The CORE concept for economic and environmental sustainability of mobile and stationary sources of power generation

Concept

The scope of the CORE concept is the development of an action-ready economically viable technical solution to mitigate the environmental, and societal effects of green house gas emissions (GHG) resulting from internal combustion (IC) engines. The developed and proposed technology has been deemed Combustion of Optimized Reactivity in Engines, or CORE for short. In the United States, the transportation sector consumes approximately 1/3 of all non-renewable petroleum sources. Furthermore, the transportation sector is 97% dependent on liquid hydrocarbon fuels. Figure 1 shows the United States energy source and GHG emissions distribution for both fuel stock and societal sector per Environmental Protection Agency (EPA) calculations on a per barrel of oil energy equivalent basis. It can be seen that the transportation sector uses ~28 quadrillion BTUs of energy per year (i.e., nearly 40% of the total energy usage). Additionally, the transportation sector produces nearly 30% of the total GHG emissions. Finally, it should be pointed out that not only does the transportation sector make up large portion of the total GHG emissions, but this sector is the fastest growing source of GHG in the United States [1].

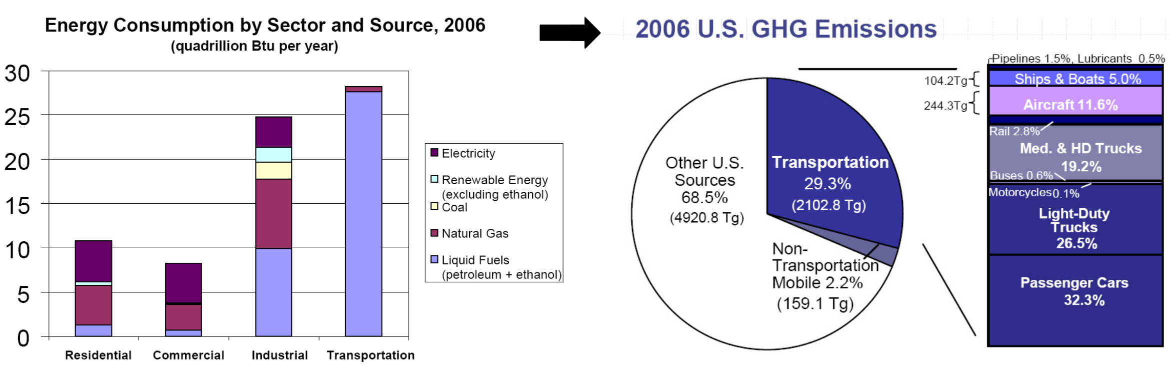

Figure 1. Fuel source, sector end use breakdown, and detailed transportation sector per EPA calculation [1]. Note the significant dependence of all sectors on non-renewable fossil fuel sources, and in particular the transportation sector on liquid fossil fuels.

At the present time, nearly all transportation vehicles are powered by internal combustion engines. The fact that nearly all 40% of GHG emissions result from a single device presents a unique opportunity from a GHG reduction standpoint. That is, if the internal combustion engine can be replaced with a device that emits lower GHG emissions or improved such that the GHG emissions are significantly reduced a substantial reduction in the overall GHG emissions could be achieved by a single device.

As is shown in the background section, the most sustainable (economically as well as socially) solution for reducing GHG emissions from the transportation sector appears to be by developing a highly-efficient device that converts bio-mass derived fuel into vehicle motion. That is, an internal combustion engine that has improved efficiency compared to traditional and state of the art engines and is designed to operate on bio-mass derived fuels.

The CORE strategy is a new way for operating current internal combustion engines using conventional and/or bio-derived liquid and gaseous hydrocarbon fuels, to lower adverse health and GHG emissions. For bio-fueled operation, the fuels could be ethanol and bio-diesel, both of which have distinctly different combustion characteristics. That is, ethanol is difficult to auto-ignite while biodiesel auto-ignites easily. By blending the two fuels, combustion can be optimized such that heat transfer losses can be significantly reduced. These losses typically account for approximately 30% of the total fuel energy, and their reduction offers great potential to increase engine efficiency, thus decreasing GHG emissions. The key to the CORE technology is the advanced fuel delivery and blending strategy. The charge preparation strategy (i.e., the method to blend the two fuels in-cylinder) was developed through detailed computational fluid dynamics (CFD) modeling [2] combined genetic algorithm (GA) optimization. Figure 2 shows the proposed method of fuel blending. At intake valve closure, the combustion chamber is filled with a blend of ethanol, air, and residuals. Near 60 degrees before top dead center (°BTDC), the first bio-diesel direct injection is delivered (shown by the dark colored spray plumes in the second image from the left). This injection targets the outer region of the combustion chamber and allows the premixed fuel to achieve complete combustion to improve the fuel conversion efficiency. Near 35 °BTDC, the second bio-diesel injection is delivered into the inner region of the combustion chamber to control the ignition timing and combustion duration.

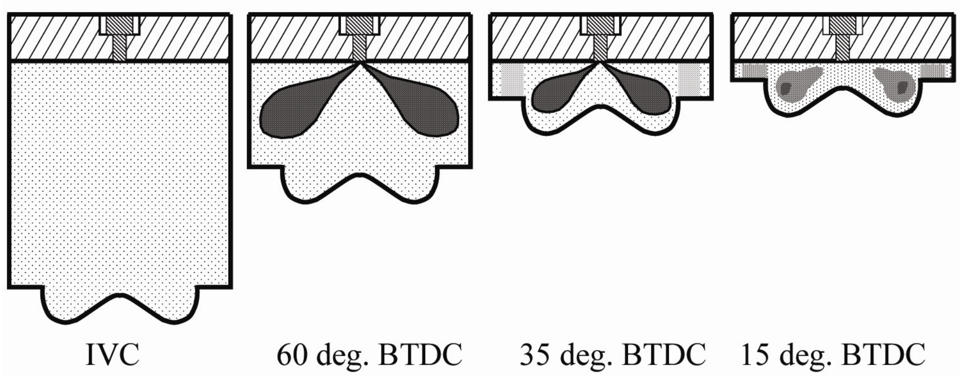

Figure 2. Depiction of the CORE concept fuel blending strategy [3].

While the CORE concept uses existing hardware and existing fuels, it results in a new combustion strategy that exists only with optimized charge delivery conditions. A full description of the invention can be found in the recent patent application [3]. The CORE strategy is applicable to both diesel and gasoline engines, and to engines of all sizes. This enables all IC engine market sectors to see huge improvements in thermal efficiency, while simultaneously reducing the size, complexity, fuel economy losses, and cost of after-treatment systems required to reduce NOx and soot emissions.

The CORE concept results in what is demonstrated to be the most fuel-efficient, internal combustion engine in the world that is capable of meeting present and known future NOx and soot emissions limits. The high thermal efficiency lowers the amount of fuel consumed to accomplish the identical amount of work, and thus is directly proportional to reduced GHG emissions. Through a series of engine experiments using the CORE strategy presented above, the team [4-7] has shown that NOx and soot are reduced below mandated levels (i.e. US EPA 2010 Heavy-Duty) without using aftertreatment. Furthermore, the CORE strategy resulted in optimum combustion phasing, by tailoring the fuel reactivity to the specific operating condition with the optimal blend of the two fuels in-cylinder, allowing the engine to achieve 53% net indicated thermal efficiency. That is, 53% of the fuel chemical energy is converted directly into useful work. In contrast, at the time of this document's preparation, the average conventional diesel CI engine has a thermal efficiency of approximately 42%, and the average gasoline SI engine has a thermal efficiency of approximately 30%, as shown in Figure 3. Thus, the CORE concept reduces GHG emissions of CO_2 by 17% and 83% for CI and SI engines, respectively. The increase in efficiency is the result of optimal combustion, allowing for reduced heat transfer losses and less energy lost to the exhaust stream.

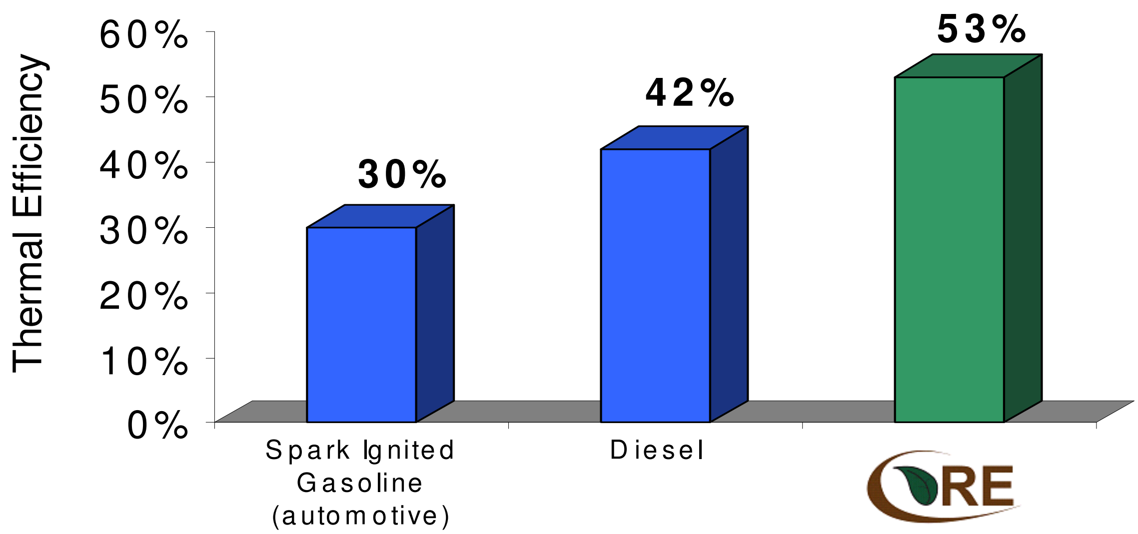

Figure 3. Comparison of thermal efficiencies for engines using spark ignition, compression ignition and or the CORE system [8].

It was further found that the CORE strategy proposed by the team [5] that results in superior engine efficiency and GHG emissions reduction can be achieved with relatively inexpensive low pressure port- and direct-injection fuel system hardware. That is, existing parts that are standard equipment on current vehicles. The ability to see a drastic reduction in overall GHG emissions without the need to develop new technology or infrastructure makes the CORE strategy a very promising action ready solution.

To realize the maximum GHG benefits, the CORE strategy must be taken from the lab to the field. The commercialization method described in the project timeline and distribution sections follows the proposed pathway to enable widespread implementation of this strategy. The pathway involves a business plan in three stages to allow the CORE concept to be demonstrated in the field. In Stage 1 of this strategy, the team will conduct further computational simulations to fully characterize the CORE concept on several engine platforms. Then the team will leverage these simulations with previous modeling and experimental results conducted in their Ph.D. research at the University of Wisconsin's Engine Research Center to refine a business model and strategy to prove the benefits of the CORE concept to investors and secure capitol funds required to move into Stages 2 and 3. In Stage 2 the team will demonstrate experiments and commercially viable product for industrial-type generator engines using the improved efficiency and reduced emissions from the CORE concept. Then in Stage 3 the team will take the CORE concept into mobile applications of both hybrid and non-hybrid configurations. This three step strategy will be used to develop product that can be seamlessly integrated into several current and future IC engine markets. Doing so will maximize the profitability of corporations and global GHG reduction provided by the CORE concept.

Background

To minimize GHG emissions from the transportation sector, the question that must be answered is: Should the internal combustion engine be replaced or can greater GHG reductions be achieved if the improvements are made to the existing internal combustion engines. In a recent study [1], the United States Environmental Protection Agency addressed this question. In that work, they evaluated the GHG emissions from current technology, as well as future solutions that they considered feasible alternatives to current technology. Figure 4 shows the current technology GHG emissions using a compact sedan as a baseline. That study found that a current vehicle (IC engine, non-hybrid) emits 320 to 360 grams of CO_2 per mile traveled ($gmCO_2/mi$). Adding hybrid powertrain to that vehicle reduces the CO_2 emitted to 230-270 $gmCO_2/mi$. Clearly, hybrid powertrains are a positive step to reducing GHG. However, if the vehicle is a plug-in-hybrid-electric-vehicle (PHEV) or fully-electric vehicle (EV), the CO_2 emitted jumps up to 290-435 $gmCO_2/mi$. Additionally, notice that the CO_2 emissions are lower for a PHEV that is operated completely on the internal combustion engine. This demonstrates that PHEVs and EVs are only as clean as their power source. Therefore using current power generation techniques, if reducing CO_2 is the primary intent, it is better to never plug in a PHEV.

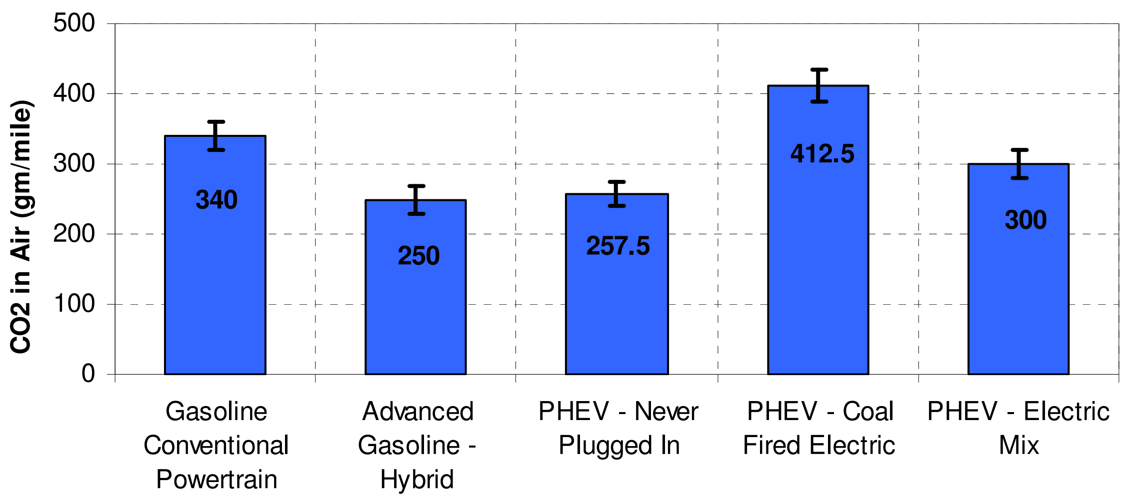

Figure 4. CO2 emissions for current transportation sector technology [1]. PHEV stands for Plug-in Hybrid Electric Vehicle.

Figure 6 shows the GHG emissions for several future technologies. Using carbon capture and sequestration (CCS), a PHEV of the future is expected to emit 60-85 $gmCO_2/mi$. If a significant investment were made in nuclear power, the EPA's estimated most promising widespread power dense from of current and foreseeable power generation, the CO_2 emissions could be reduced to 5-10 gmCO_2/mi. The nuclear-PHEV appears to be a promising solution. However, at the current time, only 20% of the total electricity is generated using nuclear energy [9], see Figure 5.

However, the benefits offered by nuclear power do not come without penalty. Besides potential environmental and security hazards, as well as the availability of nuclear fuel, expanding the US nuclear power infrastructure to provide carbon free electrical load for electrified transportation sources is unrealistic in both cost and duration. For instance, the only approved nuclear power plant installations in the United States since 1973 were approved in February of 2010. The two approved facilities generate a combined 2,200 MW-hr at a projected cost of 22.9 billion (or approximately $1 million per megawatt hour instillation). Of that cost 80% was loaned from the federal government [10].

Using the EPA estimates of energy consumed by the transportation sector in Figure 1, and assuming a optimistic 40% total sector efficiency, the total energy required for moving vehicles in the US is 3.2 billion [MW-hr]. Therefore to accommodate the additional load of electrified vehicles of an assumed 100% operational efficiency the installed capacity would be approximately 3 million additional nuclear power plants, with an estimated first cost of 3 quadrillion dollars (i.e. $1.0e15). Therefore, if further clean (i.e. GHG free) energy sources such as nuclear energy are required for PHEV and EV technologies, significant cost and effort will be required to install the necessary capacity to reduce GHG emissions of transportation sources. Alternatively to supplement the added electrified vehicle load from wind based generation would cost approximately twice as much as nuclear (wind power cost are estimated to be 1.2-2.6 $million per installed MW-hr) [9]. These figures also assume that there is sufficient wind capacity and land available to make such instillations.

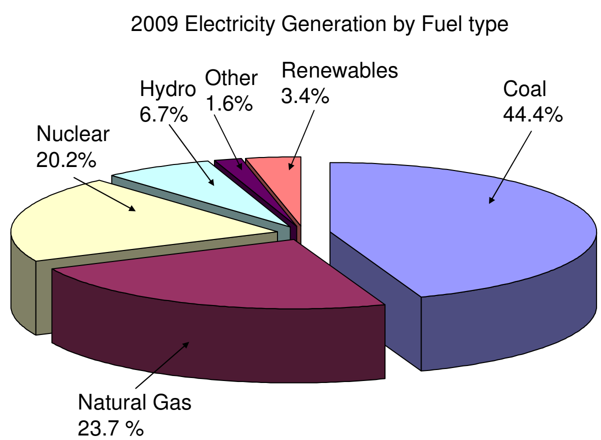

Figure 5. US Electricity production by fuel type for 2009 [9].

A more feasible approach to lowering GHG emissions and meeting demands for energy appears to continue to use IC engines with renewable biofuels made by biomass gasification. An internal combustion engine operating with a hybrid powertrain on fuel derived from biomass gasification is able to reduce CO_2 emissions to 20-30 gmCO_2/mi [1]. Furthermore, if carbon capture and sequestration is used during the fuel production process, CO_2 emitted into the air can be driven negative. That is, the CO_2 emitted during operation of a compact sedan powered by an internal combustion engine with a hybrid drive train operating on biomass derived fuel with carbon capture and sequestration removes 70 to 90 gmCO_2/mi [1], see Figure 6.

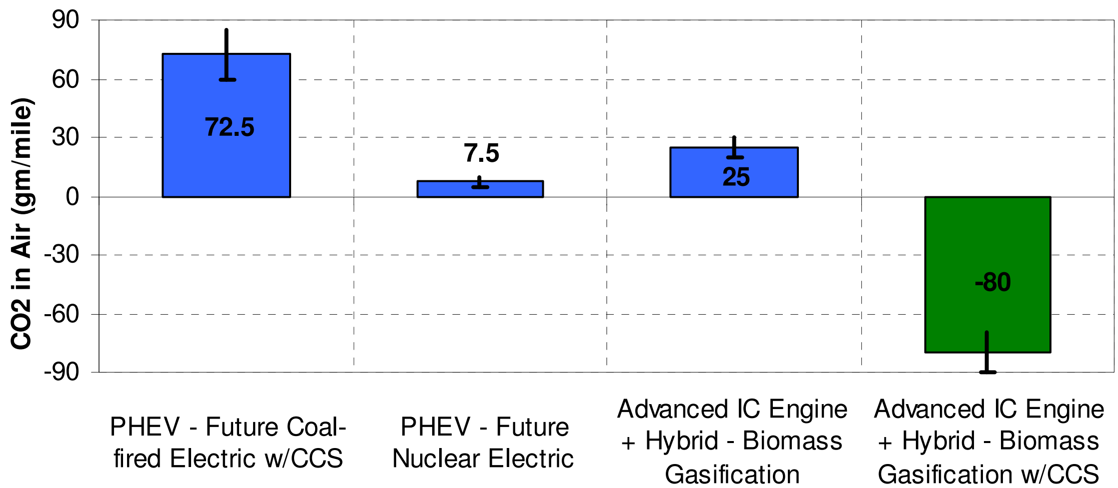

Figure 6. CO_2 emissions for future transportation technology [1]. CCS stands for Carbon Capture and Sequestration.

From the above discussion, it appears that the best near/short term approach to reduce GHG emission from the transportation sector is through improvements in the internal combustion engine using bio-derived fuels.

Recent research [6, 11-13] has demonstrated improved compression ignition engine performance with the use of alternative fuels. This research has demonstrated that a combustion strategy known as premixed charge compression ignition (PCCI) could lead to simultaneous reductions in fuel consumption and GHG. Premixed combustion strategies can be thought of as a melding of conventional spark ignition engines with compression ignition engines. The extended fuel-air mixing time is similar to conventional spark ignition engines; however, there is not spark plug to initiate combustion. Instead combustion occurs from chemical decomposition of the fuel through compression heating. Once sufficiently decomposed, the fuel globally autoignites (spontaneous ignition throughout the cylinder). This combustion strategy is highly desirable for two reasons. First, it has engine efficiencies that are similar to those of diesel engines. Second, unlike the diesel combustion process, the premixed combustion process has low health impacting emissions like NOx and soot. As seen in Figure 7, the CORE strategy operates in a clean combustion region where minimal amounts of NOx and PM are produced.

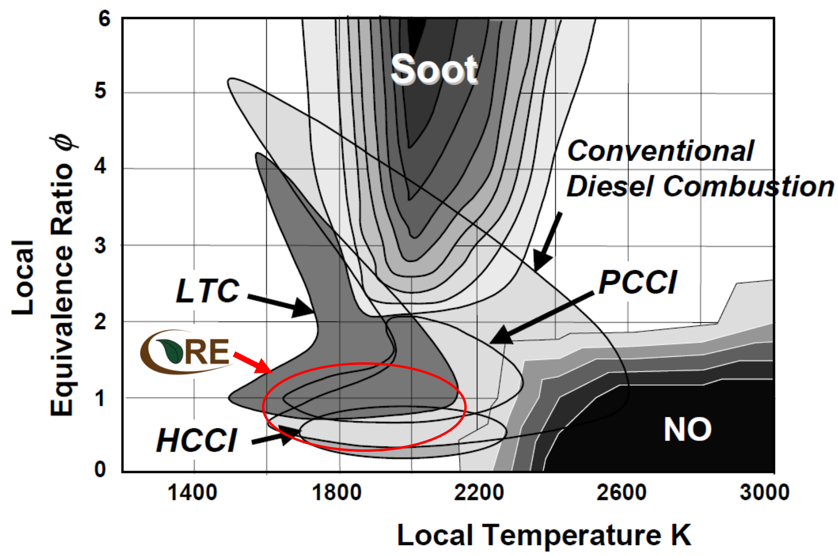

Figure 7. Local equivalence ratio vs. local temperatures for different combustion strategies [14].

With the CORE strategy, it is possible to increase or maintain the GHG and efficiency benefits of traditional PCCI, while simultaneously adding control of combustion phasing thereby widening the operating range. With the added benefits of combustion phasing control, low noise and wider operating range, the CORE strategy allows a way to bring premixed combustion to the mass market and realize these benefits on a large scale.

Environmental and Social Impact

Since its introduction in the late 1800's, the internal combustion engine has been utilized in almost every aspect of modern life, from transportation to energy generation to food production. Several emissions are of prime concern for air pollution: nitrogen oxides (NOx), carbon monoxide (CO), unburned hydrocarbons (HC), and particulates (soot). These pollutants are damaging to the environment and human health. Reduction of these harmful pollutants while maintaining fuel economy has been a primary driving factor for internal combustion engine research in recent years.

In recent years, much attention has focused on also reducing the GHG emissions from the transportation sector by improving the efficiency of the internal combustion engine. To assess the effect of the CORE concept on GHG emissions, the Greenhouse gases, Regulated Emissions, and Energy use in Transportation (GREET) Model [15] developed at Argonne National Laboratory was used. The basis of this model was developed to assist metropolitan areas in estimating the impact of emissions reduction technology. It has since been extended to assess the impact of alternative fuels and energy sources using a well-to-wheels (WTW) approach to equally compare the GHG emissions from competing technology. In this analysis, all assumptions (e.g., hybrid drivetrain efficiency improvements) were left untouched. The only modification to the base GREET code was updated fuel economy for the presented CORE combustion concept. The thermal efficiency of CORE engines was shown experimentally to be greater than 50% [4]. To provide a conservative estimate, a thermal efficiency of 50% was assumed. The GREET code uses a spark-ignited automotive type engine the baseline. The thermal efficiency of these types of engines is ~30%. Therefore, the miles per gallon (MPG) required as an input for the dual-fuel engine can be calculated as

$$MPG_{CORE} = 50/30 MPG_{Base} \qquad (1)$$

The GREET model was used to evaluate current and future technologies. Four platforms were considered: spark ignited, compression ignited, fuel cells, and plug in vehicles. The fuels or energy sources considered were petroleum (i.e., gasoline and diesel fuel), bio-fuels (i.e., ethanol and bio-diesel), hydrogen, electricity, natural gas, methanol, naphtha, and DME. For energy generation, the base GREET [15] assumptions for the year 2015 were used. Figure 8 shows the 6 highest impact technology and fuel combinations for GHG reduction based on the results of the GREET analysis. It can be seen that several promising technologies exist to reduce GHG emissions. Clearly, the largest impact comes from a combination of hybrid powertrain with a bio-fueled vehicle using the CORE technology.

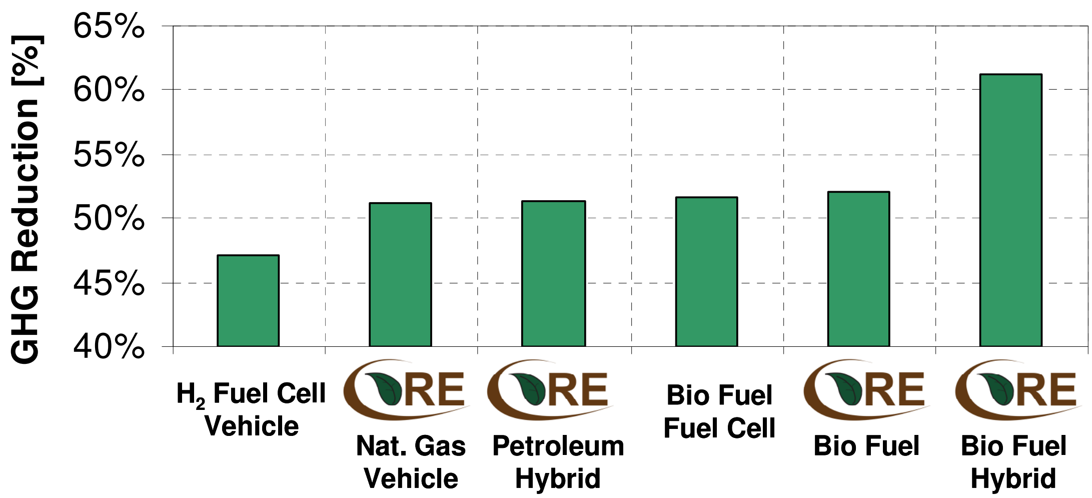

Figure 8 Effect of vehicle technologies on GHG emissions. Note the benefits of the CORE concept with a bio-fueled hybrid strategy.

The social and economic impact must also be considered when evaluating future technology. To address the social and economic impact of the presented technology, the potential reduction in oil consumption is addressed. Obviously, the oil consumer benefits from reduced consumption due to supply and demand economics. This was clear during the recent financial recession that resulted in significantly reduced oil consumption and plummeting oil prices [16]. Therefore, it seems reasonable to address both the social and economic impact together.

Currently, the United States consumes 20.7 Million Barrels of Oil per Day (MBOD). 65% of this oil (13.5 MBOD) is used for transportation purposes. As a side note is equivalent to a train of 33,000 tanker cars that would stretch from Milwaukee to Minneapolis. The transportation sector can be split into heavy-duty trucks (i.e., diesel engines) and light-duty vehicles (e.g., spark ignited engines). Heavy-duty trucks consume ~4.2 MBOD with a thermal efficiency of ~42%. The CORE strategy has demonstrated 53% thermal efficiency; therefore 0.9 MBOD (1435 tanker cars of oil) could be saved simply by switching vehicles over to the proposed CORE strategy. Further reductions are possible if bio-fuels are used (see Figure 8). The light-duty sector (Gasoline SI) consumes 9.3 MBOD at ~30% thermal efficiency. Applying the CORE strategy to these engines (i.e., increasing the thermal efficiency to 53%) would result in 4.1 MBOD saved (6537 fewer tanker cars of oil). Again, further savings are possible with bio-derived fuels (see Figure 8). Based on the above discussion, it can be seen that by applying the CORE strategy to existing engines, using existing feedstocks would result in a savings of 5.0 MBOD. This is a reduction in total oil consumption of ~1/4 and is approximately to the amount of oil that the US imports from the Persian Gulf. The economic benefits of this oil savings are outstanding. Based on an oil price of $80 per barrel [16], the reduction in oil consumption by applying the CORE strategy presented here would result in over $145 billion per year remaining in the United States. Additionally, the fuel savings prevent nearly 4 Billion pounds of CO2 from being emitted per year.

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Distribution

As stated earlier, the scope of this project is the development of an action-ready, economically viable technical solution to mitigate the environmental and societal effects of green house gas emissions resulting from internal combustion engines via the CORE system. The target audience for this technology is original equipment manufactures (OEM) and aftermarket manufacturers of stationary and mobile internal combustion engines. These industries produce products that must meet the three requirements outlined in the following paragraphs.

Primarily their products must meet current governmental regulated emissions and corporate averaged fuel economy (CAFE) mandates. For instance, the present EPA 2010 heavy-duty emissions and 2016 CAFE standards present a particular challenge to manufactures in the respective heavy- and light-duty markets. Although historically meeting emissions and fuel economy mandates have been achievable with current technology, the stringent 2010 and future emissions mandates of NOx, soot, and fuel economy are extremely difficult to meet. For instance the heavy-duty emissions mandates of the last two decades can be seen in Figure 9, where the current 2010 mandate demonstrates multiple orders of magnitude reduction in emissions of NOx and soot.

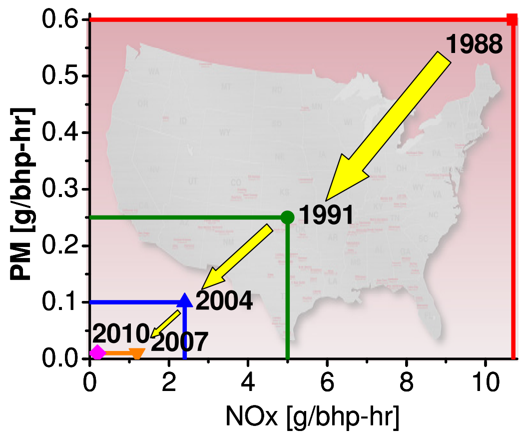

Figure 9. US EPA NOx and PM emissions standards as a function of time

Although the emissions and fuel economy mandates are the societal and environmentally responsible task of engine manufacturers, meeting increasingly stringent mandates has historically added additional engine cost for manufactures. This cost is ultimately absorbed by consumers. In addition, the current US EPA 2010 heavy-duty emissions standards have been unable to be met by many engine manufactures. When a manufacturer cannot meet the mandates they must use credits that are awarded by other products sold by that company that exceed the mandates. In doing so additional consumer and manufacturer cost can be added the non-attainment products, and the potential environmental benefits of the emissions mandates are not fully realized. The proposed CORE concept is very appealing to engine manufacturers, because current and future emissions mandates are actually exceeded while simultaneously reducing engine cost and complexity. This ability is unrivaled in other competing technologies that often require additional and more complex engine components and thus cost.

Once a manufacturer has met emissions mandates or paid significant non-attainment penalties through credits, they are allowed to then sell their product to consumers. However, now they must now meet a new requirement; consumers must find their product economical to purchase and use. Consumers of IC engines have a wide range of usages and preferences, but the underlying concepts of viable economics to purchase and use the product unify all users. That is, the engine must have reasonable first cost and life cycle cost for the end user. If additional emissions reduction equipment or penalties for non-attainment are required to comply with emissions mandates, the first cost to the consumer will likely increase. For example, Volvo has increased the first cost of their heavy-duty semi-trucks by more than $18,000 in model year 2010 trucks because of the emissions equipment required for the new mandates [17]. Secondly, in operation the engine uses fuel, this cost is somewhat unknown due to market volatility, but ultimately is a large percentage of all life cycle cost for all engine users. These consumer costs ultimately dictate the viability of the product marketed by engine manufacturers. Regardless of the regulated and GHG emissions levels of the engine consumers must be able to afford its purchase and usage. The CORE concept is paramount in this consumer requirement. Not only is the engine less expensive for the manufacturer to produce, it has considerable fuel cost savings for the end user. This doubled savings provides unparallel economic savings to the end user of IC engines.

The last requirement that IC engine manufactures must meet is that consumers must accept their product as being of high quality and longevity. If a manufacturer markets a product that has little regulated GHG emissions and fantastic fuel economy, but has limited life expectancy and negative operation attributes (e.g., noise), a majority of consumers will not purchase that product. Thus, the product must meet consumer preferences of noise, vibration, harshness, and quality. Unlike other advanced and traditional diesel combustion strategies that produce sizable combustion noise, the CORE concept operates quietly, and smoothly. This not only meets customer preference requirements, but also lessens the manufacturers mechanical and engineering costs associated with mitigation and isolation of combustion noise and harshness from the engine.

The combined three fold benefits of the CORE concept are beneficial to manufactures through a reduction in engine development and component cost. This lowers the overhead cost associated with the engine and can be added to the bottom line of the company and or passed onto the consumer, making the company more economically strong. The CORE concept also aids manufactures in marketing strength through the not only the economics of lower fuel costs for consumers, but also demonstrates how the manufacturer is committed to cutting GHG and regulated emissions in their products. Furthermore, the quiet operation of CORE aids in marketing potential of the product through instilling a sense of quality and reliability in the customer from quiet and smooth operation.

To introduce these benefits to engine manufactures, the team proposes to start a consulting company. The company will be designed to demonstrate the economic and strategic benefits of the CORE concept to OEM and aftermarket engine manufactures. To do so, advanced modeling of manufactures engines will be performed. The proposed modeling has been demonstrated to be extremely accurate by the team members' previous research [4, 6]. To reach manufactures most effectively, the team proposes to first market the idea to investors such that additional capitol to develop the technology from computer, to engine, to vehicle is realized. In doing so the company will leverage their technical and fundamental expertise in the concept and specialize in the development of it to the point of seamless integration with OEM and aftermarket manufactures.

Project Timeline

To enable successful viability and market penetration of the CORE concept, the consulting business must launch its strategy in three successive stages. Primarily, the team requires initial capitol through winning the most action-ready project in this competition. That capitol will be used to fund Stage 1 of the development process. Stage 1 consists of the assembly of the organization, procurement of computational hardware, and the building of the business framework required for the consultation business. In Stage 1 the team will use the procured computational hardware to organize and conduct multi-dimensional computational simulations of various engine sizes, platforms, and operating parameters. The simulation code has already been experimentally validated by the team in their Ph.D. research [18, 19], publications [2, 5-7], and patent [3], to be both valid and accurate at simulating the CORE concept. Through this previous validation, the simulation code will be expanded upon to optimize several different engine configurations and operating conditions. Using simulations will expedite and reduce the cost of later experimental and development work by reducing the number of engine experiments needed for development. As the team produces accurate simulation data, the team will initiate the process of raising additional capitol from private investors, grants, and industry that is required to initiate Stage 2 of the development. The team estimates that the time required for completion of Stage 1 development and capitol securement will be approximately one to one and a half years in duration.

In this stage of the development process, the team faces the lowest level of risk, but the highest number of market roadblocks. Since computational simulations are low relative cost compared to engine research and development, the team faces the smallest financial risks at this stage. In Stage 1, the biggest financial risks the team faces are not winning the most action-ready climate solution in this competition, and then not finding sufficient capitol investment to move to Stage 2. Although these two Stages present the lowest risks to the team, they also present the biggest road blocks to getting this technology to market. For the team to have a viable marketable solution to significantly reduce GHG emissions from stationary and mobile source, the team must raise the required capitol to initiate the business and for the business to move from simulations to experiments.

Upon successful completion of Stage 1, the team will enter into Stage 2. Stage 2 will consist of taking the concept from the computer laboratory to experimental validation in an engine laboratory. Although the team has conducted initial experiments at the University of Wisconsin Engine Research Center that have and proven very high efficiency and low emissions operation of the combustion concept, a more advanced engine lab and hardware are required to further the development process for commercialization. The capitol required will be used to secure a development facility, hardware, and funding required for commercialization. The facility and hardware for Stage 2 will consist of construction of an experimental laboratory and initiation of the commercial proof of concept validation process. To reduce the required capitol and time for Stage 2, initially a small diesel generator will be used with a transient engine dynamometer. This facility will enable cost and time efficient development of the combustion concept.

The primary focus of Stage 2 is to gain further understanding of real world vehicle operation and make engineering decisions of the engine control architecture required for commercial viability. This second stage of the development process is critical to the commercialization process from the proof of concept already demonstrated in a research environment, to real world operation and conditions. Once demonstrated in stationary applications the team will leverage their technical and engineering knowledge of the engine requirements and enter into Stage 3 where development of mobile applications will be conducted.

Upon entering Stage 2, the risks faced by the team increase. The responsibility of investor return will be significant and successfully and timely delivering a product will be paramount in the success of Stage 2. With the additional work requirements in Stage 2 required to materialize, engineer and develop the strategy the organization will require expert employees and thus take on further responsibility to their well being and livelihood. The greatest risk at this stage of the three stage process is risk of failure due to improper business management, and engineering success. The organization members will not only use their personal experience in product development but also require the hiring of business and electronic controls experts. With such individuals, the organization will be positioned to develop the proper foundation for success. Like the additional risks that the organization has assumed in Stage 2, the road blocks to market have also increased. Although the organization has generated capitol to begin physical research and development, it is still vulnerable to the economics of the development process. The organization will need effective and efficient business management to stay on budget, and time. The organization will for certain face unforeseen dilemmas in the development process. The initial budget presented in the budget section of this proposal has reserve funds allocated for such obstacles; where the number and severity of these are unknown. The team presently estimates that these are manageable and will provide opportunities to further develop the product beyond the current research level design, and reduce later obstacles. Successful completion and management of the technical, business, and marketing aspects of Stage 2 will allow the organization to enter Stage 3

Although Stage 3 may require additional capitol, the organization may or may not have to raise funds from investors, grants, or industry. It may be able to reinvest cash flow from the sale of the stationary application concept developed in Stage 2 into the business for the mobile development process of Stage 3. The primary interest of Stage 3 is to develop demonstration vehicles of the CORE technology. The organization will be able to use the developed technology and insight in the stationary applications in Stage 2 to more seamlessly enter into a series hybrid vehicle design. The design will use a steady state engine as a generator and an electric drive system for propulsion. The team estimates that this development process will require additional capitol and personnel as noted in the budget section, and is estimated to take an additional two years beyond Stage 2. While developing the series hybrid drive proof-of-concept demonstrator vehicle, the organization will simultaneously develop a transient operating strategy. The transient strategy will be implemented into a parallel hybrid or IC engine only demonstrator vehicle.

Although there are other engine startup companies, what makes this team and potential organization unique is their technical expertise at combustion optimization. This core competency positions the team to fully realize the CORE concept in the market place. For instance, other manufactures and researches have experimented with fuel reactivity controlled combustion [20] with only marginal success; however, the expertise of the CORE team has enabled them to achieve outstanding results and patent the described CORE technology. The uniqueness of the CORE optimization process will be used to increase the economic viability for manufactures and expand their marketing potential of the product, while simultaneously reducing operator costs, GHG emissions, petroleum dependence, and regulated emissions. The end result of the new start up company is to introduce a market ready solution to OEM and aftermarket manufactures via licensing of the CORE technology. In doing so, the team estimates that the development cost by the start up company will be more economical than that by a major OEM through the advanced understanding of the combustion concept. Although there are several economic and environmental benefits of the CORE system, they are not without risk. The team believes that they can challenge and conquer these risks to bring a viable GHG reduction solution for the transportation and the stationary power generation sectors to market efficiently and economically.

In the event that the team is unable to overcome the associated risks of a start up corporation, the team has the ability to alter the business scope from a development and consulting company, to a technical consulting company. In this transformation, the team will specialize in optimization of the combustion process for high efficiency and low emissions for current and future OEM and aftermarket manufactures. This will leverage the core technical expertise of the team, but still will require quality marketing and business skills to compete against private consulting companies already in existence. The team will use the lean company architecture, advanced multi-dimensional simulation tools, and technical expertise to compete against already established corporations in this market. Using these skills, in conjunction with industry contacts the team estimates that the corporation has the market penetration potential for successful transition of the CORE concept from the laboratory to the field.

Financial Feasibility

As stated in the project timeline and distribution sections, the team plans to start a company focused at economically bringing the CORE concept from a research environment to a commercial market. The process to do so consists of three stages. Wherein each successive stage will build upon the knowledge learned during the previous stage, but will also require additional capitol investment. That is, for Stages 2 and 3 to commence the team must secure additional capitol. Procuring the additional capitol will begin in Stage 1. In Stage 1 the team will initially develop accurate multi-dimensional engine simulations of fuel reactivity controlled combustion on three engine platforms, and refine the long term business plan. As detailed in the award budget section of this proposal, Stage 1 will require the team to be awarded the most action ready prize. The $50,000 grand prize will be used as described in the award budget section as to organize the business, complete computational simulations, and promote the three stage process to investors for securing capitol to move to Stages 2 and 3.

As detailed in the award budget section, the team estimates that approximately one third of the most action ready ward would be required for purchase of computing power to accomplish the simulations. A second third of the prize money would be required for establishment of the business through travel, legal fees, and business expenses. The final third of the awarded prize would be required for both reserve funds and promotional funds to enable both business viability and team members to retain an active role in the project without personal economic risk. In using the winnings, the team estimates that procurement of the additional capitol and completion of Stage 1 will take between one to one and a half years. A timeline of what the team would accomplish in a one year timeline is presented in Table 1.

Table 1. Timeline for Stage 1

Task	Month											
	1	2	3	4	5	6	7	8	9	10	11	12
Organize Business Materials	■											
Obtain Engine Geometry for Simulation	■											
Initiate Cluster	■	■										
Initiate and Develop Engine Simulations		■	■	■								
Process Simulations			■	■	■							
Initiate Capitol Generation					■	■	■	■	■	■	■	■
Enter Stage 2												■
Initiate Corporation												■

To procure the funding for the team to move from Stage 1 to Stage 2 the team must demonstrate that the CORE concept is not only a viable combustion strategy, but team must also market the concept to investors and financial backing sources. This will require two tasks. One task is the completion of multiple engine platform simulations that can be financed by winning the competition. These simulations will be used to market the idea to investors and financial backing sources. Secondly the team must us the marketing potential of the accurate simulations to demonstrate the big picture market breadth and investment return potential of the CORE concept. In the concept, background, and environmental implications sections of this document, similar analogies have been demonstrated. However, to present this material to investors with significant financial backing and persuade them to invest in a start up company of the CORE concept further work is required. The team will need to demonstrate advanced simulations analysis and research of the concepts specific market scope, sector penetration, economic, and environmental impacts that commercialization of the CORE concept in the areas of mobile and stationary IC engines would have both nationally and internationally.

The capitol that the team needs to generate from investors and grants may potentially come from a wide variety of sources. In specific there are grant sources that are both from government and non-government sources, and investment from private individuals, corporations, and venture capitol firms. To maximize the speed of generating capitol required to move the team from Stage 1 to Stage 2, the team plans on applying for funding from multiple sources. For instance the team plans to submit proposals to the United States Department of Agriculture for development of biofueling of the CORE concept. The team also plans to submit a proposal to the United States Department of Energy for development of the CORE concept with both bio and conventional fuels in stationary and mobile applications. In the private sector, there is potential to develop collaboration with established corporations within the engine industry. Potential ventures could help to aid in hardware, personnel, and speed of moving from Stage 1 to Stages 2 and finally, Stage 3. To obtain such a relationship, the team will market their idea and three-step process to industry both thorough existing industry contacts developed in their Ph.D. research as well as through corporate interest already expressed to Wisconsin Alumni Research Foundation (WARF) in the technology, and by meeting with contacts at professional meetings and conferences. Another source for funding is through venture capitol sources. Current advanced combustion corporations such as Transonic Combustion and Achates Power have demonstrated that venture capitol such as Sequoia Capital, Madrone Capital Partners, Rockport Capital Partners, Khosla Ventures and InterWest Partners [21] are willing to make significant investment in advanced combustion technologies that have market potential for both environmental and economic sustainability. Venture capitol firms also have backed long term solutions such as fuel cell and hydrogen technologies. Although such long-term goals are needed, near term solutions are just as important. The team will use the simulation and previous experimental results of their Ph.D. research to demonstrate the economic sustainability and savings that corporations and consumers would realize, as well as the positive environmental impact that commercialization of the CORE concept would have.

While other corporations like Transonic and Achates Power have initiated start up concepts of advanced combustion technologies, they are not the only combustion and vehicle propulsion technology research and consulting firms. Firms such as AVL, South West Research Institute (SWRI) and FEV have specialized in contracting services and facilities to the engine and vehicle propulsion industries for several decades. These companies have demonstrated that, although the dynamic environment of the combustion and vehicle propulsion research and development market is already populated, it is not saturated. The viability of start up companies like Achates Power and Transonic Combustion demonstrate that with proper financial backing and management, start up corporations focused at sustainability and economically reducing GHG emissions in transportation systems with combustion engines are viable and are generating positive results. However, unlike these two specific companies the CORE concept is unique. Unlike Transonic Combustion and Achates Power, the CORE concept uses inexpensive parts and requires no specialized development of unique components. This reduces overhead, development and most importantly and capitol investment required to bring the product to market. This reduced cost and complexity makes the CORE concept a lean and adaptable strategy that can dynamically respond to market preferences and fluctuations. Furthermore, the CORE concept has already demonstrated in preliminary research testing that it offers at least the fuel economy benefits claimed by companies like Transonic and Achates. The team believes that these advantages position its CORE concept as a successful investment for venture capitol and for successful market penetration.

Team Biography

Sage Kokjohn

Sage has a BSME from Iowa State University and an MSME from the University of Wisconsin – Madison. He is currently working on his PhD at the University of Wisconsin's Engine Research Center. Other than his work at the Engine Research Center, through cooperative education programs and internships, Sage has worked in engine development at Mercury Marine, Caterpillar, and Toyota. His current research focuses on the development and application of advanced simulation tools used to improve the understanding of the processes occurring during the spray and combustion events of internal combustion engines.

In this project Sage has worked in the team as both an initial researcher of the idea, and in formulation of this document and business concept. He has contributed to approximately 1/3 of the total technical development of the technology and this document.

Reed Hanson

Reed received a Bachelors of Science in Automotive Engineering Technology from Minnesota State University – Mankato in 2004. After completing the BS degree, he went on to work for Arctic-Cat Inc in Thief River Falls MN. There he performed EFI calibration and general prototype engine development on 4 stroke high performance snowmobiles. One of the projects he worked on was the 2007 Jaguar Z1 which was/is the lowest emitting snowmobile currently for sale to the general public. After completing this project, he decided to continue his education and further his interest in IC engines, combustion and emissions. To accomplish this, Reed completed a Master of Science in Mechanical Engineering from the University of Wisconsin – Madison in 2009. While working at the UW Engine Research Center, Reed pursed research on advanced combustion regimes in a heavy-duty compression ignition engine using conventional and renewable fuels. Reed plans to continue his passion for increasing engine efficiency and lowering emissions by pursuing a Ph.D. in Mechanical Engineering. During this degree, he plans on continuing to look at advanced combustion regimes using renewable and conventional fuels to further reduce engine emissions and decrease fossil fuel usage.

In this project Reed has worked in the team as both an initial researcher of the idea, and in formulation of this document and business concept. He has contributed to approximately 1/3 of the total technical development of the technology and this document.

Derek Splitter

Derek obtained a Bachelors of Science in Mechanical Engineering from the University of Wisconsin-Madison in 2006. He recently has completed his Masters of Science research in 2010 at the Engine Research Center, where he is continuing education by perusing a PhD. Derek has worked on engines not only at the engine research center but also through a cooperative education program at Mercury Marine and internships at both Polaris industries and Ford Motor Company. Through these work experiences Derek has been involved with engine research and development on both low and high speed engines ranging from 25 hp to 400 hp in both spark ignited and diesel configurations. Derek's specific area of expertise is in the areas of engine calibration and emissions compliance, where he has performed both dynamometer and vehicle engine calibration in industry. At the Engine Research Center Derek has complimented his industry experience with research of advanced compression ignition combustion strategies. Derek has three consecutive years of experience in the engine research center and approximately two yeas of industrial work experience through student internships and cooperative education programs.

While in an undergraduate student at the University of Wisconsin Madison, Derek was a member of the Society of Automotive Engineers mini Baja team. On the team he was responsible for testing, fabrication and development of chassis and powertrain components. Derek also has several years of personal experience in vehicle fabrication while perusing personal automotive restoration and fabrication, where he has restored classic and antique automobiles. Derek plans on using his industrial, educational, and personal experiences to further develop sustainable economic and dependable advanced combustion strategies by reducing the transportation industries dependence on petroleum, while simultaneously reducing both regulated and non-regulated emissions. In this project Derek has worked in the team as both an initial researcher of the idea, and in formulation of this document and business concept. He has contributed to approximately 1/3 of the total technical development of the technology and this document.

Professor Rolf Reitz

Professor Reitz's research interests include internal combustion engines and sprays. He is currently developing advanced computer models for fuel injected engines, including diesel and spark-ignited engines. Reitz also performs engine experiments using two fully instrumented single-cylinder research diesel engines equipped with programmable high-pressure electronic fuel injection systems. The experimental results are used to study the effect of fuel injection characteristics (including variable rate and multiple injections) on diesel engine soot and NOx emissions, as well as to provide validation data for the computer models. Reitz also conducts spray experiments in a high-pressure spray facility to study the mechanisms of spray breakup. His current interests are in air-assist atomization (which is used in modern direct-injected two-stroke engines) and other applications, such as paint spraying, and dispersing industrial and household products. Before joining the university in 1989, Reitz spent six years at the General Motors Research Laboratories, three years as a research staff member at Princeton University, and two years as a research scientist at the Courant Institute of Mathematical Sciences, New York University. He is a consultant to many industries and is a member of the Combustion Institute and the Society of Automotive Engineers. He has served on the executive board of the Institute of Liquid Atomization and Spraying Systems--North and South America

Budget

Stage 1

For the CORE concept to become a viable business, various phases of funding will be required. Assuming the Project is successful in winning the CLC competition, the resulting two-part award is itemized in Tables 2 and 3. This round of funding is designed to complete stage 1 of the overall timeline.

Table 2. Stage 1, Phase 1 Funding

Budget Category	Description	$ Value
Consultant Services/Salary	Development of CORE strategy	6,350
Office Supplies	Misc. supplies/Overhead	1,000
	Laptops and software	6,000
	Printer	500
	Website	1,500
	LLC Formation	150
Computational Resources	Computer cluster for development of CORE strategy	8,000
	Computer Cluster IT	1,500
TOTAL STAGE 1, PHASE 1 CLC AWARD		$25,000

As seen in Table 2, the first of round of funding is expected to be $25,000. Some of the funding in Phase 1 will be reserved to assist enabling team members to focus more proactively on the business by reducing personal debts, but a majority of the winnings being used on computational resources. The initial investment in phase 1 will enable the team to generate the simulation results and to cover initial costs associated with initiating the business in Stage 1. The computer simulation results will be performed to assess the requirements of different operating conditions and applications to demonstrate that CORE concept is viable for as wide of range of applications as possible. As noted in Table 2 there is insufficient funding from $25,000 to progress through Stage 1 of the three-step business plan.

To progress through Stage 1 the additional $25,000 prize will need to be issued to cover travel promotion and marketing expenses. To maintain professional business practices, the corporation will need adequate facilities to convince interested parties to use our product. The facilities provided to the winning competition will be sufficient for stage 1 of the development process, As seen in Table 3, the additional $25,000 will primarily be used to fund promotional travel to various industry, venture capitol conferences and firms, as well as and OEM and after market manufactures. At these conferences and meetings, the data and developed business plan will be presented to the appropriate audience to back further development of the CORE concept. After securing sufficient contracts/capitol, the team will use a portion of the additional need funding to cover negotiations, and resulting legal expenses, as noted in Table 3. Once capitol has been raised and business deals have been closed, Stage 2 can begin.

Table 3 Stage 1, Phase 2 Funding

Budget Category	Description	$ Value
Consultant Services/Salary	Development of CORE strategy	6,250
Office Supplies	Furniture	750
	Whiteboard and presentation supplies	250
	Video/teleconferencing capabilities	250
	Video projector	1,000
	Misc. professional and office supplies	500
Computational Resources	Computer Cluster IT	1,000
Promotion/Advertising	Presentation of CORE strategy to venture capitol and industry to secure funding	6,000
	Presentation of CORE strategy at technical conferences	4,000
Legal and accounting	Fees associated with securing and retaining CORE intellectual property	4,000
	Accounting fees	1,000
TOTAL STAGE 1, PHASE 2 CLC AWARD		$25,000

Stage 2

After successful completion of Stage 1, the team can progress to Stage 2. As stated before, Stage 2 will require capitol investment to begin the commercial development of the technology. This stage will transition from computational simulations to engine testing in a new laboratory. A majority of the capitol will be required to purchase, maintain, and operate the laboratory hardware and hire staff required for successful development. To lower the projected cost of this transition, initiating testing will use a small compression ignition generator engine. None the less, the laboratory will require the related emissions, fuel, air, and data acquisition systems to be installed. The estimated cost of these systems can be seen in Table 3. The engine related expenses will comprise about 1 million dollars. The rest of Stage 2 funding will be utilized to promote the business and hire additional personnel to bring additional expertise that the authors do not possess.

Table 4 Stage 2 Funding

Budget Category	Description	$ Value
Test Engine	Yanmar single cylinder or Kubota multi-cylinder diesel engines	10,000
Emissions Equipment	5 gas exhaust analyzer and AVL smoke meter	400,000
Test Dynamometer	AVL eddy current transient	200,000
Data Acquisition System	National Instruments	50,000
Fuel Metering and Injection	Fuel flow meter, injectors, pumps, tubing, filters, plumbing, etc.	50,000
Building	Lease, permits, etc.	200,000
Laboratory Equipment	Heat Exchangers, Engine Isolation, Cooling/Heating Water, Air Handling, Exhaust Handling, Office materials	100,000
Promotion/Advertising	Presentation of CORE strategy to venture capitol and industry to secure funding	25,000
	Advertising CORE strategy at conferences	100,000
Personnel	Three (3) technical staff members	270,000
	One (1) business/marketing staff member	90,000
	One (1) office staff member	40,000
Legal and accounting	Fees associated with securing and retaining CORE intellectual property	20,000
	Accounting fees	5,000
Tools	Hand tools, Specialty tools, Tool storage	100,000
Misc.		200,000
Estimated Stage 2 Total		$1,860,000
Safety Factor		1.8
Final Stage 2 Estimate		$3,348,000

Stage 3

After successful completion of Stage 2, the team can progress to Stage 3. As stated before, Stage 3 will entail use capitol investments to further the commercial development of the technology. This stage will require the transition from stationary engine testing to vehicle testing in a laboratory and eventually on the road. The projected rough cost of this transition to vehicle testing is projected to use 1-5 prototype vehicles fitted with new electronic controls to utilize the control algorithms discovered in the stationary dynamometer tests. The new laboratory will require similar emissions, fuel, air and data acquisition systems as the dynamometer to also be installed as what was used in the preliminary testing at the ERC as well as a new vehicle chassis dynamometer. The estimated cost of these systems can be seen in Table 4. Most of the expenses from Stage 3 involve setting up the vehicle dynamometer and certification testing of the final vehicle. The other major expenses include simulation software, additional travel and legal expenses, and hiring of additional personnel to assist with the new stage of testing.

Table 5. Stage 3 Funding

Budget Category	Description	$ Value
EPA certification	Certification of CORE engines/vehicles for use on-highway (Available at Minnesota State University - Mankato)	250,000
Vehicle	Five (5) test vehicles for demonstration of CORE strategy	200,000
Chassis Dynamometer	In-vehicle testing of core strategy (Mustang eddy current type)	100,000
Manufacturing fees	Casting and machining of prototype parts for demonstration of CORE strategy	500,000
Promotion/Advertising	Presentation of CORE strategy to venture capitol and industry to secure/retain funding	50,000
	Advertising CORE strategy at conferences	200,000
Legal and accounting	Fees associated with securing and retaining CORE intellectual property	100,000
	Accounting fees	15,000
Personnel	Six (6) technical staff members	540,000
	Three (3) business staff members	270,000
	One (1) office staff member	40,000
Software	Licensing of software for manufacturing and technical development (SolidWorks, GT-Power, National Instruments, KIVA)	500,000
Tools	Hand tools, Specialty tools, Tool storage	100,000
Miscellaneous		200,000
Initial Estimate		$3,065,000
Safety Factor		1.4
Final Estimate		$4,291,000

Required Capitol Total for Stages 2 and 3	$7,639,000

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Appendix

CORE Team Portfolio

An article from the monthly publication by the American Society of Mechanical Engineers (ASME), *Mechanical Engineering* magazine, that briefly describes the fuel economy benefits of the CORE concept developed by the team.

TECH FOCUS

Power Transmission & Motion Control

This section was edited by Associate Editor Alan S. Brown.

+ Blending Fuels to Boost Efficiency

RESEARCHERS AT THE UNIVERSITY OF WISCONSIN-MADISON SAY THAT BLENDING DIESEL FUEL WITH GASOLINE CAN IMPROVE DIESEL ENGINE FUEL EFFICIENCY by an average of 20 percent while meeting U.S. government emissions mandates without costly pollution control equipment.

While fast-response fuel blending technology would require modification of diesel engines and separate fuel tanks for diesel and gasoline, it would use fuels readily available at the pump today. Rolf Reitz, a mechanical engineer who led the research, said the technology can also be applied to gasoline engines.

▲ Rolf Reitz (with tie) and his research team believe diesel-gasoline mixtures could slash vehicle fuel use by one-third.

UNIVERSITY OF WISCONSIN

If all internal combustion vehicles were converted to dual fuel engines as efficient as his most efficient prototype—53 percent—Reitz estimates that the United States would save one-third of all petroleum used for transportation, or roughly 4 million barrels per day.

Industry is apparently listening. The Department of Energy and University of Wisconsin's Diesel Emissions Reduction Consortium, which includes 24 industry partners, are funding Reitz's research.

Fast-response fuel blending calls for mixing the two fuels inside the engine's combustion chamber. Ordinarily, gasoline does not burn in a diesel engine because it is less reactive than diesel fuel. When Reitz sprays the two fuels into the combustion chamber together, however, the diesel ignites the gasoline.

The blending technology matches the diesel-gasoline ratio to operating conditions. Under heavy loads, such as accelerating or climbing a hill, the fuel mix might go as high as 85 percent gasoline. Under lighter cruising loads, the percentage of gasoline would fall to 50 percent.

According to Reitz, the mix enables diesel engines to operate up to 40 percent cooler, which reduces energy loss through thermal transfer. Better yet, controlling the diesel-gasoline ratio not only improves burn efficiency but also reduces emissions. In fact, it enables trucks to meet particulate and nitrogen oxide emission levels mandated by the Environmental Protection Agency without buying expensive catalytic reduction or exhaust gas recirculation equipment.

Reitz used computer models to develop the blending strategy. This enabled him to run thousands of simulations and optimize his power strategies before testing the technology on a Caterpillar heavy-duty diesel engine. The tests confirmed the model's predictions.

The best tests achieved 53 percent thermal efficiency, 20 percent higher than conventional diesel engines. In fact, it was higher than today's gold standard for commercial engines, the turbocharged two-stroke diesels used in maritime shipping.

"Even more striking, the blending strategy could also be applied to automotive gasoline engines, which usually average a much lower 25 percent thermal efficiency," Reitz said. "Here, the potential for fuel economy improvement would even be larger than in diesel truck engines."

18 mechanical engineering | November 2009

An article from the *Milwaukee Journal Sentinel,* describing the benefits of the CORE concept developed by the team, with input from Navistar International corp. (maker of the International brand of heavy duty trucks).

JSOnline
MILWAUKEE • WISCONSIN
JOURNAL SENTINEL

Fuel blending could boost performance, cut pollution

By Lee Bergquist of the Journal Sentinel

Posted: Aug. 17, 2009

In the future, cars and trucks could run on a special cocktail of gasoline and diesel fuel, boosting fuel efficiency and cutting pollution.

A University of Wisconsin-Madison researcher has developed technology that takes advantage of the best attributes of both fuels to help engines run more efficiently.

Engines would be able to change on the fly by burning different blends of regular and diesel fuel as they adjust to changing conditions on the road.

The result has been an average improvement of 20% in fuel efficiency, the research found.

The special fuel blends also meet new diesel emissions standards in 2010 that require major reductions at the tailpipe - a 90% cut in particle pollution, or soot, and an 80% cut in nitrogen oxides from 2007 levels.

The research, which was funded by the U.S. Department of Energy and a consortium of engine makers, was led by Rolf Reitz, a professor of mechanical engineering at UW-Madison.

Initially, the aim was to help manufacturers of diesel engines, which have struggled to meet the new emission standards and are tacking on thousands of dollars to the price of heavy-duty trucks to meet the new limits.

Reitz said his combustion cocktail, known as "fast-response fuel blending," could also be applied to conventional gasoline-fired cars.

In both cases, vehicles would require installing two fuel tanks and making changes in fuel injection systems. The costs would be much less than the changes manufactures are making today, he said.

Eventually, Reitz thinks blended fuel technology could be melded with hybrid technology to produce even more fuel efficiency and bigger cuts in emissions.

Reitz and his team at UW aren't alone. Others also are experimenting with gasoline-diesel blends in the hope of taking advantage of the special qualities in both fuels, said Ning Lei, director of advanced combustion at Navistar International Corp., based in Warrenville, Ill.

For example, under Reitz' fuel strategy, in heavy loading conditions, a diesel truck might burn 85% gasoline and 15% diesel. Under lighter loads, the percentage of diesel would increase to a 50-50 mix.

Lei thinks the UW research has produced the best results so far.

"The challenge," she said, "is how the research will hold in the real world when there are different engine conditions.

"But it does look promising," she said.

Reitz and a team of graduate students used advanced computer simulation models to study how the two fuels burn when mixed together. Then, they experimented with the mixtures on a heavy-duty Caterpillar diesel engine housed at UW's Engine Research Center.

Reitz is applying for a patent for the technology through the Wisconsin Alumni Research Foundation.

Despite the promise, it could take five years for blended fuels to move into production, Reitz and Lei said.

Reitz presented the findings this month in Detroit at the Energy Department's Diesel Engine-Efficiency and Emissions Research Conference.

Popular Science Online **article describing the benefits of the CORE concept developed by the team, taken from University of Wisconsin press release Aug. 3 2009 "Gasoline-diesel cocktail: a potent recipe for cleaner, more efficient engines", by Brian Mattmiller .**

POPSCI THE FUTURE NOW

A Cocktail of Diesel and Gasoline Runs 20 Percent More Efficiently Than Either One Alone

By Adrian Covert Posted 08.04.2009 at 5:24 pm

Diesel and Gasoline: United At Last *blmurch/Flickr*

A team of gearheads at the University of Wisconsin-Madison have developed an engine that can handle a blend of gasoline and diesel fuel. It outputs low emissions, and offers up to 20 percent greater fuel efficiency.

The fuel injection system, called "Fast Response Fuel Blending," mixes the fuels in the combustion chamber to precise proportions. Because the control is so precise, the engine runs at a lower temperature, which means less heat-related energy loss. Also, because the fuel mix is carefully optimized, there's less wasted fuel in the combustion process.

The proportions adjust on the fly according to real-time situations a vehicle faces. Depending on how much weight a truck is carrying and work an engine is putting in, you might see the gasoline-to-diesel ratio vary from 85:15 to 50:50--it really just depends.

Traditionally, the two fuels won't combust when mixed in a diesel engine -- "any attempt to use such a mixture as a motor fuel would be disastrous," says one source -- but the research team says that by controlling the amount and timing of the diesel spray, they can successfully cause combustion.

Team leader Rolf Reitz presented his study at a Department of Energy conference yesterday, and says that they're regularly meeting the EPA 2010 fuel efficiency standards with this blend. He also thinks it could reduce auto-related oil consumption by 33 percent.

[via Science Daily]

RELATED ARTICLES


Diesel on a Diet


Is Petroleum the Greenest Fuel We Have?

Media coverage by the University of Wisconsin Department of Mechanical Engineering, in their alumni publication, *Alumni Perspective*, describing the benefits of the CORE concept and the team.

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PERSPECTIVE

FALL 2009 / Vol. 36, No. 1

IN THIS ISSUE

Spotlight on 2009 CAREER award recipients

The National Science Foundation is supporting early-career engineering research in such areas as cell fusion, data processing in digital communication, and breast cancer screening and diagnosis methods. Earning prestigious CAREER awards in 2009 are Industrial & Systems Engineering Professor **Oguzhan Alagoz**, Electrical & Computer Engineering Assistant Professor **Stark Draper**, Biomedical Engineering Assistant Professor **Brenda Ogle**, and Mechanical Engineering Assistant Professors **Dan Negrut** and **Kevin Turner**. *(Continued on page 2)*

Alagoz *Draper* *Ogle* *Negrut* *Turner*

Gasoline-diesel 'cocktail' A potent recipe for cleaner, more efficient engines

Diesel and gasoline fuel sources both bring unique assets and liabilities to powering internal combustion engines. But what if an engine could be programmed to harvest the best properties of both fuel sources at once, on the fly, by blending the fuels within the combustion chamber?

The answer, based on tests by the engine research group headed by Wisconsin Distinguished Professor of Mechanical Engineering Rolf Reitz, would be a diesel engine that produces significantly lower pollutant emissions than conventional engines, with an average of 20 percent greater fuel efficiency as well. These dramatic results came from a novel technique Reitz describes as "fast-response fuel blending," in which an engine's fuel injection is programmed to produce the optimal gasoline-diesel mix based on real-time operating conditions. Under heavy-load operating conditions for a diesel truck, the fuel mix in Reitz' fueling strategy might be as high as 85 percent gasoline to 15 percent diesel; under lighter loads, the percentage of diesel would increase to a roughly 50-50 mix. Normally this type of blend wouldn't ignite in a diesel engine, because gasoline is less reactive than diesel and burns less easily. But in Reitz' strategy, just the right amount of diesel fuel injections provide the kick-start for ignition.

From left: Reed Hanson, Rolf Reitz, Derek Splitter and Sage Kokjohn

"You can think of the diesel spray as a collection of liquid spark plugs, essentially, that ignite the gasoline," says Reitz. "The new strategy changes the fuel properties by blending the two fuels within the combustion chamber to precisely control the combustion process, based on when and how much diesel fuel is injected."

Reitz presented his findings on August 3 at the U.S. Department of Energy (DOE) Diesel Engine-Efficiency and Emissions Research Conference in Detroit, Michigan. Reitz estimates that if all cars and trucks were to achieve the efficiency levels demonstrated in the project, it could lead to a reduction in transportation-based U.S. oil consumption by one-third.

"That's roughly the amount that we import from the Persian Gulf," says Reitz.

Two remarkable things happen in the gasoline-diesel mix, Reitz says. First, the engine operates at much lower combustion temperatures because of the improved control—as much as 40 percent lower than conventional engines—which leads to far less energy loss from the engine through heat transfer. Second, the customized fuel preparation controls the chemistry for optimal combustion. That translates into less unburned fuel energy lost in the exhaust, and also fewer pollutant emissions being produced by the combustion process. In addition, the system can use relatively inexpensive low-pressure fuel injection (commonly used in gasoline engines), instead of the high-pressure injection required by conventional diesel engines.

Development of the blending strategy was guided by advanced computer simulation models. These computer predictions were then put to the test using a Caterpillar heavy-duty diesel engine at the UW-Madison Engine Research Center. The results were "really exciting," says Reitz, confirming the predicted benefits of blended fuel combustion. The best results achieved 53-percent thermal efficiency in the experimental test engine. This efficiency exceeds even the most efficient diesel engine currently in the world—a massive turbo-charged two-stroke used in the maritime shipping industry, which has 50 percent thermal efficiency.

"For a small engine to even approach these massive engine efficiencies is remarkable," Reitz says. "Even more striking, the blending strategy could also be applied to automotive gasoline engines, which usually average a much lower 25-percent thermal efficiency. Here, the potential for fuel economy improvement would even be larger than in diesel truck engines."

Thermal efficiency is defined by the percentage of fuel that is actually devoted to powering the engine, rather than being lost in heat transfer, exhaust or other variables.

"What's more important than fuel efficiency, especially for the trucking industry, is that we are meeting the EPA's 2010 emissions regulations quite easily," Reitz says.

That is a major commercial concern as the bar set by the U.S. Environmental Protection Agency is quite high, with regulations designed to cut about 90 percent of all particulate matter (soot) and 80 percent of all nitrogen oxides (NOx) out of diesel emissions.

Some companies have pulled from the truck engine market altogether in the face of the stringent new standards. Many other companies are looking to alternatives such as selective catalytic reduction, in which the chemical urea (a second "fuel") is injected into the exhaust stream to reduce NOx emissions. Others propose using large amounts of recirculated exhaust gas to lower the combustion temperature to reduce NOx. In this case, ultra-high high-pressure fuel injection is needed to reduce soot formation in the combustion chamber.

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Gasoline-diesel 'cocktail'

(Continued from front page)

Those processes are expensive and logistically complicated, Reitz says. Both primarily address cleaning up emissions, not fuel efficiency. The new in-cylinder fuel blending strategy is less expensive and less complex, uses widely available fuels, and addresses both emissions and fuel efficiency at the same time.

Reitz says there is ample reason to believe the fuel-blending technology would work just as well in cars because dual-fuel combustion works with lower-pressure and less expensive fuel injectors than those used in diesel trucks. Applying this technology to vehicles would require separate tanks for both diesel and gasoline fuel—but so would urea, which is carried in a separate tank.

The big-picture implications for reduced oil consumption are even more compelling, Reitz says. The United States consumes about 21 million barrels of oil per day, about 65 percent (13.5 million barrels) of which is used in transportation. If this new blended fuel process could convert both diesel and gasoline engines to 53 percent thermal efficiency from current levels, the nation could reduce oil consumption by 4 million barrels per day, or one-third of all oil destined for transportation.

Computer modeling and simulation provided the blueprint for optimizing fuel blending, a process that would have taken years through trial-and-error testing. Reitz used a modeling technique developed in his lab called genetic algorithms, which borrow some of the same techniques of natural selection in the biological world to determine the "fittest" variables for engine performance.

The work is funded by DOE and the College of Engineering Diesel Emissions Reduction Consortium, which includes 24 industry partners.