California Energy Commission

Clean Transportation Program

FINAL PROJECT REPORT

Wrightspeed Digital Drive System Manufacturing Facility

Prepared for: California Energy Commission

Prepared by: Wrightspeed, Inc.

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PREFACE

Assembly Bill 118 (Núñez, Chapter 750, Statutes of 2007) created the Clean Transportation 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 PON-11-604 to cost-share the development of manufacturing and/or assembly facilities in California that produce alternative fuel vehicles, advanced technology vehicles, and/or eligible components. In response to PON-11-604, the recipient submitted an application which was proposed for funding in the CEC's notice of proposed awards on June 20, 2012 and the agreement was executed as ARV-13-001 on October 30, 2013.

ABSTRACT

Wrightspeed's Route™ retrofit kits replaces the entire drive system with a minimal increase in weight and includes sophisticated integrated electronics and a software management system that provide industry leading efficiencies. For this project Wrightspeed has transitioned from an Engineering Start-up who had built two successful prototypes to a company that has doubled in size, raised in excess of $40M dollars from outside investors, hired an executive team, and entered a new 8-year lease for a facility that is perfectly situated and sized. Wrightspeed has benefitted from support of the California Energy Commission who has committed an additional $7 million investment. We are on the verge of beginning production to meet the $40 million backlog we have in orders from our customers.

Keywords: Wrightspeed, Route, retrofit kit, drive system, integrated electronics, software management

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EXECUTIVE SUMMARY

The Energy Commission awarded a contract to Wrightspeed in 2013 to set up the manufacturing and assembly facilities and processes for Wrightspeed's Digital Drive System Retrofit Kit for Class 3 to Class 5 trucks. During this program the powertrain kit was renamed the Route™ and redesigned to suit heavy duty vehicles up to Class 8. The Route consists of a complete powertrain kit to replace a trucks engine, transmission, axle, propeller shaft and certain electronic components. The project meets the principal goals of the California Energy Commission for establishing and supporting manufacture of alternative and renewable fuel and vehicles.

The project tasks include the renovation of an existing structure in the former Navy base on the Alameda Point. This renovation met objectives for re-use of existing structure, preservation of the historic character of the building and the area, and adequate provision for Wrightspeed to carry out manufacturing activities. The project includes procurement of production equipment, including unique tooling of suppliers, materials handling equipment, and assembly and manufacturing equipment. Objectives of this project include verification that the factory processes manufacture products meeting the specified performance.

Chapter 1: Introduction

Ian Wright was a co-founder of Tesla Motors when he left in 2005 to become the sole founder of Wrightspeed, Inc., a California based company. Wrightspeed is focused on building cleaner and more fuel-efficient powertrain systems for use in high fuel consumption medium and heavy-duty trucks. In frequent-stop applications, such as refuse collection, urban transit, and parcel delivery, conventional piston-engine powertrains are highly inefficient. The Wrightspeed Route™ family of powertrains configurations can be retrofitted to vehicles already in service to improve their fuel consumption and further reduce their criteria pollutants emitted per gallon of fuel consumed. The Route™ is a highly advanced integrated system that relies on software to achieve industry-leading synchronized function between as many as four electric motors (each with its own gearbox), batteries, inverters, and a range extending turbine generator engine that is capable of recharging the battery during driving of the vehicle. The Wrightspeed Route™ powertrain can also be fitted to new vehicle "gliders" in place of the conventional powertrain that would normally be installed.

Wrightspeed saves fuel and costs in five areas for fleet operators:

1. Fuel savings from less fuel consumed. The Wrightspeed Route™ powertrain will increase the equivalent miles per gallon in excess of 100 percent, in some cases. For instance, if a diesel truck gets 5 miles per gallon, the truck retrofitted with Wrightspeed's Route powertrain will get in excess of 10 miles per gallon.
2. The turbine engine runs only at the RPM to generate electricity at its optimal efficiency – in contrast to conventional piston engines, which are operated across the RPM range and have very poor efficiency at low speeds.
3. High-power regenerative breaking – effective stopping power through regenerative braking requires a high-power pulse which the Wrightspeed motor, gearbox, and battery are specifically engineered to provide. An average garbage truck can make 1,000 hard stops, which today means wasted fuel used to get the truck moving energy and rapid wear out of the brakes. Wrightspeed allows exceptionally efficient recapture of this energy while eliminating brake wear for most stopping conditions.
4. Maintenance and associated costs, such as downtime, are greatly reduced. Wrightspeed powertrains require far less maintenance then traditional piston engine driven drivetrains because there are far fewer moving parts.

The Wrightspeed Route uses electric-drive power for up to the first 30 miles per day after being recharged from the electrical grid. The system then activates a range-extending micro-turbine generator which supplies the necessary electrical energy to charge the batteries for extended driving range. Wrightspeed identifies commercial heavy-duty trucks with frequent stop and go drive patterns as the perfect market for the Route powertrain system because the most cost savings and shorter payback can be achieved in applications that today are wasting the most fuel through frequent braking. The Wrightspeed retrofit kit is estimated to have a 64 percent carbon density reduction when compared to the truck with a diesel engine.

Technology Background

There are limited fuel saving technologies that can be applied to conventional piston engine driven trucks. Trucks are heavy vehicles that require high power engines for adequate performance. In the normal drive cycles for local delivery trucks, most heavy-duty trucks consume a considerable amount of fuel to accelerate from frequent stops and then energy is wasted when the truck brakes are applied. For fuel efficiency reasons, larger truck engines are diesel piston engines; and, in order to meet California emission standards, they require a complex and expensive exhaust after-treatment system. The maintenance of these engines and emissions controls systems is quite expensive. Electric drive technology is known to be efficient, clean and lower maintenance compared to piston engine drive technology. However, development and investment in electric drive systems is relatively new and investment in these technologies is just beginning to emerge. As a result, electric drive systems are expensive to manufacture. Wrightspeed has proven the technology works and, as a successful start-up, is now on the verge of beginning production. The company currently has $40M in backlog and intends to begin shipping product by late 2016.

Personnel Requirements

Wrightspeed has gone to great lengths to hire only the brightest, energetic and productive employees we can find. It is a core value for Wrightspeed; only with exceptional employees could we have accomplished so much at such a relatively low cost.

Numerous positions were hired to support manufacturing efforts including stockroom personnel, logistics personnel, supply chain management, technicians, manufacturing engineers, and an executive level manufacturing leader. When the grant contract was approved in November of 2012, the company had 2 manufacturing employees; now, as of the effective date of this report, the company currently has 9 manufacturing employees. Wrightspeed expects that number to increase to 15 by year end.

Wrightspeed has increased headcount companywide from November 2012 as well. These efforts of Wrightspeed, with the support of the Energy Commission, has allowed Wrightspeed to create jobs in an area that has been economically challenged since the closure of the Alameda Point Navy base.

Chapter 2: Project Overview

Goals of the Agreement

The first goal of the agreement was to expand and improve existing manufacturing facility including partial conversion of current office space to accommodate the company's manufacturing line requirements. This goal has been met with a freshly renovated space ready to support manufacturing in California for years to come. The second goal was to design, develop, install and configure manufacturing lines, tooling, processes, and test procedures to build, assemble and integrate the Digital Drive System Retrofit Kit components and sub-assemblies, and set up handling procedures to ship the final product to customer. Wrightspeed has achieved this goal with the support of the CEC. Our assembly lines are now working on products that will be shipped to customers. The final goal of this agreement was to test and validate the manufacturing line and test setup processes and specifications. The completion of initial units has allowed us to begin the process of continuous improvement that will cumulatively result in higher levels of quality, efficiency, and productivity.

Project Objectives

The first objective of the agreement was to design and implement facilities modification and infrastructure improvement of the manufacturing space so that it is configured to handle the full cycle of manufacturing, assembly, integration, and test of Digital Drive System Retrofit kits. To prepare the former Navy hangar for use as a manufacturing facility, shown in Figure 1, Wrightspeed resurfaced the main hangar floor, repairing as needed, shown in Figure 2. Where repair was not feasible, sections of concrete pad were re-poured. Existing electrical infrastructure was removed, including lighting, wiring, and transformers. New wiring, including conduit and sub-panel, will support the electrically driven machines in the fabrication shop, as well as electric vehicle grid charging for vehicles in the retrofitting process.

The fire suppression system was substantially replaced to bring it up to contemporary code requirements. Plumbing was replaced and new facilities constructed to support contemporary standards for water consumption. The existing roof was allowing water penetration and was replaced. Extensive remediation work was required to bring the windows into acceptable condition while preserving their historic character. Where feasible, historic hardwood paneling was preserved in the walls, saving not only the character of the hangar but also conserving natural resources through re-use. Figures 3 and 4 show the final assembly floor and existing vehicles undergoing powertrain refitting.

Figure 1: Exterior of Wrightspeed Building

Source: Wrightspeed, Inc.

Source: Wrightspeed, Inc.

Figure 3: Wrightspeed Final Assembly

Source: Wrightspeed, Inc.

Source: Wrightspeed, Inc.

The second objective of the agreement was to relocate and expand the parts stockroom to accommodate volume purchasing requirements for components and sub-assemblies. Wrightspeed implemented a new Enterprise Resource Planning System, that is designed to support manufacturing operations. Enterprise Resource Planning System is a fully integrated “cloud” based system that was selected based on its complete suite of manufacturing features including Materials Requirements Planning, Inventory Control, Cycle Count, Approval workflows, bar scanning and many other unique features for manufacturing organizations. The company hired Enterprise Resource Planning System consulting to implement the software and train personnel leading up to our go live date on February 1st, 2016. Prior to go-live, the company conducted a full physical inventory of parts on hand so Enterprise Resource Planning System could be loaded with correct part numbers and quantities.

Enterprise Resource Planning System implementation and the physical inventory were preliminary steps to relocating our Inventory from our prior location to the new facility in Alameda. The new facility has been set up with dedicated workstations for various sub-assemblies. Inventory is located alongside each sub-assembly workstation to minimize manufacturing “waste” of unnecessary travel or motion of assembly personnel. ”Conex” shipping containers have been positioned close to the assembly lines for storing high-value inventory. These containers can be secured to ensure only authorized personnel withdraw inventory.

The company hired stockroom, receiving and support personnel to manage and perform transactions for inventory logistics. We also purchased shelving, lifts and pallet moving equipment, shown in Figure 5.

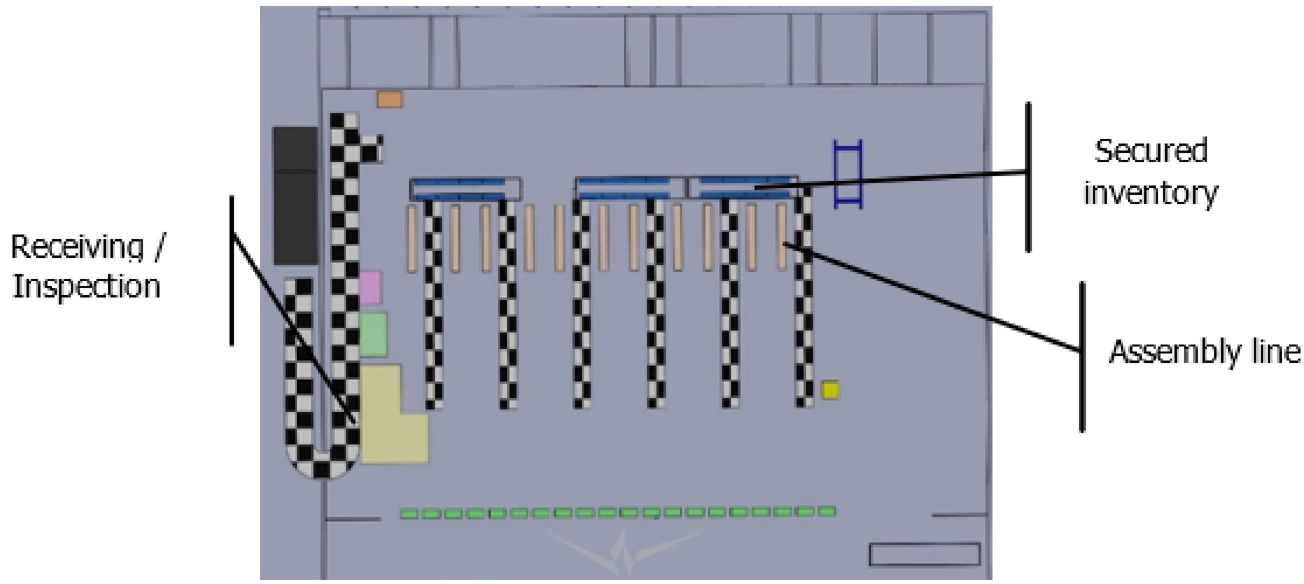
Figure 5: Wrightspeed Receiving and Inspection

Source: Wrightspeed, Inc.

with all the key requirements identified. We have a master plan including assumptions, detailed analysis and financial impacts for headcount, cost reductions, capital requirements, tooling needs and estimates of units being capable of producing over the next two years. Our analysis includes critical path charts with months for completions and cost projections for all key subassemblies.

The production floor has been laid with all sub-locations to support manufacturing activity. We have dedicated receiving and inspection locations, stockrooms, assembly workstations and various bins strategically located to support sub-assemble works areas, shown in Figure 6.

Figure 6: Wrightspeed Powertain Sub-Assembly Layout



The third objective of this agreement was to purchase and install the manufacturing equipment. Wrightspeed has established the following assembly lines in the renovated manufacturing space: Turbine Assembly, Geared Traction Drive and Axle assembly, Power Electronics assembly and Battery assembly.

Turbine Assembly

The Wrightspeed Fulcrum™ Turbine is the range-extending generator that allows the Wrightspeed Powertrain to drive today's vehicles on today's jobs with today's fuels, reducing total fuel consumption without reducing performance on the job. On this assembly line the precision-ground castings are built up and tolerances checked at the micrometer level, shown in Figure 7.

Figure 7: Wrightspeed Fulcrum™ Turbine Sub-Assembly

Geared Traction Drive and Axle Assembly

The Geared Traction Drive is a motor and transmission drive unit exceptionally powerful for its weight, due to a clutch-less design that replaces heavy mechanical components with software to control gear-matching. This assembly area handles the largest individual components and produces axles weighing thousands of pounds. Equipment in this assembly area includes an overhead hoist, a press, and a fixture that can hold and rotate heavy components during assembly, shown in Figure 8.

Figure 8: Wrightspeed Geared Traction Drive™ and Axle Sub-Assembly

Power Electronics Assembly

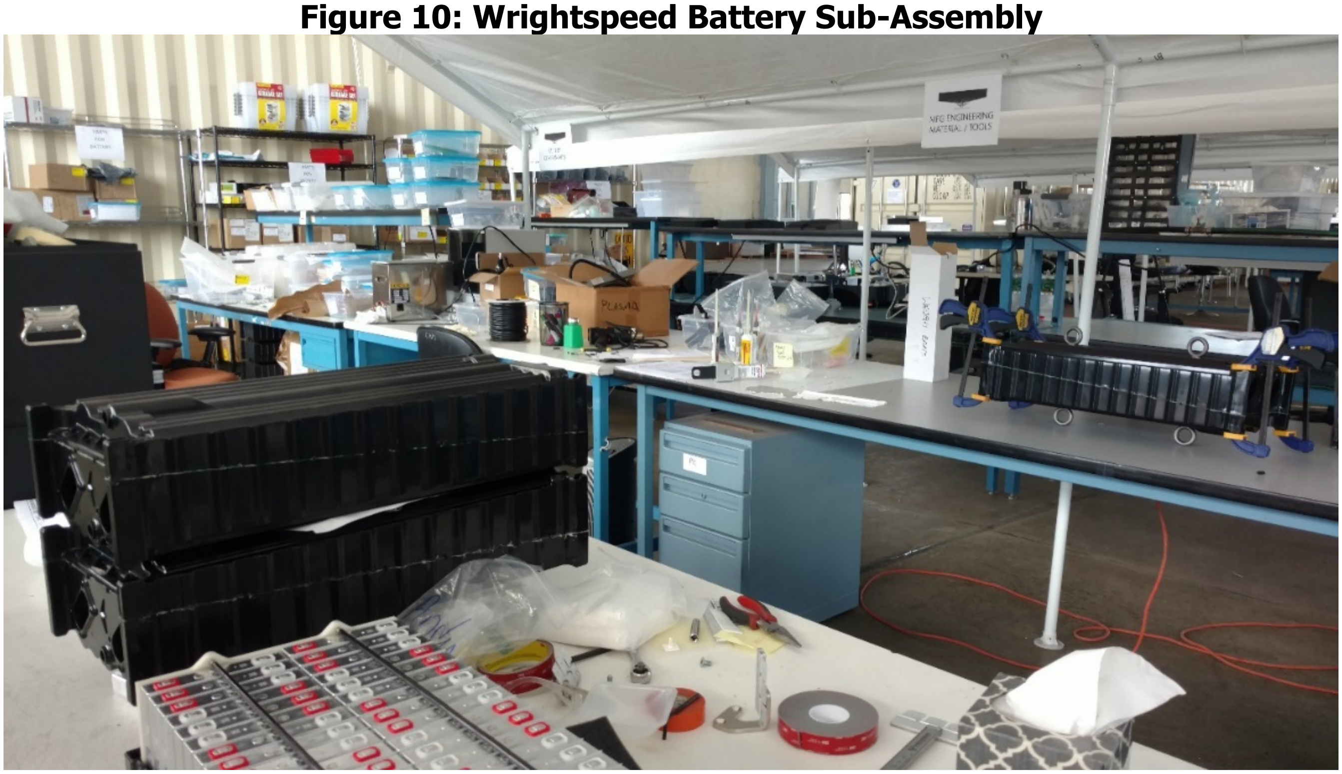
Inverters play a crucial role in a modern alternating-current electric motor platform. In the Wrightspeed system the inverters are particularly important since fine control of the motor speed is necessary to accomplish clutch-less gear shifting. Wrightspeed assembles custom-designed power electronics in house, shown in Figure 9. Circuit boards built into the power electronics could be damaged by electrostatic discharge, so the workbenches have anti-electrostatic discharge mats and wristbands as well as assembly tools.

Figure 9: Wrightspeed Power Electronics Sub-Assembly

Battery Assembly

As with any electric vehicle, the capability of the battery has a significant impact on the overall capability of the vehicle. Temperature tolerance and temperature control, charge and discharge rates, and physical protection must all be considered in the battery design. Wrightspeed builds its own battery modules. Individual modules are below the voltage threshold at which special handling precautions become necessary. This design will also allow easier field service. Individual cells procured from a top-quality global supplier are protected with an advanced polycarbonate housing. Figure 10 shows the battery sub-assembly line.

Figure 10: Wrightspeed Battery Sub-Assembly



Motor Assembly

Electric motors provide 100 percent of the power for travel in the Wrightspeed powertrain. The motors also perform nearly all the braking function, while acting as generators to recharge the batteries. Although electric motors are ubiquitous in today's technology, most are not suited for the industry-leading levels of performance that Wrightspeed demands. Final assembly of electric motors is performed in-house. On the motor assembly line, shown in Figure 11, the cooling jackets and other unique Wrightspeed features are built up on motor cores provided by one of the leaders in the motor segment.

Figure 11: Wrightspeed Motor Sub-Assembly

Wrightspeed purchased key manufacturing equipment to begin the production line. Examples include forklifts, wire rack shelving, vehicle lifts, torque wrenches, work benches, heavy duty inventory handling devices including engine lifts, transmission lifts, gearbox stands, axles mounting stands. The equipment has been strategically laid out to support number workstations that have been segregated by sub-assembly requirements.

We have designed and laid out a complete machine shop to provide specialized fabrications, bracketing and other unique requirements for packaging and mounting the Route powertrain to each unique vehicle chassis, shown in Figures 12 and 13. A Computer Numerical Control machine was purchased to support specialized tooling requirements, allowing quick in-house turnaround on key components that otherwise may take weeks to obtain. This state-of-the-art manufacturing equipment is capable of high precision machining.

Figure 12: Computer Numerical Control Machine for Rapid Prototyping and Custom Final Assembly Parts

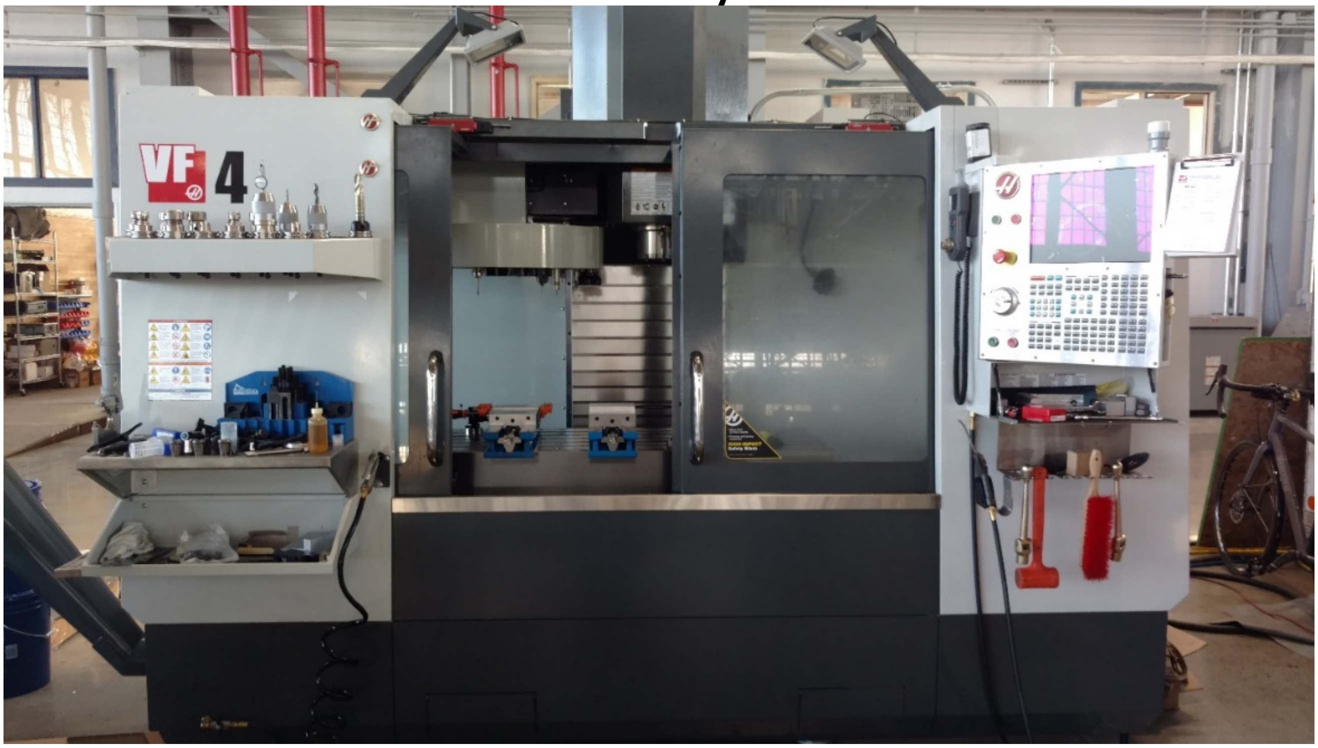


Figure 13: Machines for Custom Fabrication

The fourth objective of the project was to purchase and install manufacturing test equipment. Wrightspeed has established the following test stations:

Geared Traction Drive Test - for electric motors, motor controller, gearbox, and gear shift actuator, is shown in Figure 14. The Wrightspeed powertrain employs electric motors for both travel and braking power, so motors must be tested in the forward and reverse directions. By connection opposing motors we can test both functions simultaneously, meanwhile minimizing our net energy consumption with the resistive load of the motor providing regenerative braking. This test stand also allows us to test and refine the software-controlled clutch-less shifting, the technology that allows Wrightspeed to achieve industry-leading power-to-weight density in our Geared Traction Drive. Reducing weight is a priority for vehicle efficiency but compromising on power isn't feasible for heavy duty applications.

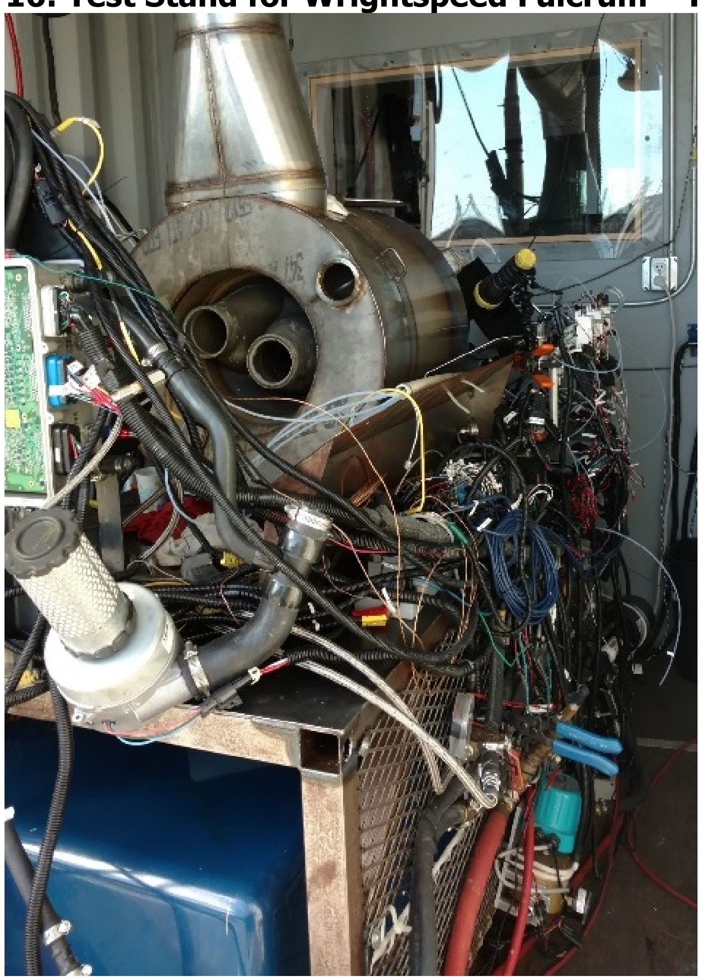
The Wrightspeed regenerative braking is far more powerful than current technologies in electric cars and light duty vehicles. The Wrightspeed solution for heavy duty trucks delivers up to 1,000 hp for braking, which is the power required in high-intensity garbage truck applications that stop up to 1000 times a day. The pulse of electrical power generated by regenerative braking is captured efficiently by Wrightspeed's proprietary high-power battery design. Efficient capture of regenerated electricity is another example of Wrightspeed's environmentally friendly heavy-duty drivetrain.

Figure 14: Test Station for Geared Traction Drive™

Fulcrum Turbine Test - including air intake, recuperation (pre-heating), combustion, exhaust and emissions, and electricity generation, is shown in Figures 15 and 16. Wrightspeed purpose-built this specialized test environment within a rugged conex steel container to achieve safety, isolation and protection requirements while maintain a degree of flexibility and adaptability. The fully enclosed chamber has numerous sophisticated sensors and measuring devices which monitor all critical elements of testing a turbine engine. Heat abatement, safety infrastructure, and audible readings, are all self-contained in the test station. This allows testing of the Fulcrum gas turbine engine at speeds up to 100,000 revolutions per minute.

Figure 15: Control Room for Wrightspeed Fulcrum™ Turbine Test Station

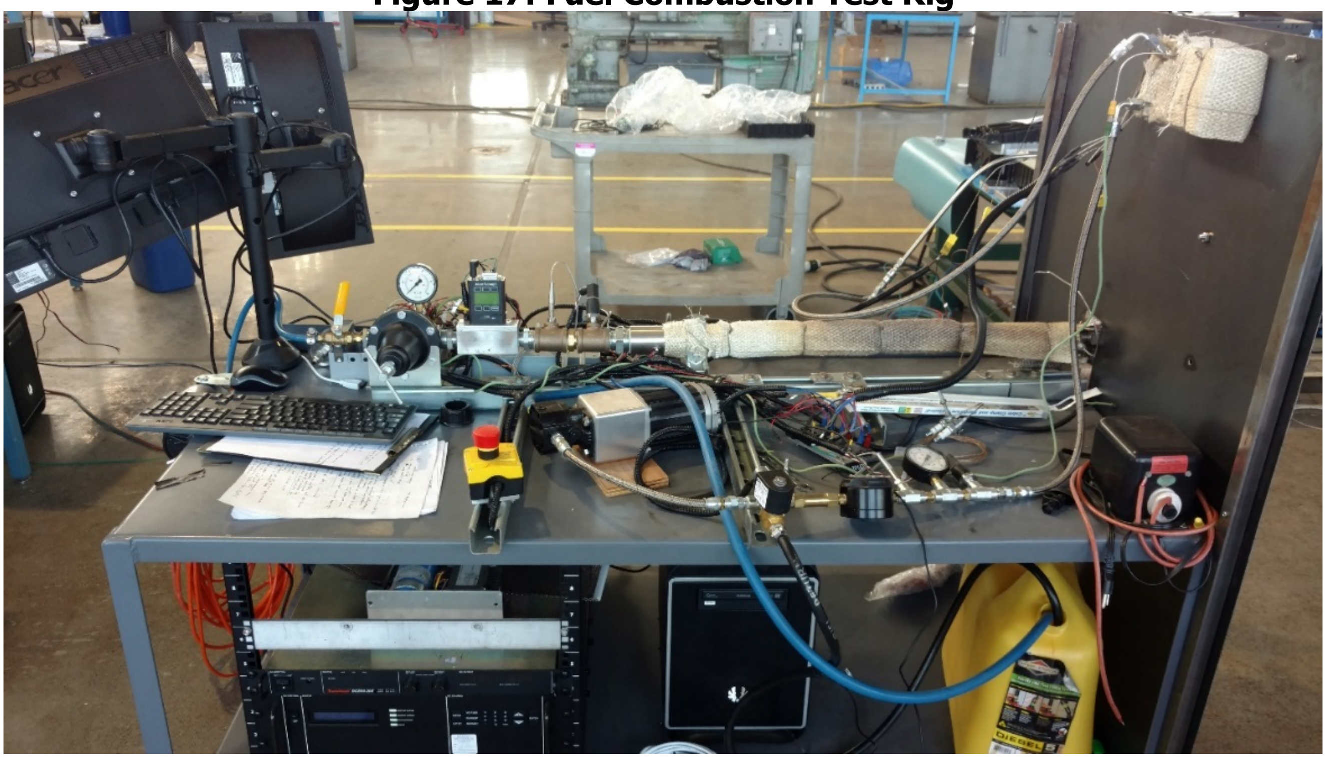
Figure 16: Test Stand for Wrightspeed Fulcrum™ Turbine



Fuel Combustion Test - allows Wrightspeed to test performance of its innovative methods for achieving cleaner diesel combustion. Fossil fuels are still about two orders of magnitude (100X) more energy dense than today's commercial battery technology; this level of energy density is crucial when powering heavier vehicles. Since mass scales cubically, larger vehicles require disproportionately more energy than electric vehicle passenger cars. Optimized fuel use allows significant improvements in total fuel use (reduction by 50 percent or more) while solving energy distribution infrastructure problems that aren't addressed by current or near term electric vehicle charging infrastructure, which is not scaling for high power (great energy in a short time) requirements of heavy vehicles.

The Wrightspeed range extended electric vehicle powertrain represents a double improvement over the current state: both reducing the fuel consumed and, when fuel is consumed, generating fewer criteria pollutants per gallon. This kind of deployable, scalable, step-change improvement technology is especially characteristic of efforts the CEC desires and wants to sponsor. Wrightspeed is recognized as a technology pioneer by the World Economic Forum for our powertrain technology. Fuel Combustion Test rig is shown in Figure 17.

Figure 17: Fuel Combustion Test Rig



Materials Strength Analysis Test Equipment - capable of testing both compressive and tensile strength, is shown in Figure 18. Since we target the heavy-duty market, proving the strength of the materials is essential for many components.

Figure 18: Tensile and Compressisive Materials Strength Analsysis Test Equipment

The fifth objective of this project was to develop and implement specialized software tooling required for manufacturing and manufacturing test. Software for testing subsystems is integrated into the testing apparatus for the Wrightspeed Fulcrum™ Turbine testing and for the Wrightspeed Geared Traction Drive™ traction power testing. For the complete powertrain, system diagnostic information and failure mitigation is incorporated into the control system, the Wrightspeed Vehicle Dynamics Control System.

The sixth objective of this project was to design, purchase and validate product-specific tooling and fixtures to enable low-cost volume manufacturing of components and sub-assemblies. Wrightspeed's overall competitive strategy is to focus on the area where we bring the most value (integrated system engineering), while accessing existing process experts for component manufacturing. Accordingly, a large portion of grant funds were used by Wrightspeed to invest in tooling expenses (fixed assets) that supported production objectives to cost reduce parts & components that were expensive by nature, but cost reduced as a result of tooling investment. Examples include service level agreements, molds, castings, patterns, wiring harnesses and other tools to improve existing designs for manufacturability and cost reduction. Such supply chain investment is essential to establishing a competitive, cost-effective manufacturing operation; the support from the CEC has been vital to helping Wrightspeed establish the supply chain necessary to support a manufacturing footprint in Alameda Point. Fixed assets purchased for this objective over the term of the grant totaled $673,000.

Wrightspeed also has invested heavily in non-recurring engineering charges for designs and related engineering costs from our suppliers to custom design processes and protocols to produce highly complex components. The laser welding for our battery modules, the recuperator design for the Wrightspeed Fulcrum turbine generator, the gearbox housings and many others are huge development efforts to allow production in mass quantities at required quality & cost levels.

The seventh objective of this project was to determine shipping and handling methods and acquire necessary equipment. Wrightspeed initiated a contract with a local logistics company who specialized in consolidations to offer Wrightspeed some of the cheapest freight rates available. Wrightspeed also hired individuals with the specialized knowledge to understand freight requirements for sensitive components especially the handling and shipping of batteries. The batteries are the most expensive component of the Wrightspeed Route powertrain kits and transporting the batteries required special care that we have become experienced in.

The company has purchased three forklifts, numerous hand lifts, and other machinery to manage heavy & bulky inventory that is inherent in heavy truck powertrains. We have built custom sub-assembly mounting systems including racks for transmissions, axles, turbine engines and drive motors. We have hired experienced stockroom and logistics personnel who have established methods for handling heavy freight and methods of ingress and egress from the facility. CEC funds supported the purchase of equipment for inventory movement totaled $59,000.

The eighth objective of this project was to design and implement off-line test infrastructure for detailed validation of the quality and performance of product samples. Wrightspeed has developed and written code for real time telemetry embedded in our powertrains that monitors performance and key operating indicators. All key subsystems can be continually monitored remotely, and any faults or potential issues can be understood long before the driver of the vehicle knows there is anything wrong in most cases. Wrightspeed experienced this with one of our prototype trucks that is currently being used by a well-known fleet operator who is committed to clean vehicles and big supporter of Wrightspeed. These systems communicate key performance and test information so technicians will know when any service is required and avoid vehicle faults while in service.

The ninth objective of this project was to implement the use the off-line test infrastructure to complete validation test of several sample Digital Drive System Retrofit Kits to ensure the quality of manufacturing and manufacturing test processes. The embedded telemetry has been deployed in two systems for our pilot customer. Data from the embedded monitoring systems in the deployed powertrains has given us insight into product performance and the user experience which we have already incorporated into product design changes for commercial production units. The support from the CEC has allowed us to leverage learnings from the prototype stage to design superior commercial product offering. Notably, we have observed that operator misunderstanding of the system design can lead to avoidable service disruption – a non-technical issue difficult to identify without the experience of units in operation.

The tenth objective for this project was to design and implement Ongoing Reliability Testing infrastructure and processes to ensure continued product quality. Process definition and refinement efforts were initiated following the hiring of our Vice President of Manufacturing, Greg Anderson. Under Greg's leadership we have instituted manufacturing best practices such as First Article Inspection. Development of these quality processes represents a significant inflection point in the growth of the company, transforming us from a research and prototyping shop into a process-oriented culture organized around repetitive manufacturing and continuous improvement driven by traceable results. Greg's background in manufacturing medical devices gives us access to world-class quality control standards based on one of the most strictly regulated industries in the nation.

Chapter 3:
Future Opportunities

Current Events

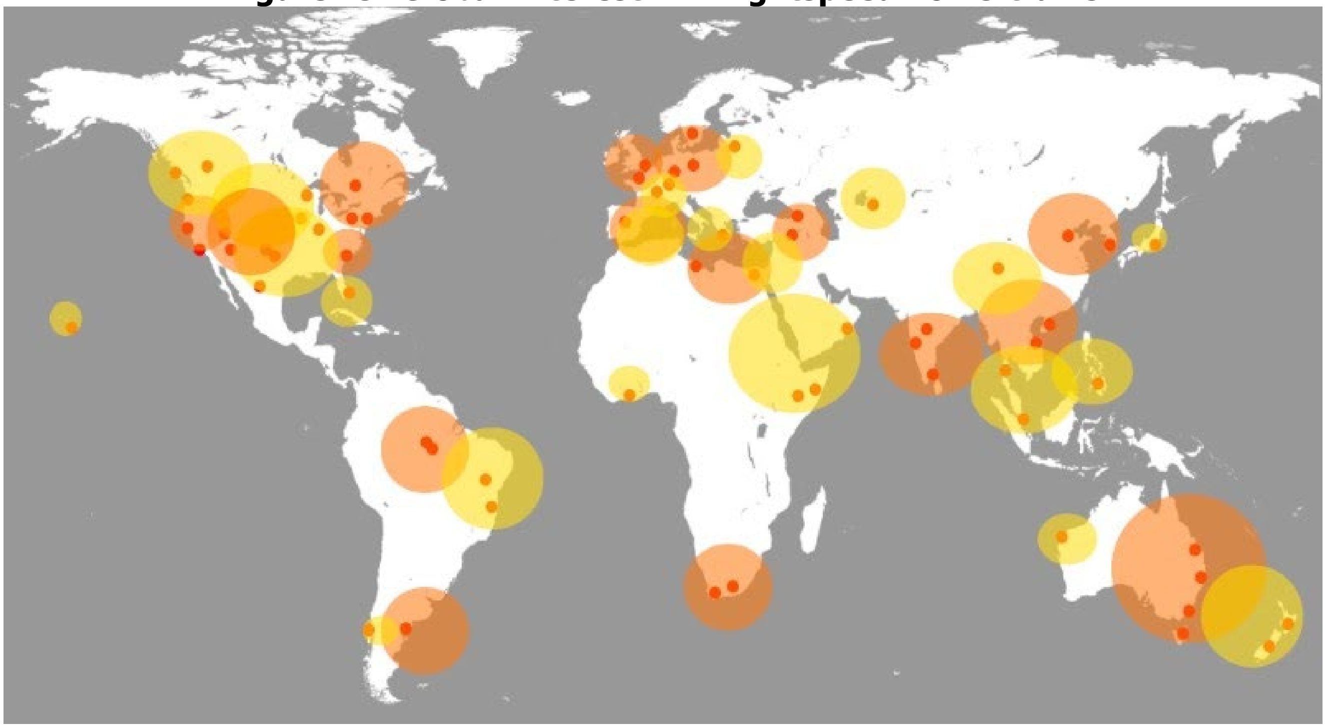
Wrightspeed relocated to the new facility in June of 2016. We expect to begin production in the 4th quarter of 2016. We have secured tens of millions of dollars in firm orders and are negotiating additional orders. Wrightspeed has recently hired a Chief Business Officer to complement the executive team, bringing the total executive team to 5 members. Our total headcount has now grown from approximately 12 when the grant was awarded to a total of 37 as of August 31, 2016.

We have been engaged in design enhancements of our major subsystems to improve cost and performance. These activities are concluding as we establish our new footprint in Alameda. The convergence of designs incorporating lessons learned from prototype production, new manufacturing facilities, and an expanded team with an emphasis on manufacturing personnel positions us for a strong ramp up in Q4 2016 and Q1 2017.

Market Prospects

The Wrightspeed system is highly in demand. We have tens of millions of dollars in currently booked orders and hundreds of millions of dollars in potential orders in discussion. We have received inquiries from all around the world, shown in Figure 19, many asking us to expand into new applications such as marine applications, material handling equipment, recreational vehicles, ski slope grooming equipment, or long-haul trucking. Although not all applications will ultimately prove viable, we see strong potential for Wrightspeed to expand into additional markets.

Figure 19: Global Interest in Wrightspeed Powertrains



Source: Wrightspeed, Inc.

Such expansion opportunities lie beyond the already vast potential of our primary markets, led by refuse collection trucks and city transit buses. The worldwide bus market totals over 500,000 units annually[1]. Our first units in this market will already be addressing the international market, in service for NZ Bus in New Zealand. Other international markets have already made inquiries as well. We look forward to a strong presence both domestically and internationally, as the advantages of the Wrightspeed powertrain become evident: a drastic reduction in emissions without any reduction in range or climbable grade, and fully compatible with both current and future transit energy infrastructure (since the range extender can be configured for diesel, compressed natural gas, liquefied natural gas, liquefied petroleum gas, or even landfill gas).

Although precise statistics for buses specifically in city transit use in California are difficult to find, Statista's figure of 18,000 publicly owned buses in 2009[2] seems consistent with other available data. Taking this as an approximate figure for buses in frequent-stop city transit applications suitable for the Wrightspeed powertrain, adjusting for growth since 2009 and assuming the engine and powertrain must be overhauled or replaced between 5 and 8 years, the annual market for Wrightspeed powertrain is between 2,000 and 3,000 units per year. We expect slower growth in this market due to public perception of other hybrid and battery

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[1] World Bus data is available at http://www.freedoniagroup.com/World-Buses.html

[2] California Bus Registrations is available at http://www.statista.com/statistics/196460/number-of-registered-buses-in-california-in-2009/. It isn't clear from the publicly available information whether this number includes school buses or not. However, comparing with estimates on School Bus Fleet Data, available at http://www.newgeography.com/content/004801-school-buses-americas-largest-transit-system, for school buses in California, it appears that California has at least 20,000 school buses alone, while a share of city transit buses by share of national population supports approximately 18,000.

electric solutions. As multi-year data becomes available for the Wrightspeed powertrain in comparison with perceived alternatives, we expect strong growth in this market as well.

Inform reported nearly 180,000 refuse trucks in operation in the United States in 2003[3]. Since the Wrightspeed powertrain can be retrofitted to vehicles already in operation, instead of the customary mid-life powertrain replacement, our addressable market includes both new and existing equipment. Our early partnership with the North Bay Corporation and our recent cooperation with Mack Trucks give us a strong point of entry into this ideal market for our technology. Heavy vehicles making frequent stops are the least efficient use of conventional piston engine technology and the most efficient use of our high-power range extended electric vehicle. Figure 20 shows a demonstration Mack LR truck.

The California Air Resources Board estimated 13,000 refuse trucks operating in California in a 2003 bulletin[4] outlining the negative health impacts of particulate matter and nitrous oxides. While a diverse range of options exist for addressing these health risks, most have drawback such as limited range, decreased hill-climbing ability, sluggish response, or marginal payback over operating life. Wrightspeed offers a uniquely compelling payback in this high-power frequent stop application, since we have optimized the size and performance of range-extending generator and of the battery pack; we expect rapid growth in the California market due to the combined effects of the regulatory pressures for cleaner emissions and the intrinsic attractiveness of a lower lifetime operating cost available without compromising job performance. Since our powertrain is available both for new trucks and as a retrofit, we expect a majority share of California trucks in this application within approximately 5 years.

Figure 20: Demonstration Mack LR with Wrightspeed Route 1000 Powertrain

Source: Wrightspeed, Inc.

[3] Informinc available at http://www.informinc.org/reportpdfs/st/GreeningGarbageTrucks.pdf

[4] Consumer Fact Sheet available at https://www.arb.ca.gov/msprog/swcv/consumerfactsheet3.pdf

On-Going Activities & Future Intent

Wrightspeed will be continually adjusting our manufacturing infrastructure as our capabilities expand. Assembly lines will continue to add more fixtures and purpose-built tooling as manufacturing engineering observes iterations of the build process and uses empirical observations to optimize ergonomics and efficiency. Equipment additions will focus on improving speed, reliability, and convenience for assembly and quality checks. Expansion in machining equipment will be minimal; our strategy is to source components rather than fabricating in house, other than prototyping. Investments in supplier tooling will continue, but at a reduced pace, matched to continuous design improvements.

The vehicles best suited for the Wrightspeed Route™ powertrain typically require a complete overhaul of the powertrain at least once during the total vehicle life. Thus, prospective customers have existing facilities or partners capable of vehicle overhaul. Wrightspeed plans to rely on these existing overhaul capabilities for most vehicle overhauls and bring vehicles into the Alameda facility mainly for prototyping or first-in-series builds. A relatively small number of complete vehicles will be in progress.

We will continue to build the Wrightspeed Route™ powertrain kit components in the Alameda facility. The components of the kit include the Wrightspeed Fulcrum™ range-extending turbine generator, the Wrightspeed Geared Traction Drive™, and the Wrightspeed proprietary high-power battery modules. These components are common across all configurations of the Wrightspeed Route™ powertrain family (comprised of the Route™ 250, the Route™ 500, and the Route™ 1000), allowing rapid progress toward economies of scale. Assembly of these subsystems in a context where Wrightspeed fully controls the quality and can verify the performance is essential to building our reputation as a provider of powertrains that meet or exceed the performance of the incumbent technology.

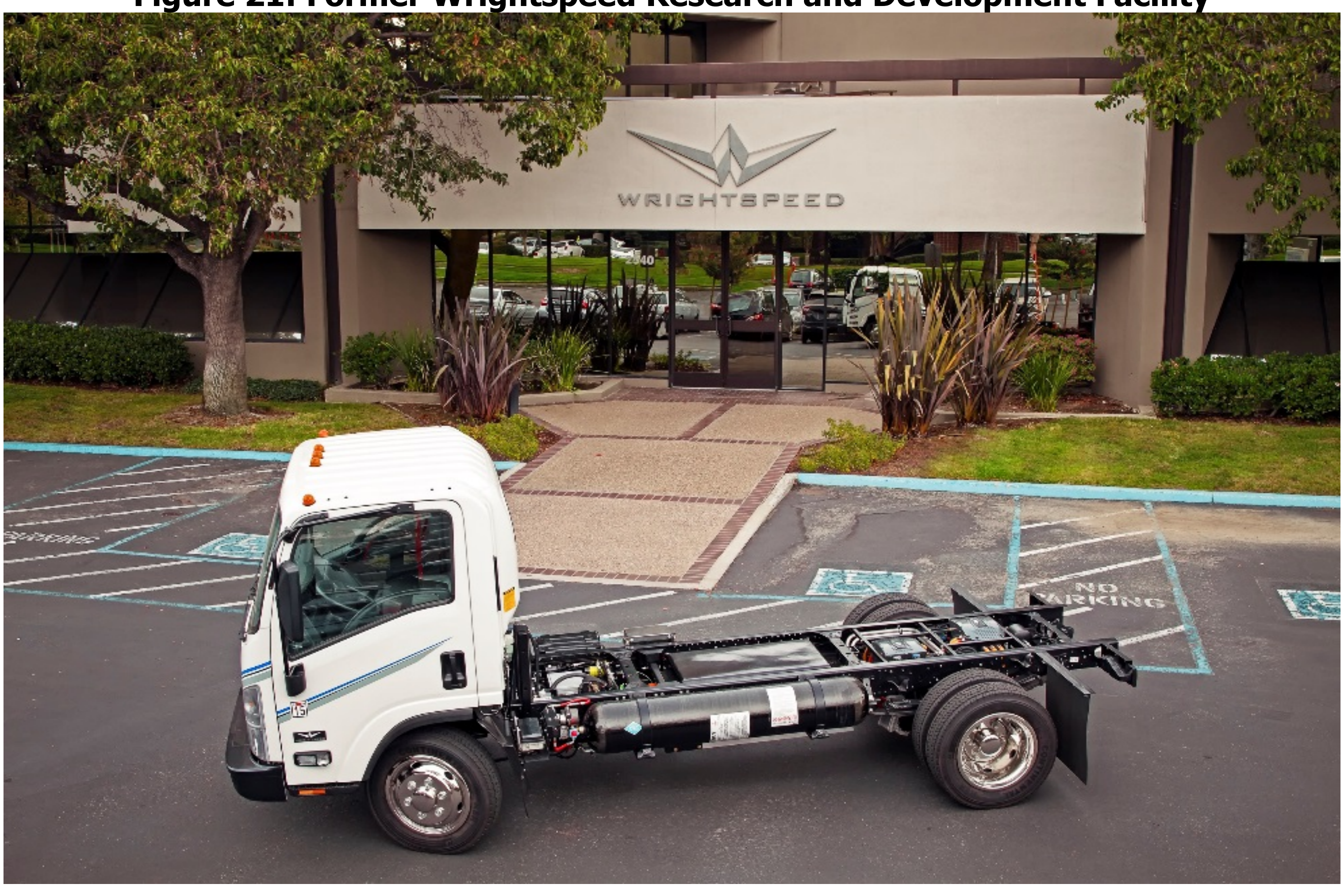
Currently our primary growth challenge is adding enough talented people to keep pace with the rate of demand. Wrightspeed's approach is a fully integrated powertrain (rather than a bolt-on hybrid upfit offered by some other companies), but only the powertrain – not the complete vehicle. We need engineers with deep expertise in our powertrain components, but flexible enough not to rely on highly segregated responsibilities or complete control over the vehicle design that characterizes conventional full-vehicle manufacturers. We are fortunate that the legacy of the Alameda Point Naval station includes strong training programs in turbine technology and diesel engines. This gives us a local talent pool to draw from as our manufacturing team grows.

Chapter 4: Conclusion

Prior to the CEC grant, Wrightspeed occupied a building in San Jose, shown in Figure 21, that was adequate for prototyping but untenable for production, due to its physical configuration and pricing. With the help of the CEC, Wrightspeed was able to not only stay in California, but to participate in the rejuvenation of the former Alameda Point Naval Base, shown in Figures 22 and 23, – a languishing resource in an increasingly supply-constrained real estate market. Wrightspeed was able to preserve the character of the historic building while expanding its operating footprint and reserving room to grow further.

In expanding its operations in California, Wrightspeed also increased its payroll, roughly tripling the number of employees during the program. Along the way Wrightspeed has tapped into suppliers in California and elsewhere who have historically served the traditional piston combustion engine industry, providing them with an opportunity for new business in vehicles that consume half the fuel and emit less than half of the particulates and nitrous oxides than conventional heavy duty vehicles. The support of the CEC has added jobs, preserved history, and set the stage for drastic reduction of emissions in applications where conventional technology is least efficient.

Figure 21: Former Wrightspeed Research and Development Facility

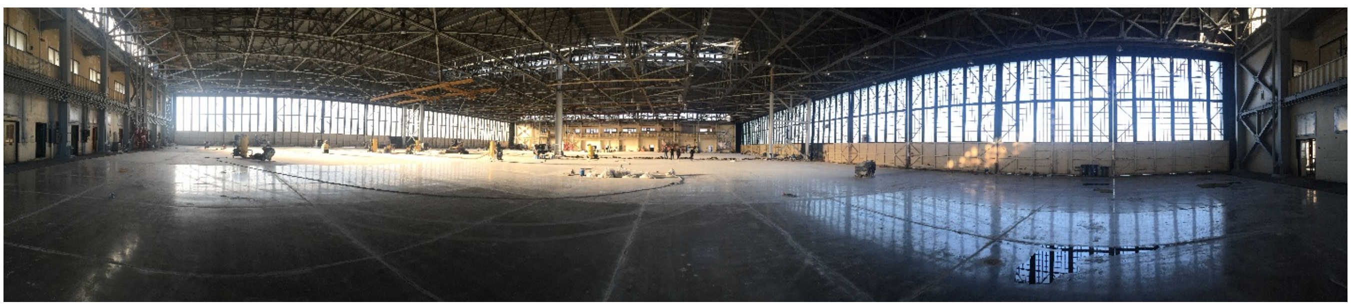


Source: Wrightspeed, Inc.

Figure 22: Wrightspeed Team at New Facility

Source: Wrightspeed, Inc.

Figure 23: Panoramic View of New Facility During Renovation



Source: Wrightspeed, Inc.

GLOSSARY

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 CEC's five major areas of responsibilities are:

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

Funding for the CEC's activities comes from the Energy Resources Program Account, Federal Petroleum Violation Escrow Account, and other sources.