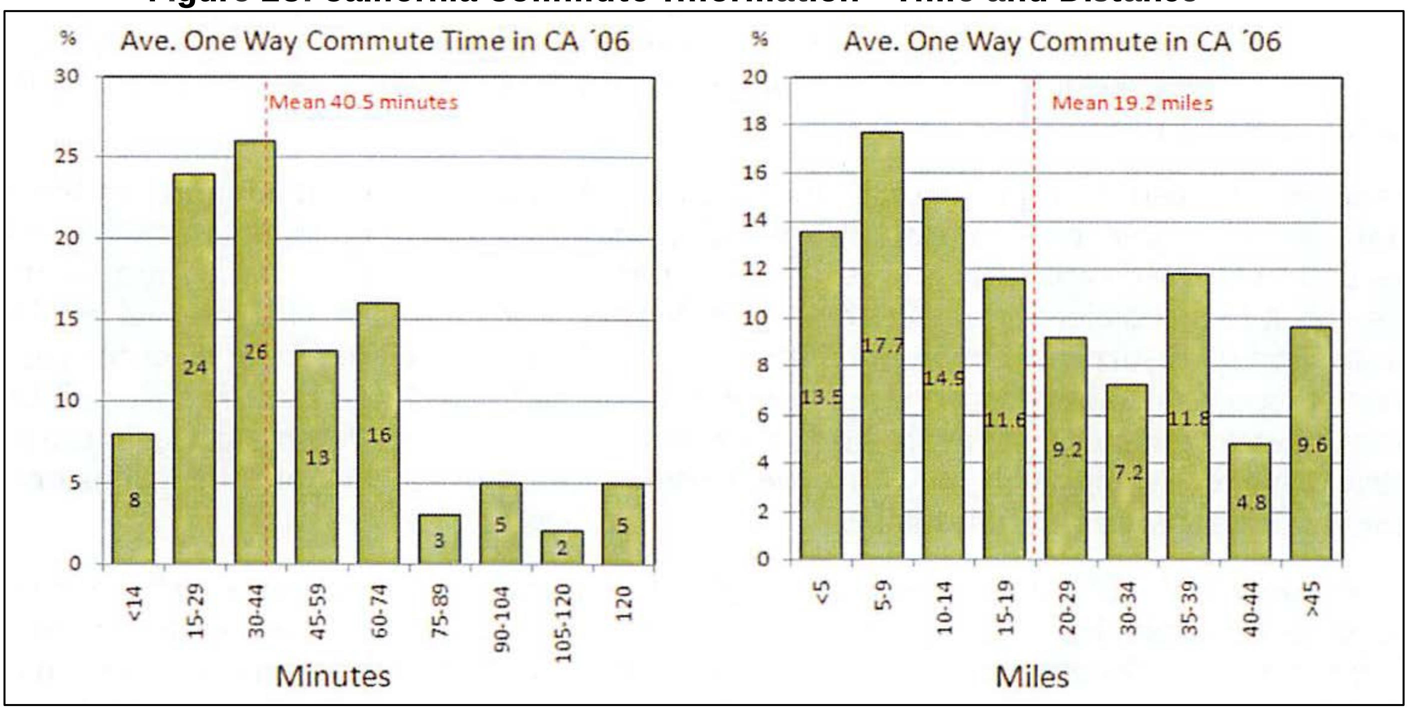
(https://ww3.arb.ca.gov/msprog/zevprog/2009zevreview/attachment_b_2050ghg.pdf)

The primary goal of the project was to complete the development of an advanced electric powertrain that can be used in a wide variety of electric vehicles, starting with the most affordable, electric motorcycles.

California census data reveals that many citizens have a commute that is within range for riding a motorcycle, with over 16.3 million commuters in California alone.

Moreover, it is clear that with the shifting transportation landscape, many consumers are considering motorcycles as a commute alternative. According to American Community Survey data released by the US Census Bureau in March 2005: "Americans spend in excess of 100 hours commuting to work each year. For the nation as one, the average daily commute to work lasted about 24.3 minutes in 2003. A motorcycle or a scooter does not offer a lot of passenger room or storage space, but most get far better mileage than even a hybrid car and at a far cheaper price. Moreover, two wheelers have the added advantage of maneuverability to beat the rush hour traffic. With fuel prices skyrocketing, motorcycles and scooters can be a practical fuel-economy transportation option for the typical half hour drive to work."[5]

Figure 23: California Commute Information - Time and Distance



Source: Southern California Association of Governments[6]

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5 2005 American Community Survey (https://factfinder.census.gov/faces/tableservices/jsf/pages/productview.xhtml?src=bkmk)

6 "2006 State of the Commute," Southern California Association of Governments (https://www.scag.ca.gov/Documents/2006_StateoftheCommute_Report.pdf)

A recent Consumer Reports Auto Pulse survey found that 26 percent of people would consider switching to either a motorcycle or motor scooter.[7] As discussed in the Market Viability section, California is the largest market in the United States for motorcycles. More benefits from the advanced electric powertrain will be realized in California than anywhere else in the US.

By focusing on electric motorcycles initially, Zero plans to take advantage of consumer interest and desire for a fun method of transportation at a lower price point than other electric vehicles. Zero can also capture a market segment that has been traditionally more polluting and has generated more GHGs due to lower standards for the engines in this class. Zero's advanced electric powertrains will have zero tailpipe emissions and represent at least an 89 percent reduction in carbon intensity as compared to similar gasoline engines.

7 Consumer Reports "Downsizing to Two Wheels" (https://www.consumerreports.org/cro/news/2008/07/downsizing-to-two-wheels-motorcycle-interest-revs-up/index.htm)

CHAPTER 7: Next Steps

Zero is encouraged by the results of this project and is pursuing several future objectives. First, Zero will continue to develop the powertrain and leverage the key personnel who have joined the company as part of the program. Zero now has deeper expertise in motor development, motor controller design, development, and programming, battery technologies, and real-time systems integration. As we grow in California, Zero will use its unique position in the market to attract the best talent and expand both R&D and manufacturing operations.

Zero fully evaluates its entire supply chain at each new model year introduction with the intent of identifying as many components as possible for in-country manufacturing, especially with manufacturing partners in California. Zero continues to look for opportunities to enhance our own manufacturing capability wherever possible. Zero has shown significant sales and revenue growth over the past two years during the timeline of this grant program and has determined that we will be able to dramatically expand and build capacity for full e-motorcycle manufacturing here in California.

As Zero achieves new growth in the development and sales of the AEVP powertrain to other electric vehicle manufacturers, it plans to evaluate opportunities to invest capital in both the AEVP motor and the development of additional powertrain modules so that these key components can be built here in California as well.

The market for electric vehicles is growing rapidly and the AEVP powertrain provides a major opportunity for a small company like Zero Motorcycles, Inc. to have a major impact on the overall marketplace.

Figure 24: AEVP Powertrain in Production Versions of MY 2013 Zero S and DS Models

Photo Credit: Zero Motorcycles

GLOSSARY

ALTERNATING CURRENT (AC)—Flow of electricity that constantly changes direction between positive and negative sides. Almost all power produced by electric utilities in the United States moves in current that shifts direction at a rate of 60 times per second.

BATTERY ELECTRIC VEHICLE (BEV)—Also known as an "All-electric" vehicle (AEV), BEVs utilize energy that is stored in rechargeable battery packs. BEVs sustain their power through the batteries and therefore must be plugged into an external electricity source in order to recharge.

CALIFORNIA ENERGY COMMISSION (CEC)—The state agency established by the Warren-Alquist State Energy Resources Conservation and Development Act in 1974 (Public Resources Code, Sections 25000 et seq.) responsible for energy policy. The Energy Commission's five major areas of responsibilities are:

- Forecasting future statewide energy needs
- Licensing power plants sufficient to meet those needs
- Promoting energy conservation and efficiency measures
- Developing renewable and alternative energy resources, including providing assistance to develop clean transportation fuels
- Planning for and directing state response to energy emergencies.

CARBON DIOXIDE (CO2)—A colorless, odorless, non-poisonous gas that is a normal part of the air. Carbon dioxide is exhaled by humans and animals and is absorbed by green growing things and by the sea. CO2 is the greenhouse gas whose concentration is being most affected directly by human activities. CO2 also serves as the reference to compare all other greenhouse gases (see carbon dioxide equivalent). The major source of CO2 emissions is fossil fuel combustion. CO2 emissions are also a product of forest clearing, biomass burning, and non-energy production processes such as cement production. Atmospheric concentrations of CO2 have been increasing at a rate of about 0.5% per year and are now about 30% above preindustrial levels. (EPA)

CARBON INTENSITY (CI)—The amount of carbon by weight emitted per unit of energy consumed. A common measure of carbon intensity is weight of carbon per British thermal unit (Btu) of energy. When there is only one fossil fuel under consideration, the carbon intensity and the emissions coefficient are identical. When there are several fuels, carbon intensity is based on their combined emissions coefficients weighted by their energy consumption levels.

DIRECT CURRENT (DC)—A charge of electricity that flows in one direction and is the type of power that comes from a battery.

ENERGY ECONOMY RATIO (EER)—An EER is a dimensionless value that represents the efficiency of a fuel as used in a powertrain as compared to a reference fuel. EERs are often a comparison of miles per gasoline gallon equivalent (MPGe) between two fuels. In this case, the EER represents a comparison between electric motorcycles and their gasoline internal combustion engine (ICE) counterparts. In the LCFS Program, EERs are used in calculations to generate credits.[8]

GREENHOUSE GAS (GHG)—Any gas that absorbs infra-red radiation in the atmosphere. Greenhouse gases include water vapor, carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O), halogenated fluorocarbons (HCFCs), ozone (O3), perfluorinated carbons (PFCs), and hydrofluorocarbons (HFCs). (EPA)

KILOWATT (kW)—One thousand (1,000) watts. A unit of measure of the amount of electricity needed to operate given equipment. On a hot summer afternoon a typical home, with central air conditioning and other equipment in use, might have a demand of four kW each hour.

MOTOR CONSTANT (K_M)—The motor constant (expressed as Km) defines the ability of a motor to transform electrical power into mechanical power and is a valuable tool for any project or application engineer looking to recommend a "best fit" replacement for an existing motor. The motor constant defines the ratio of the motor torque (mechanical power) to motor input power (electrical power).[9]

PLUG-IN ELECTRIC VEHICLE (PEV)—is a general term for any car that runs at least partially on battery power and is recharged from the electricity grid. There are two different types of PEVs to choose from - pure battery electric and plug-in hybrid vehicles.

REVOLUTIONS PER MINUTE (RPM)—The number of turns in one minute. It is a unit of rotational speed or the frequency of rotation around a fixed axis.

VEHICLE MILES TRAVELED (VMT)—The miles traveled by motor vehicles over a specified length of time (e.g., daily, monthly or yearly) or over a specified road or transportation corridor.

WELL TO WHEEL (WTW)—A specific LCA (Life-cycle Assessment) used for transport fuels and vehicles. The analysis is often broken down into stages entitled "well-to-station", or "well-to-tank", and "station-to-wheel" or "tank-to-wheel", or "plug-to-wheel". The first stage, which incorporates the feedstock or fuel production and processing and fuel delivery or energy transmission, and is called the "upstream" stage, while the stage that deals with vehicle operation itself is sometimes called the "downstream" stage. The well-to-wheel analysis is commonly used to assess total energy consumption, or the energy conversion efficiency and emissions impact of marine vessels, aircraft and motor vehicles, including their carbon footprint, and the fuels used in each of these transport modes. WTW analysis is useful for reflecting the different efficiencies and emissions of energy technologies and fuels at both the upstream and downstream stages, giving a more complete picture of real emission.

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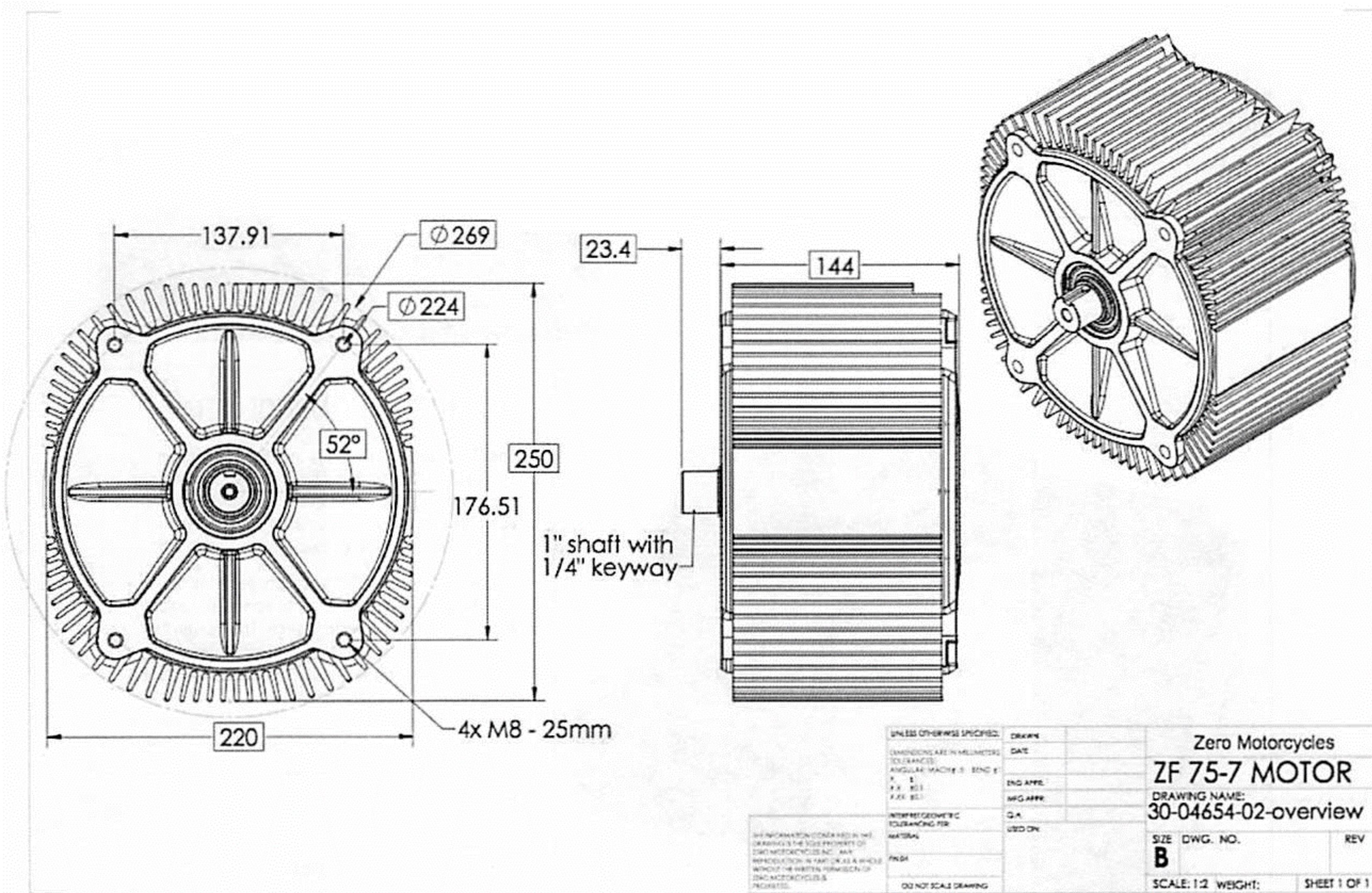
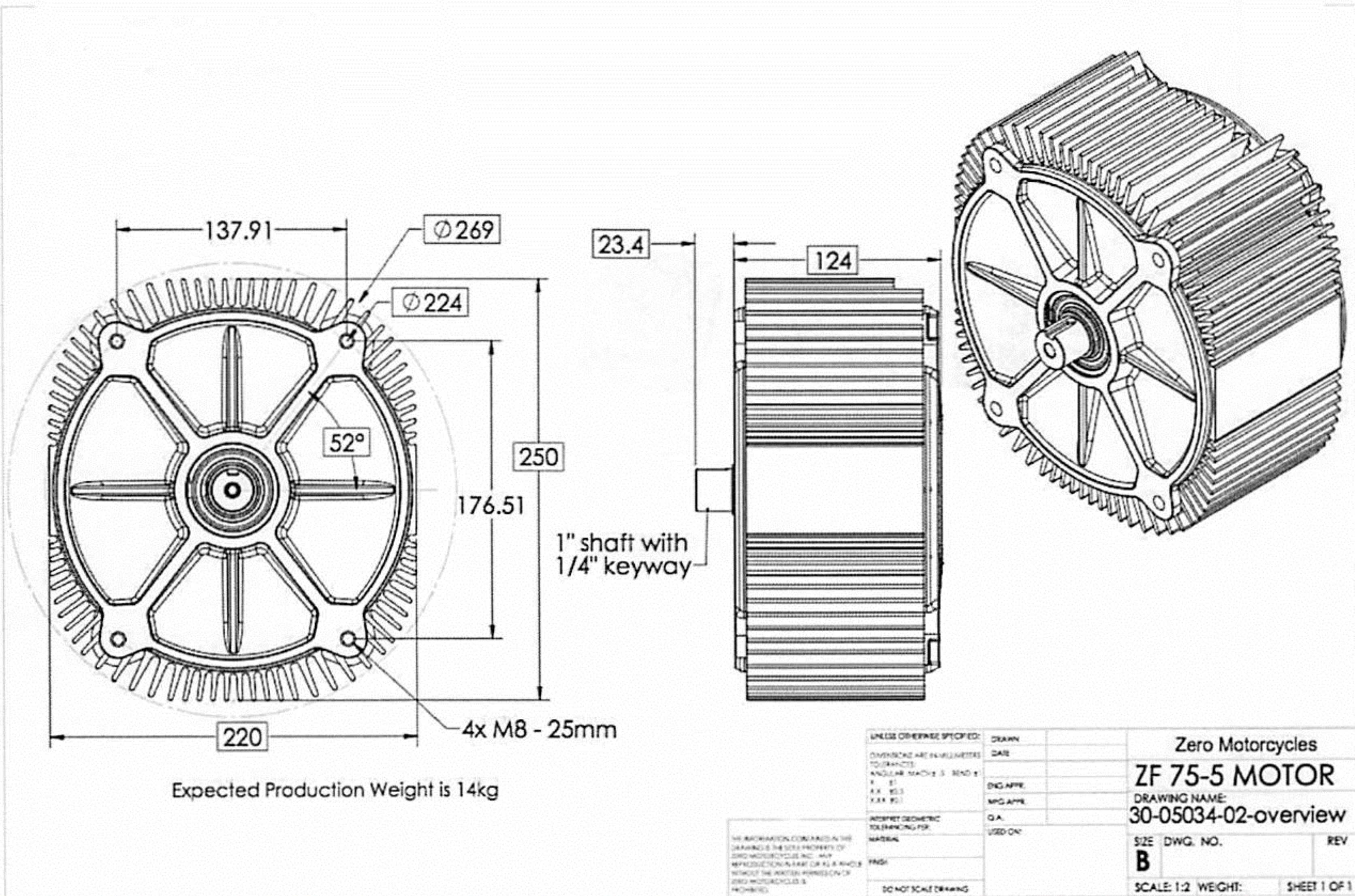
8 "Estimate for Energy Economy Ratios for Consideration of On-Road and Off-Road Motorcycles in the Low Carbon Fuels Standard Program." October 9, 2017. California Air Resources Board. (https://ww3.arb.ca.gov/msprog/offroad/orrec/zem_eer_calcs_10_9_17.pdf)

9 "Understanding the Motor Constant in DC Motor Sizing." Electromate.com Website. (http://www.electromate.com/pub/media/assets/pdf/news/Understanding-the-Motor-Constant-v2.pdf)

APPENDIX A: Final AEVP Design





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1/4" keyway
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SHEET 1 OF 1

APPENDIX B: Sevcon Motor Controller Datasheet

SEVCON

Gen4

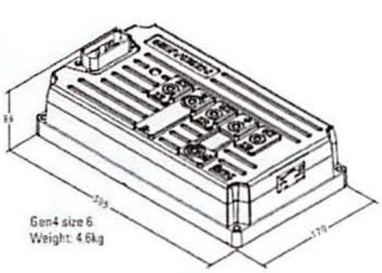
AC MOTOR CONTROLLER

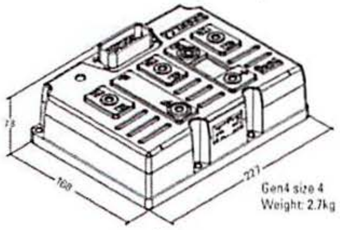
The Gen4 range represents the latest design in compact AC Controllers. These reliable controllers are intended for on-road and off-road electric vehicles and feature the smallest size in the industry for their power capacity.

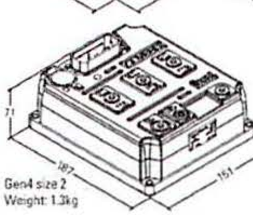
Thanks to the high efficiency it is possible to integrate these controllers into very tight spaces without sacrificing performance. The design has been optimized for the lowest possible installed cost while maintaining superior reliability in the most demanding applications.

FEATURES

- Advance flux vector control
- Autocheck system diagnostic
- Integrated Logic Circuit
- Hardware & software failsafe watchdog operation
- Supports both PMAC motor and AC induction motor control
- Sensorless control for select applications
- Integrated fuse holder
- IP66 Protection







Gen4

KEY PARAMETERS

Model	Size 2	Size 4	Size 6	Size 2	Size 4	Size 6	Size 2	Size 4	Size 6	Size 2*	Size 4	Size 6*
Nominal Battery Voltage	24 VDC	24 to 36 VDC		36 to 48 VDC			72 to 80 VDC			96 to 120 VDC		
Max operating voltage	34.8 VDC	52.2VDC		89.6 VDC			116 VDC			150 VDC		
Min. operating voltage	12.7 VDC			19.3 VDC			39.1 VDC			48 VDC		
Peak Current (2min)	300A	450A	650A	275A	450A	650A	180A	350A	550A	150A	300A	450A
Boost Current (10 sec)	360A	540A	780A	330A	540A	780A	215A	420A	660A	180A	360A	540A
Cont. Current (60 min)	120A	180A	260A	110A	180A	260A	75A	140A	220A	60A	120A	180A

*Not yet available. Please contact Sevcon

MULTIPLE MOTOR SENSOR FEEDBACK OPTIONS

Gen4 provides a number of motor feedback possibilities from a range of hardware inputs and software control, allowing a great deal of flexibility.

- Absolute UVW encoder input
- Absolute Sin/Cos encoder input
- Incremental AB encoder input

INTEGRATED I/O

Gen4 includes a fully-integrated set of inputs and outputs (I/O) designed to handle a wide range of vehicle requirements. This eliminates the need for additional external I/O modules or vehicle controllers and connectors

- 8 digital inputs
- 2 analogue inputs (can be configured as digital)
- 3 contactor/solenoid outputs
- 1 encoder supply output – programmable 5V or 10V

OTHER FEATURES

A CANopen bus allows easy interconnection of controllers and devices such as displays and driver controls.

The CAN bus allows the user to wire the vehicle to best suit vehicle layout since inputs and outputs can be connected to any of the controllers on the vehicle and the desired status is passed over the CAN network to the relevant motor controller.

The Gen4 controller can dynamically change the allowed battery current by exchanging CAN messages with a compatible Battery Management System.

Configurable as vehicle control master or motor slave.

CONFIGURATION TOOLS

Sevcon offers a range of configuration tools for the Gen4 controller, with options for Windows based PC or calibrator handset unit. These tools provide a simple yet powerful means of accessing the CANopen bus for diagnostics or parameter adjustment. The handset unit features password protected access levels and a customized logo start-up screen.

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APPENDIX C: Life Cycle Assessment of Zero Motorcycles' Zero Emission Vehicles

Life Cycle Associates, LLC

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985 Portola Road
Portola Valley, CA 94028 USA

May 11, 2010

Jay Friedland
VP Strategy and Sustainability
Zero Motorcycles, Inc.
1 Victor Square
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jay@zeromotorcycles.com

Dear Jay,

Life Cycle Associates (LCA) completed a life cycle assessment of the Zero Motorcycles' battery electric powered motorcycle compared to a comparable vehicle powered by conventional California reformulated gasoline (RFG). This assessment used the California Air Resources Board (ARB) default carbon intensity (CI) values for electricity and RFG fuel, combined with the fuel efficiency of a ZEV based on the Zero Motorcycles electric propulsion system and a comparable gasoline vehicle.

The life cycle Well to Wheel (WTW) GHG emissions include the emissions from fuel production and vehicle operation. The WTW results are based on the CI of the fuel combined with vehicle energy consumption such that:

> WTW GHG = CI (WTT + TTW[1]) × Energy Consumption
> Where CI represents the carbon intensity of the upstream fuel cycle, vehicle fuel, and methane and N_2O emissions from the gasoline vehicle.
> Energy Consumption is represented in MJ/mi

The WTW results are consistent with the approach used by ARB for the Low Carbon Fuel Standard. ARB reports an adjusted CI for electric transportation taking into account improvements in EV fuel efficiency, which is expressed as an energy economy ratio (EER), or the ratio of the fuel consumption (MJ/mi) of an alternative fueled vehicle compared to a comparable gasoline vehicle[2].

Energy Consumption

Energy consumption for both gasoline and battery electric motorcycles are based on range estimates or estimated driving range divided by fuel tank capacity. The baseline gasoline fuel consumption is based on a Suzuki DRZ400SM, which is comparable in size and performance to the Zero-S battery electric model with an estimated city/highway fuel economy of 44.4 mpg. The energy consumption for the battery electric motor cycle is 74 Wh/mi. Table 1 shows the energy consumption for both vehicles in MJ/mi with the ratio indicating an EER of 10.1. This EER is considerably higher than the 3.5 to 4 estimated for battery electric cars because motorcycle engines must achieve very high power outputs and two or four stroke engines of comparable power are not as efficient as highly developed passenger car engines.

[1] WTT: Well to Tank, the fuel production CI including all life cycle components leading to a fuel in a vehicle tank; TTW, Tank to Wheel, the CI of the vehicle emissions comprised of the carbon in the fuel (as CO_2) plus the combustion generated N_2O and CH_4. For the Zero Motorcycles motorcycle, the TTW CI is 0.

[2] Thus, the EER for a gasoline vehicle is 1.0; more efficient vehicles fueled with an alternative fuel have EERs greater than 1.0.

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Fuel Carbon Intensity

The carbon intensity for the baseline gasoline and electric power cases are also shown in Table 1. These carbon intensity values are based on the LCFS and reflect fuel production in California (ARB 2009). The CI for gasoline includes both the WTT plus vehicle emissions. Electric power reflects new or marginal generation for California. This resource mix would primarily be based on natural gas production. However, in order to meet the renewable portfolio standard requirements, additional load growth would also need to include renewable power. Therefore, the marginal resource mix for the LCFS reflects a combination of natural gas and renewable power.

Life Cycle GHG Emissions

Table 1 outlines the WTW GHG calculations for each vehicle giving the final results in g CO_2e/mi. The percent reductions for the Zero Motorcycles ZEV cases are also given in the table. Figure 1 illustrates these reductions. As shown, Zero Motorcycles' ZEVs achieve an 89% reduction using the electricity resource mix for the LCFS. An all renewable resource mix is also examined here. Of course the GHG emissions from this option will be zero and the lower power consumption from the electric motor cycle can enable operation on resources such as home solar power.

Table 1. Zero Motorcycle Carbon Intensity Reduction

Vehicle	MJ/mi	Fuel Use		EER	CI (g CO_2e/MJ)	GHG (g/mi)	Reduction
Zero Motorcycle, Renewable Power	0.27	0.074	kWh/mi	10.1	0.0	0	100%
Zero Motorcycle, NG/RPS	0.27	0.074	kWh/mi	10.1	104.7	28	89%
Gasoline Motorcycle, RFG	2.68	44.4	Mpg	1.0	95.9	257	0%

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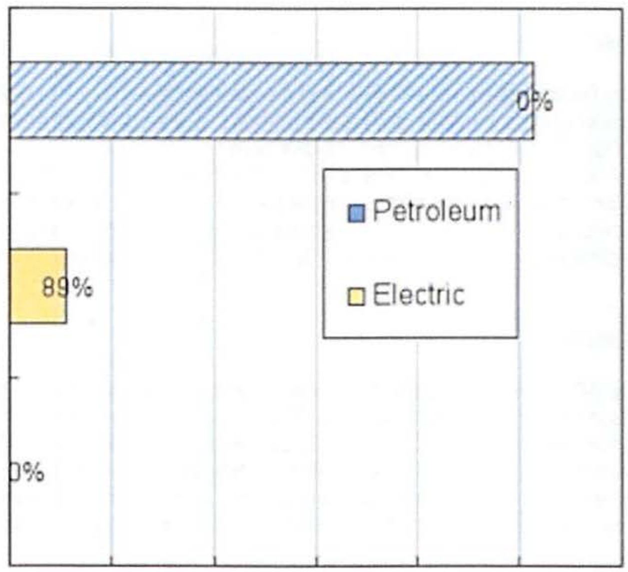

Figure 1. Motorcycle Carbon Intensity Reduction

Best Regards,

Stefan Unnasch
Managing Director

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ARB (2009) Detailed California-Modified GREET Pathway for California Average and Marginal Electricity, California Air Resources Board, Stationary Source Division
Release Date: February 27, 2009, Version 2.1

MCN (2005) 2005 Suzuki DRZ400SM, SPECIFICATIONS AND PERFORMANCE DATA July 2005, MOTORCYCLE CONSUMER NEWS