Essential Power Systems

R&D Multi-Year Program Plan

December 2002

Less dependence
on foreign oil,
and eventual
transition to an
emissions-free,
petroleum-free
vehicle

freedomCAR & vehicle technologies program

U.S. Department of Energy
Energy Efficiency and Renewable Energy
Bringing you a prosperous future where energy is clean, abundant, reliable and affordable

ESSENTIAL POWER SYSTEMS
R&D MULTI-YEAR PROGRAM PLAN

Sponsored by
U. S. Department of Energy
Energy Efficiency and Renewable Energy
Office of the FreedomCAR and Vehicle Technologies

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EXECUTIVE SUMMARY

This plan outlines a research program that is directed toward saving energy and reducing dependence on petroleum by increasing the efficiency of essential power systems in heavy-duty trucks. Essential power systems include all functions on the vehicle that are not involved in moving it but require electrical or mechanical energy. Specific objectives are to develop technologies that are cost-effective in terms of initial and operating costs, reliable, and durable, and that will provide the following benefits:

- Reduce the parasitic energy losses in essential power systems, while the truck is moving, by 50 percent through the development of ways to replace gear-driven or belt-driven accessories with electric accessories. This will reduce fuel consumption by 480 million gallons per year.

- Reduce consumption of diesel fuel while idling by 80 percent through development of ways to improve or replace current idle-reduction technologies. At the current level of 840 million gallons per year, this will reduce consumption by 670 million gallons per year.

Thus, the program has the potential to save more than 1 billion gallons of diesel fuel per year.

This plan is based upon information obtained from interviews with truck manufacturers and their suppliers; a workshop that was held in Washington, DC in December 2001; recent studies of auxiliary power units (APUs) and truck electrification at Oak Ridge National Laboratory and the National Renewable Energy Laboratory; and other relevant Department of Energy (DOE) reports and publications.

Recent calculations have shown that considerable energy could be saved if accessories like pumps, fans, and compressors were powered by electric motors rather than being gear- or belt-driven, as they currently are. By disconnecting those accessories from the drive shaft, they could be operated at optimum speeds rather than speeds proportional to the engine speed. Electrification of such components would have additional benefits as well. They could be made smaller, and they could be located remotely from the drive shaft. The resulting flexibility in design could be used to streamline the vehicle, thereby achieving additional increases in fuel efficiency through reductions in aerodynamic drag. In addition, the size of the main engine could be reduced as could the thermal load. All of those changes would have compounding beneficial effects on fuel savings and emissions reduction.

Research on truck electrification is recommended in the following areas:

- System development. A systems approach will be necessary to fully appreciate the benefits and costs of truck electrification. Research should be conducted to develop techniques for
  - Load management
  - Control strategies

  - Diagnostics
  - Sensors
  - Electrical/mechanical interfaces

- Modeling. To compare the benefits of electrical versus mechanical components, modeling should be done for various duty cycles with the entire system in mind. Negative impacts on energy and weight from adding electric motors need to be balanced against the positive gains from eliminating the belt and gear drives.

- Component development. Research should emphasize integration, weight reduction, reliability, durability, and serviceability of the various components. Important issues include the following:
  - Size, cost, efficiency, torque, temperature range, and function of electric motors
  - Power conversions from AC to DC and between different voltage levels
  - Power electronics
  - High current/voltage packaging

- Development of a demonstration vehicle. This needs to be done to facilitate technology transfer and assist in standardization

The use of diesel-powered APUs appears to be the most viable near-term solution to truck idling. Currently those devices can be added to trucks in the aftermarket, but having them installed by the OEMs at the time of manufacture probably would provide increased durability and reliability, lower weight, and lower cost. Currently, APUs are used on only a small percentage of the trucks in the U.S. because of concerns about reliability, noise, and cost effectiveness. In order to alleviate those concerns and promote the use of APUs to decrease fuel consumption due to idling, research is recommended in the following areas:

- Technology assessment
- Hardware development
  - Use of light-weight materials
  - System integration
  - Noise reduction

Ultimately, perhaps in 10 to 15 years, diesel-powered APUs probably will be replaced with fuel-cell APUs and/or truckstop electrification. Both solid-oxide fuel cells (SOFCs) and proton-exchange membrane (PEM) fuel cells are being considered, but SOFCs appear to be more appropriate for truck APUs. PEMs are much less tolerant of sulfur and carbon monoxide, and the process of reforming diesel fuels for PEMs is much more complicated because of their low operating temperature. Substantial technical barriers exist to the use of fuel cells on a truck, but those barriers are being addressed in other DOE research programs. Coordination with those programs will be an important function of the Essential Power System (EPS) program.

Barriers to truckstop electrification are primarily economic rather than technical. It is difficult for truckstop operators to justify the cost of installing equipment for electrification when very few trucks are equipped to use it, and it is difficult for a trucker to justify the cost of modifying the truck for electrification when very few truckstops offer the service. Moreover, the total number of parking spaces at truck stops is far less than the number needed for all of the trucks in service. Nevertheless, a growing number of new trucks are being equipped for electrification, and some truckstops are beginning to install the necessary equipment. The trend probably will continue until truckstop electrification becomes a significant factor in reducing idling. Establishing standards for electrical hook-ups will be important for accelerating the transition. Therefore, research is recommended to determine present and future requirements for

- Voltage
- Current
- Connectors

It also will be important for the EPS program to coordinate with other synergistic areas of DOE research such as batteries, thermoelectrics, power electronics, heavy-hybrids, and parasitic energy losses.

In the near term, power for electrified components probably will be provided by a combination of an integrated generator and a turbo generator. In the longer term, fuel-cell APUs and thermoelectric devices also may become practical.

A $20 million program through FY08 is recommended to provide the technological base for modifying the essential power system to save over 1 billion gallons of diesel fuel per year, with the concomitant reduction of emissions.

INTRODUCTION

Essential Power Systems (EPS) include all functions on the vehicle that are not currently involved in moving it but require electrical or mechanical energy. They include such things as lights, hotel loads (HVAC, computers, appliances, lighting, and entertainment systems), pumps, starter, compressors, fans, trailer refrigeration, engine and fuel heating, operation of power lifts, and operation of pumps for bulk fluid transfer. The recently initiated EPS program at DOE addresses the efficient and practical management of electrical and thermal requirements on trucks.

The amount of energy that is consumed by the essential power systems obviously depends upon many things including the duty cycle, the truck design, the climatic conditions, the terrain, driving habits, and many other factors. A typical energy audit for a fully loaded Class 8 truck moving at 65 mph on a level road is shown in Figure 1, which indicates that the auxiliary loads consume about 4 percent of the total energy.[1] That amounts to 960 million gallons of diesel fuel per year, based upon the annual diesel fuel consumption of 24.1 billion gallons[2] for heavy-duty trucks.

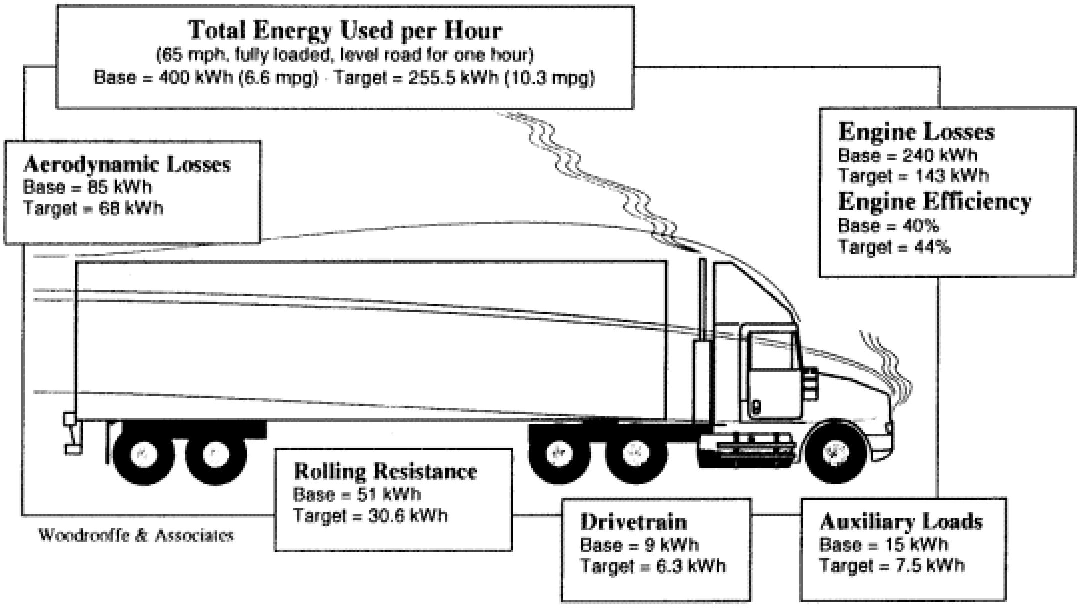


FIGURE 1 Energy Audit for Typical Line-Haul Truck

Essential power systems also consume a significant amount of energy when the truck is not moving. Stodolsky et. al.[3] found that long-haul trucks idling overnight consume more than 838 million gallons of fuel annually, and all of that is for essential power systems. Thus, the total annual fuel consumption for essential power systems in heavy-duty trucks is about 1.8 billion gallons. That provides an opportunity to save a substantial amount of energy by reducing parasitic energy losses in moving vehicles and by reducing the amount of idling of stationary vehicles. Based upon on-going research, it appears reasonable to expect an 8 to 13 percent energy savings from electrifying a heavy-duty truck and an additional 5 to 6 percent with a turbocompounder. However, the technological advances that will be needed to achieve those energy savings will require additional research and development (R&D).

This document outlines a systematic, focused national strategy for an industry/ government partnership to contribute substantially to the national goals of improved fuel economy and reduction of undesirable emissions. It identifies various technologies that might be employed to save energy, describes those technologies and their state of development, lists the advantages and disadvantages of each, identifies the technological barriers to the use of each technology, and suggests R&D efforts that will be needed to overcome those barriers.

This plan is based upon information obtained from a series of interviews with truck manufacturers and their suppliers and from a workshop that was held in Washington, DC on December 12-13, 2001, in which 51 people from industry plus 36 others from the national laboratories, government agencies, and consulting companies participated. The plan also includes material from recent studies at Oak Ridge National Laboratory (ORNL) on diesel-powdered auxiliary power units (APUs) and at the National Renewable Energy Laboratory (NREL) on truck electrification, as well as other relevant DOE reports.

BACKGROUND

Increasing the fuel efficiency of vehicles in the U.S. is important for several reasons. It is essential from the perspectives of economic stability and national security that we reduce our dependence on petroleum and especially on foreign sources of petroleum. In addition, any reduction in the amount of fuel used will have a proportionate reduction in emissions. Additional emphasis currently is being placed on fuel efficiency because most of the technologies that are being considered for reducing emissions also cause an increase in fuel usage.

It is especially important to concentrate on the fuel efficiency of trucks. In 2001, the transportation sector consumed 27 percent of the nation's energy and accounted for two-thirds of our petroleum consumption. More importantly, because over 95 percent of transportation energy is derived from petroleum, transportation contributes significantly to the nation's need for imported oil and thus to energy security concerns. Figure 2 shows the historical use of oil by the transportation sector and its projected use to 2020. While many improvements have been made in vehicle/engine fuel efficiency, transportation fuel consumption continues to increase due to the rise in the number of drivers and miles traveled, as well as the demand for larger vehicles. Our increasing transportation requirements have helped create a daily net imported oil demand of 10 million barrels, or 52 percent of the country's petroleum consumption — about equal to the petroleum consumed for highway transportation alone. The Department's Energy Information Administration (EIA) is projecting 1.9 percent annual growth in transportation energy use through 2020 while domestic oil production remains relatively unchanged. This difference creates a growing gap between oil use for transportation and available domestic supplies. As noted in Figure 2, the projected gap between domestic production and transportation oil use is dominated by increasing oil use for heavy vehicles and light trucks.

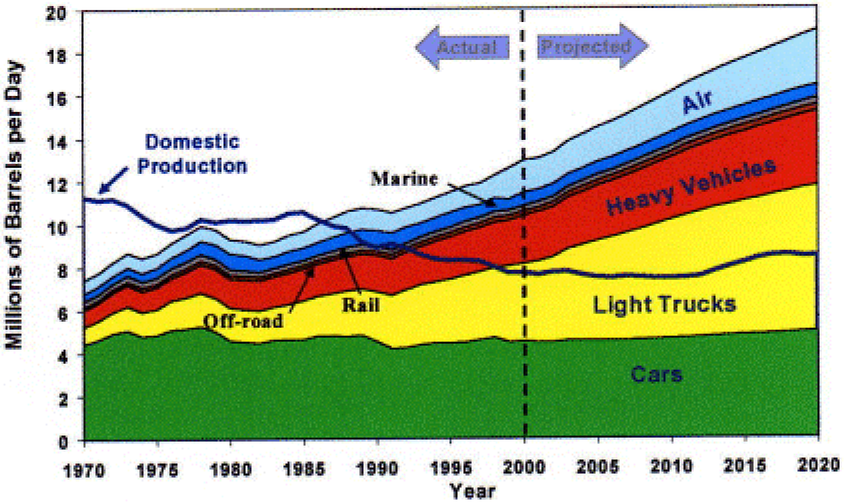


FIGURE 2 Transportation Oil Gap

Reducing energy consumption of essential power systems is of vital interest to the FreedomCAR and Vehicle Technologies (FCVT) Program at DOE. The FCVT program partners with industry, research entities, state governments, and other federal agencies to support the development and use of advanced vehicle technologies and fuels that could reduce, and eventually eliminate, the demand for petroleum, decrease emissions of criteria air pollutants and greenhouse gases, and enable the U.S. transportation industry to sustain a strong, competitive position in domestic and world markets. The FCVT program is focused on technologies to reduce oil use by cars, light trucks, and heavy vehicles. Heavy vehicles are comprised of heavy trucks, medium trucks, buses, and inland marine. Off-highway vehicles (such as vehicles used in construction, mining, and agriculture) and locomotives are additional targets for oil reductions because they use engines that are similar to those in heavy vehicles.

GOALS AND OBJECTIVES

The overall program goal is to save energy and reduce dependence on both domestic and foreign sources of petroleum by increasing the fuel efficiency of essential power systems and related vehicle systems in heavy-duty trucks and by integrating those systems in the trucks. Reducing the fuel usage should cause a proportionate reduction in emissions. It must be accomplished without reducing the reliability, durability, and safety of the vehicles, and it must be cost-effective.

Specific objectives are to develop technologies that are cost-effective in terms of initial and operating costs, are reliable, are durable, and will provide the following benefits:

- Reduce the parasitic energy losses in essential power systems, while the truck is moving, by 50 percent through the development of ways to replace gear-driven or belt-driven accessories with electric accessories. This will reduce fuel consumption by 480 million gallons per year.

- Reduce consumption of diesel fuel while idling by 80 percent through development of ways to improve or replace current idle-reduction technologies. At the current level of 840 million gallons per year, this will reduce consumption by 670 million gallons per year.

Thus, the total savings from the EPS program will be greater than 1 billion gallons of diesel fuel per year.

TRUCK ELECTRIFICATION

Component Electrification

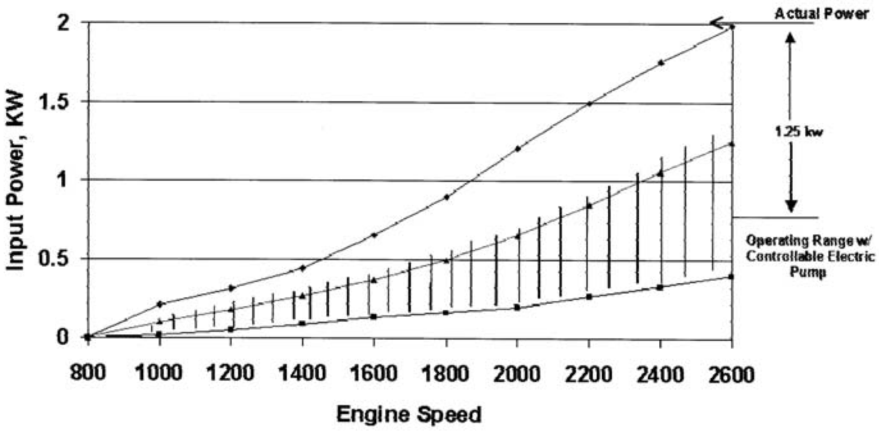
Current design concepts for trucks have the pumps, fans, and compressors driven with belts or gears connected to the drive shaft. Thus, the speed and power consumption of those accessories are roughly proportional to engine speed and independent of the actual requirements. For example, ram air produced when the truck is traveling at high speeds reduces the need for fans and water cooling. Power requirements for the oil pump are nearly independent of engine speed. Therefore, too much oil is pumped at high speeds and too little at low speeds. Typical power losses associated with this issue are show in Figure 3. If the pumps and fans were electric, their speeds could be adjusted independent of engine speed, and a significant amount of energy could be saved.[4,5]

To calculate the true energy savings due to vehicle electrification, it is necessary to consider all of the following factors:

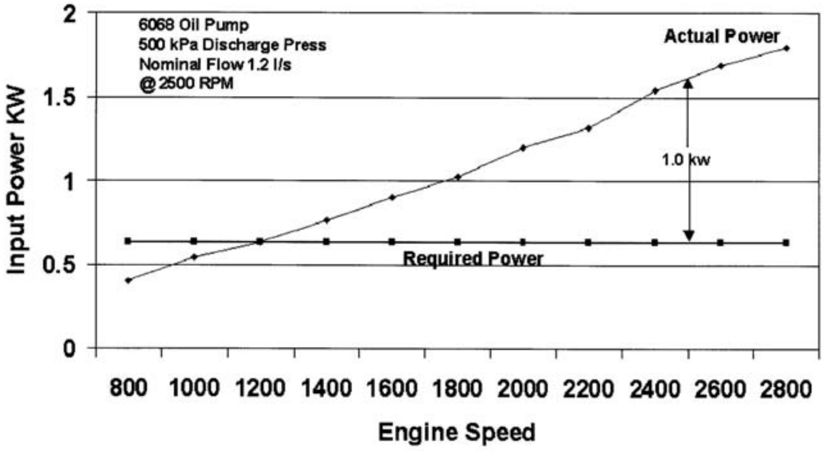
- Energy gains due to
  - Elimination of power consumption from unloaded mechanical accessories
  - (i.e., idling parasitics when accessories are not utilized)
  - Elimination of power consumption from loaded mechanical accessories
  - (i.e., energy associated with accessories being utilized)
  - Elimination of truck idling

- Energy losses due to
  - Decrease in average efficiency of the main diesel engine
  - Consumption of energy by loaded electrical accessories
  - Consumption of energy to accelerate and roll the extra mass
  - Consumption of energy for shore/EPS idle demand

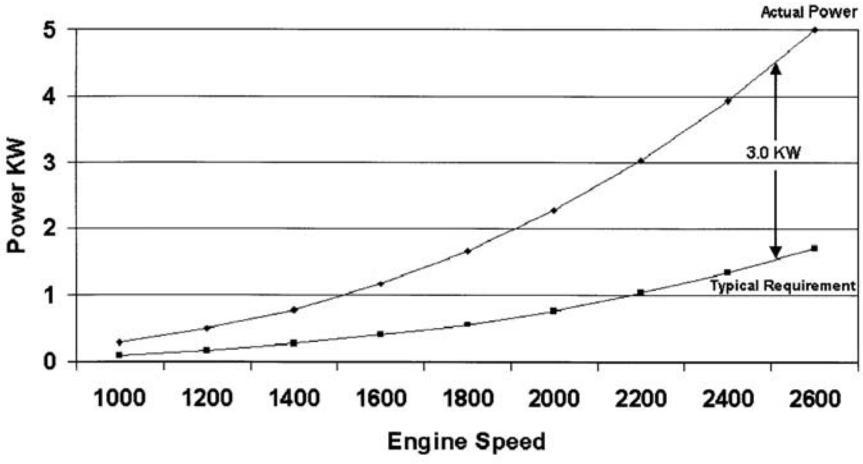
The energy savings depend upon many factors such as duty cycle, size of the main engine, and weight and efficiency of the APU. The ADVISOR program at NREL has been used to model a variety of diesel engines with different duty cycles and different APUs. An example of the output from the model is shown in Table 1 for a typical, sleeper-type, long-haul tractor-trailer, with the assumed accessory loads listed in Table 2.[6]



a. Water Pump



b. Oil Pump



c. Fan

FIGURE 3 Examples of Wasted Power When Using Main Engine to Run Accessories[4]

TABLE 1 Estimated Fuel Savings from Removal of Various Mechanical Loads from an Engine

Auxiliary Component	CSHVR	Constant 65 mph
Power-steering pump	3.2%	1.1%
Air-brake compressor	0.9%	0.7%
Engine fan	0.4%	0.4%
Air-conditioner compressor	1.2%	1.3%
Engine oil pump	1.1%	1.5%
Cumulative	7.7%	6.0%
Cumulative plus engine resize	11.5%	7.0%

TABLE 2 Example Accessory Loads for Heavy-Truck Applications[6]

Accessory Type	Max Load, kW	Avg Load, kW
Air Compressor	6	2.3
Electric Accessories	1.0	0.7
Air Conditioning Compressor	4.5	2.3
Engine Cooling Fan	22.0	1.1
Power Steering	7.5	0.8
Total	41	7.1

Table 1 shows estimated fuel economy savings by removal of various truck auxiliary loads in a Class 7/8 vehicle for two representative drive cycles. The City-Suburban Heavy-Vehicle Route (CSHVR) is a more city-like, stop-and-go drive cycle, while the Constant 65 mph cycle is representative of pure highway driving. The fuel-economy estimates were developed from heavy-vehicle auxiliary-load-electrification analyses performed by NREL using a heavy-vehicle version of ADVISOR. These estimates represent averages across several heavy-vehicle engine types. Various individual auxiliary component effects are shown (e.g., power steering pump, air brake compressor, and air conditioning compressor) along with a cumulative fuel-economy effect with and without engine resizing. The data clearly show that the largest fuel economy savings for Class 7/8 heavy-vehicle auxiliary electrification will occur in the CSHVR drive cycle, or similar city-like, stop-and-go cycles, especially upon engine resizing after the loads are removed. However, there also are significant fuel-economy savings to be captured in constant 65-mph highway driving. These data form the basis and motivation for the Essential Power Systems program. Although the potential fuel-economy savings for each individual component are relatively small, the cumulative effect of electrifying all the auxiliary components simultaneously is quite significant. Consequently, current heavy-vehicle analyses would support an all-out auxiliary-load-electrification program rather than a piece-meal approach.

In addition to fuel savings, which would be of economic benefit to the trucking industry and decrease the nation's dependence on oil, there are a number of other important potential benefits of truck electrification:

- Emissions would be reduced proportionate to the fuel savings.

- Cooling loads would be reduced due to improved efficiency.

- Much more design flexibility would result from smaller components and freedom to locate them away from the drive shaft. This could allow for better air flow under the hood and a more streamlined shape to the truck. These design options could have a compounding beneficial effect on fuel efficiency.

- All of the benefits of reduced idling will be available because a truck with electric accessories will be capable of using shore power.

A systems approach will be necessary to fully appreciate the benefits and costs of truck electrification. The system needs to be designed to take advantage of the flexibility that electrification offers. Negative impacts on energy and weight from adding electric motors need to be more than offset by the positive gains from eliminating the belt and gear drives. This will require the combined efforts of engine and truck OEMs plus component suppliers working together as a well-coordinated, multi-disciplinary team.

Research was recommended in three areas:

1. *System development and modeling.* This would involve developing techniques for load management, control strategies, diagnostics, sensors, and electric/mechanical interfaces. Modeling to compare the benefits of electrical versus mechanical components should be done for various duty cycles with the entire system design in mind.
2. *Component development.* This should include the various electric accessories with emphasis on integration, weight reduction, reliability, durability, and serviceability. Electric-motor issues include size, cost, efficiency, torque, temperature range, electromagnetic interference, and function. Other issues involve power conversion from AC to DC and between different voltage levels, power electronics, and high current/voltage packaging.
3. *Development of a demonstration vehicle.* This would be done to encourage technology transfer, demonstrate and validate real-world performance, and assist in standardization.

Generation of Electrical Power

Typical accessory loads for a truck driving during the day with cab and sleeper heaters operating were listed in Table 2.

Requirements for a generator to meet the needs are as follows:[5]

- Efficiency greater than 85 percent
- Power output from 10–75 kW
- High voltage (42 volts for light loads only)
- Multiple voltages
- Compact packaging
- High reliability and durability
- Fail safe with backup

At least four generator options can be considered:[5]

- Large flywheel-mounted motor/generator
- Turbo generation
- Fuel-cell-powdered APU
- Fuel-fired advanced thermoelectrics

Advantages of a flywheel-mounted motor/generator are that it is a known technology, 90 percent efficiency has been demonstrated, it has compact packaging and high power capacity, and it is a simple piece of hardware with excellent reliability potential. However, it requires unique application-specific hardware, and safety protocols are needed.

The advantages of turbo generation are that it also is existing technology with compact packaging, it provides up to 20 percent supplementary power using waste exhaust heat, it could be combined with a combustor for engine-off power and heat, and excess power can be used for propulsion. Disadvantages are that it requires complex controls, it produces significant output only at high engine loads, and it is not a stand-alone system. Previously a barrier to the use of a compound turbo alternator was the extra exhaust back pressure that it caused, but that will be less important in the future because the back pressure is often used to allow exhaust gas recirculation (EGR) for emission reduction.

The advantages of a fuel-cell-powered APU are that is has very high efficiency, it is quiet, and it can generate engine-off power. The major disadvantage is that a fuel-cell-powered APU is probably 8–10 years away from being commercially available. In addition, it requires a reformer to make hydrogen from diesel fuel, and it occupies a relatively large volume.

For the near term, it appears that integrated generators combined with turbo generators will be able to meet the electrical demands of electric auxiliaries. Until shore power becomes more widely available, one of the technologies mentioned earlier in the document (e.g., diesel-powered APU) also may be needed for reduction of idling.

Thermoelectrics

Thermoelectrics devices, which convert waste heat directly to electric energy, may eventually be able to provide some or all of the energy for accessories in a moving truck. In an experimental demonstration, a thermoelectric device was able to produce almost 1 kW of power when attached to the exhaust of a Class 8 diesel truck at full engine load.[7] The thermoelectric power was proportional to the engine load and almost independent of engine speed. Advanced TE systems, using the new TE materials like segmented skutterudites or thin-film superlattice materials, could easily be even more important in truck electrification applications than in truck APU applications. NREL has performed several heavy vehicle/TE system studies on placing TE systems at various locations on heavy vehicles. The most promising locations for producing significant amounts of power are the exhaust flow stream, the turbocharger compressor outlet, and the EGR system. All of these locations have significant amounts of waste thermal energy at temperatures of 450–650°C, which are very close to the optimum operating temperatures of the new TE materials. NREL's advanced TE system studies show that the power-production potential in the exhaust flow of a heavy vehicle using completely optimized and integrated heat exchanger/TE systems with the new TE materials could be as high as 5–6 kW. Power-production potential at the turbocharger compressor outlet could be as high as 500 W. Either of these locations could support a significant portion of truck electrification requirements. With proper funding, this technology could be commercialized within about 5 years.

Quantum-well (QW) TE devices are under development that reportedly have the potential to be 20 percent efficient or higher. At that level of efficiency, QW TE devices have an even stronger potential to be able to produce enough power to supplant idling, but their development, TE characterization, and implementation into a working device are at least 10 years into the future. There is much research and development work that must be executed before QW TE devices become a reality. This will likely take a coordinated, interagency effort by DOE and other government agencies (e.g., DARPA) to accomplish. However, if their development, characterization, and implementation are successful, such QW TE systems could very well compete with the system efficiencies of currently known fuel cell systems. The EPS program should serve as the lightening rod and a major program motivator and player in establishing TE material and system-level requirements, technical coordinating of TE material research, and providing the potential final applications for advanced TE systems.

OPTIONS FOR IDLE REDUCTION

A typical intercity tractor-trailer idles an estimated 1,830 hours per year when parked overnight at truck stops.[3] A survey of truckers[8] indicated that the primary reason for idling was climate control, with 67 percent of the drivers idling to power the heater and 83 percent to power the air conditioner. Other important reasons for idling are to keep the fuel and engine warm in winter to permit easier startup; to supply electricity for lights, computers, microwave ovens, and television sets; and to drown out the noise from other trucks.

A significant amount of idling also occurs at terminals while a truck is waiting to be loaded or unloaded and in stopped traffic. In addition, school bus drivers idle their buses on cold mornings to defrost the windshield and heat the bus, and transit bus drivers idle their buses to heat or cool the bus while waiting to pick up passengers at terminals.

Total fuel usage for idling is estimated to cost $1.17 billion per year, and an estimated additional $1 billion is spent on engine wear and maintenance due to idling.[8]

Power requirements for a stationary tractor-trailer are estimated to be between 4 and 8 kW[8], with 1–3 kW for base electrical loading such as lights, battery charging, communication and computer; and 3–5 kW for hotel loads including engine and fuel heating, air conditioning, and appliances.[1]

A variety of technologies are on the market or under development for reducing idling. They include the following:

- Advanced idling concepts (interrupted idling)
- Direct-fired heaters
- Batteries
- Thermal storage systems
- Diesel-powdered APUs
- Fuel-cell APUs
- Thermoelectrics
- Truck-stop electrification
- Truck electrification

However, none of the technologies has gained wide-scale use in the U. S. because each one is lacking in one or more attributes that are important to acceptance in the marketplace. The following sections will discuss each of those technologies briefly, summarizing the technical barriers to their acceptance and R&D topics that might overcome those barriers.

Advanced Idling Concepts

Advanced or enhanced idling concepts involve running the engine intermittently with the on-off control set to the temperature of the diesel engine or the state of charge of the battery.

Although this technology is being used in many new locomotives, truckers have not accepted it for several reasons. Even though it would reduce idling of the main engine, it would not eliminate it. There also are concerns about maintenance requirements, starter wear, and engine wear as well as concerns about getting a restful sleep with the engine turning on and off repeatedly.

The general feeling at the workshop was that there are a number of more attractive technologies, and no R&D into this subject was recommended.

Direct-Fired Heaters

Direct-fired heaters are small units that burn diesel fuel to produce heat for the engine and the cab. The technology is well developed, and three major manufacturers have been selling them in North America for 30 years. They are considered to be fuel-efficient, quiet, and inexpensive ($800–$1100 installed). However, there is only a 3 percent market penetration in the U.S. compared with 20 percent in Canada and 89 percent in Europe.

Perhaps the biggest drawback of direct-fired heaters is their inability to provide air conditioning, which is a need expressed by 83 percent of the surveyed drivers. Because of this basic limitation plus the maturity of the technology, no R&D on this subject is recommended, other than perhaps an unbiased study of the costs and effectiveness of the devices.

Batteries

Trucks currently are equipped with flooded lead-acid batteries, which are designed primarily to start a large diesel engine but also provide some reserve capacity to supply electricity when the engine is not running. For cycling operations, valve-regulated lead-acid batteries would be better.[9] Batteries are attractive for supplying auxiliary power because they provide power without running the engine, they are quiet, they consume no fuel, they produce no emissions, and lead-acid batteries can be recycled. The main problem with lead-acid batteries is that extremely large volumes and weights would be required to provide enough power over a sufficient number of hours.

The specific energy (energy divided by system mass) and energy density (energy divided by system volume) for various types of batteries are shown in Figures 4 and 5. The dotted lines labeled 1, 2, 3, 4, and 8 indicate the number of hours of operation. In order to obtain 5 kW of power for 8 hours, it would take over a ton of lead-acid batteries occupying about 500 liters (18 cubic feet). It clearly would not be acceptable to reduce the cargo capacity of trucks by that weight and volume.

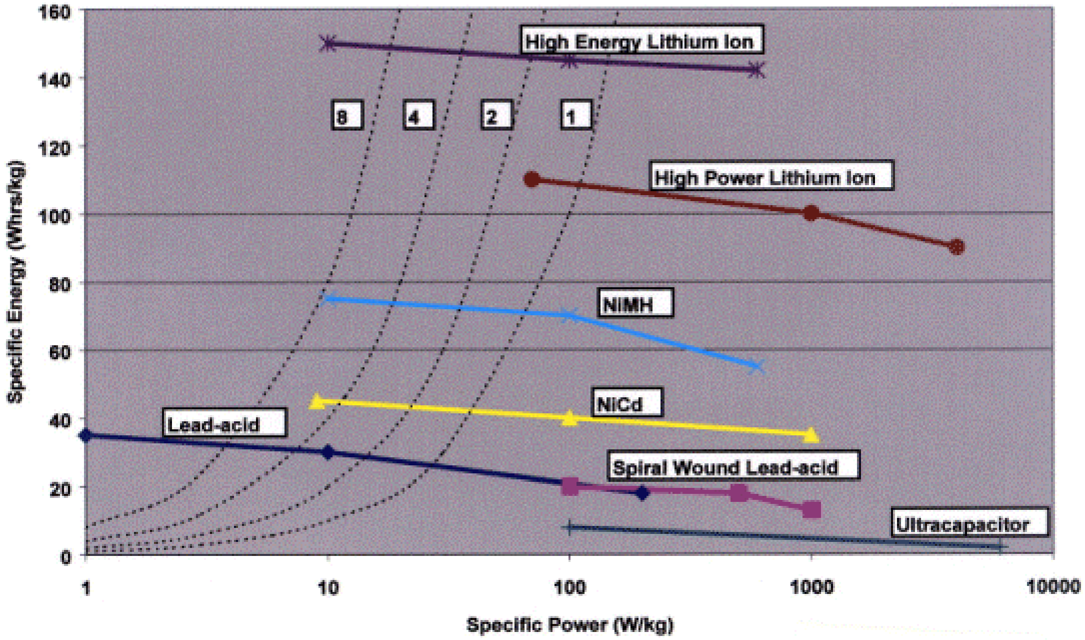


FIGURE 4 Specific-Energy Ragone Plot

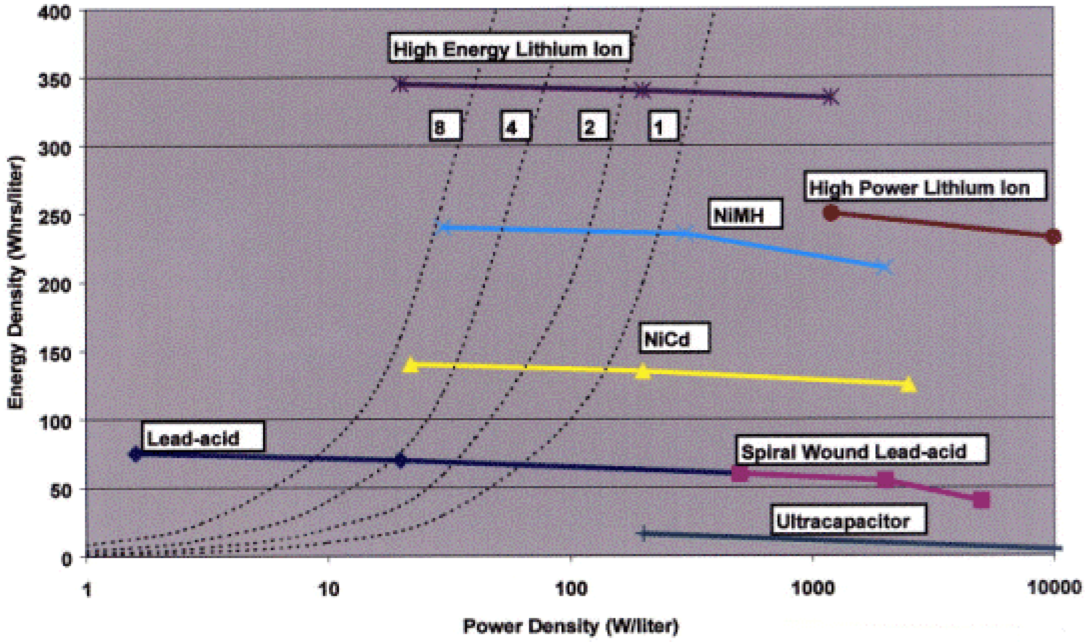


FIGURE 5 Energy-Density Ragone Plot

Other types of batteries would require less mass and volume. As can be calculated from Figures 4 and 5, nickel-cadmium batteries would require just under a ton of mass and about 250 liters of volume. Nickel-metal-hydride batteries would require about half the mass and volume of nickel-cadmium batteries. Unfortunately, on a cost-per-watt basis, nickel-cadmium and nickel-metal-hydride batteries are prohibitively expensive compared to lead-acid batteries.

Lithium-ion batteries are not available in sizes that could be used for trucks. Ultracapacitors are not suitable for hourly rate discharges; they are a possibility for engine starting only.[9]

Although the technical challenges to develop a battery system that is affordable and meets the specific-power and energy-density requirements of a truck are substantial, a considerable amount of relevant research is already underway for other applications, particularly under the sponsorship of the DOE-led U.S. Advanced Battery Consortium, the Defense Advanced Research Projects Agency (DARPA), and individual companies.

In order for the trucking industry to take advantage of that related research, the following additional research should be conducted:

- From a system level, determine more precisely the amount of stored energy that would be required for various duty cycles. Obtain accurate data on real-time peak and base loads to determine the requirements of batteries when coupled with other energy-generating devices. Separate the requirements for starting the engine from those for hotel loads. Do a vehicle-level cost analysis for various types of batteries considering the mass and volume requirements.

- Develop an optimized system design for trucks. Consider storing the energy for engine start separately from that for hotel loads. Then the battery used for off loads could be designed specifically for lower currents and higher cycle life, and the power requirements for starting the engine would be protected from the hotel loads. Consider multiple, switched strings of lead-acid batteries; ultracapacitors for starting the engine; and other battery chemistries. Consider various alternatives for recharging the batteries including the vehicle engine and alternator, grid power, solar power, or an APU.

Thermal-Storage Systems

A thermal-storage system contains a phase-change material that stores heating or cooling energy, which is transferred from the vehicle engine or air conditioning while the vehicle is operating. Commercial systems are available with thermal tank capacities from 16 to 35 gallons and heat-storage capacities up to 23,000 BTU, which is claimed to be sufficient to supply heating or cooling to the sleeper compartment for 8 hours.[3] The size is equivalent to that of an APU.

The biggest disadvantage of thermal-storage systems is that they do not supply electricity for lights, appliances, computers, and communication.

Because thermal-storage systems are commercially available, no research on this topic is recommended.

Diesel-Powered APUs

APUs consist of a small engine (usually a 1-, 2-, or 3-cylinder diesel) equipped with a generator to provide electricity and heat recovery to provide heat. They are mounted externally on the truck cab or sleeper. Some APUs supply 110 volt electricity to power an air-conditioner unit, and others drive a compressor directly.

Until recently, there were almost no public data on the fuel savings and emission reductions that could be achieved with an APU. However, some data are now available from a series of tests that were conducted at the Aberdeen Testing Center with five Class 8 trucks, one of which was equipped with an APU featuring a two-cylinder diesel engine.[10] The trucks were tested at 90°F with the air conditioner operating and at 0°F with the heater operating. Idle measurements were made at low idle speed (about 600 rpm) and at high idle speed (about 1200 rpm). Using an APU reduced the fuel consumption by 58 to 87 percent, depending upon conditions. In addition, the APU resulted in a 57 to 95 percent reduction in hydrocarbon emissions, a 78 to 97 percent reduction in NO_X emissions, and a 51 to 91 percent reduction in carbon monoxide emissions. Results for particulate matter were mixed; in one case there was a 20 percent increase, but most cases showed a 67 to 95 percent decrease.

APUs have been in commercial production for many years, but they have not been widely accepted by the truckers. It is estimated that less than 2000 APUs are sold per year for Class 8 sleepers. A number of factors discouraged truckers from purchasing APUs in the past:[11]

- The installed cost of \$5000–\$8000 could not be justified in view of the low fuel prices.
- There were serious concerns about the reliability of APUs, especially with respect to the other systems in the truck to which they are connected. Early industry product problems gave APUs an initial bad reputation.
- Fragmented anti-idle regulation did not provide much incentive to stop idling.
- Some truckers felt that the noise was objectionable.

However, the growing emphasis on emissions and fuel consumption along with technological development related to the integration of engines and vehicle systems and sound attenuation make it appropriate to re-examine the acceptability of diesel-powered APUs. Figure 6 shows how technical advances have reduced noise to acceptable levels.

At the EPS workshop, the following requirements for APUs were defined by the industry representatives:

- Reliability and durability rivaling that of truck engine
- Low maintenance
- Minimum operating life of 15,000 hours
- Peak power of 5–10 kW

- 115 volts AC and 12 volts DC; possibly 36/42 volts DC as well
- Maximum total weight of 200 pounds
- Maximum volume of 6 cubic feet
- Maximum sound level of 65 dB at 10 feet, and the sound should be continuous rather than starting and stopping
- Manufacturing cost less than $400/kW (purchase cost less than $800/kW)
- Maximum external temperature of 45°C (115°F)
- Maximum start-up time of 10 minutes.

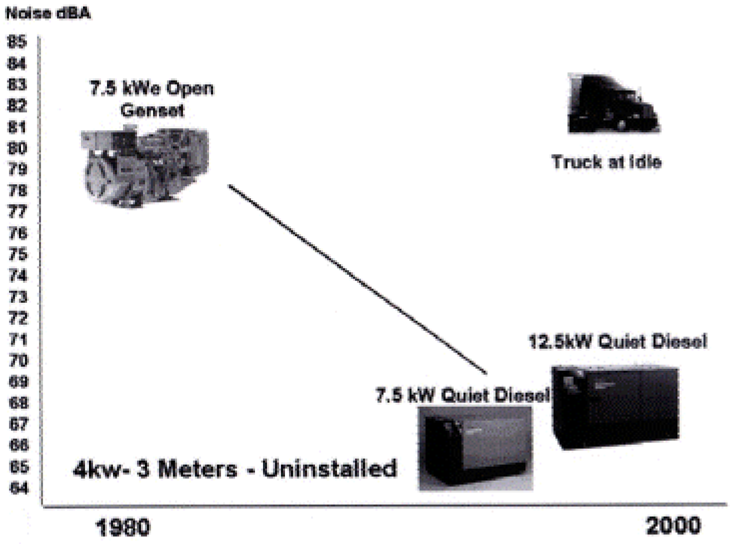


FIGURE 6 Trends in Noise Levels of Diesel Equipment[11]

Research in the following areas would help to overcome the barriers to wider use of diesel-powdered APUs:

- Use of lightweight materials and new design concept to increase the power density of the engine. For example, a fertile area for R&D would be development of a lightweight permanent-magnet generator.

- Integration of APU into the truck cooling and electrical systems by the OEM. This has the potential for improving reliability, reducing the weight through sharing of common components and fluids, and reducing the cost by eliminating the need for modifications in after-market installations.

Fuel-Cell-Powered APUs

Fuel cells are electrochemical devices that convert the chemical energy of a reaction directly into electrical energy. In a typical fuel cell, gaseous fuels are fed continuously to the anode (negative electrode) compartment, and an oxidant (oxygen from air) is fed continuously to the cathode (positive electrode) compartment. The electrochemical reactions take place at the electrodes to produce an electric current.

A variety of fuel cells have been developed: proton-exchange membrane (PEM), alkaline fuel cell (AFC), phosphoric acid fuel cell (PAFC), molten-carbonate fuel cell (MCFC), and solid-oxide fuel cell (SOFC). These fuel cells are listed in order of increasing operating temperature, ranging from 80°C for PEM to approximately 800°C to 1000°C for SOFC. As will be shown in the following paragraphs, the fuel cells of current importance for transportation are the PEM and the SOFC. The PEM is the current choice for light-duty vehicles and is being developed jointly by DOE, various fuel cell developing companies, and domestic and overseas automotive companies. The SOFC is being developed for on-site stationary applications and is emerging as a potential candidate technology for light- and heavy-duty vehicle applications, particularly for auxiliary power in the several-kilowatt electric power range.

Fuel cells are tantalizing candidates for future APUs, because they are highly efficient and quiet, and they have little or no emission of NO_x, particulate matter, or hydrocarbons. Industry representatives at the workshop exhibited a high level of interest in fuel cells as components of future APUs as well as a high level of confidence that fuel cells would ultimately be developed to meet the requirements for a truck APU. However, it also was recognized that a substantial R&D effort will be required to make them affordable and reliable over long, continuous periods of operation and under numerous start-stop scenarios.

Under the current DOE organization, the R&D to overcome the technical barriers to the use of fuel cells will be managed from the office of Hydrogen and Infrastructure. The EPS program should, at a minimum, determine the requirements for a fuel-cell-powdered truck APU, inform the appropriate DOE program managers of those requirements, and maintain an awareness of the progress in those programs with respect to the requirements for trucks. The EPS program should, in particular, closely monitor fuel cell/vehicle demonstration projects and what performance is actually demonstrated under real-world operating conditions.

The industry representatives at the workshop defined the following requirements for a fuel-cell-powered APU:

- Power: 3 to 5 kW
- Power density: 0.1 kW/kg (10 kg/kW) desired. Breakeven is about 20–25 kg/kW.
- System volume: 10 liters/kW maximum
- System manufacturing cost: $400/kW maximum (purchase cost <$800/kW)
- Lifetime
  - 30,000 hours for SOFC (4 to 5 years of continuous operation)
  - 20,000 hours for PEM (4 to 5 years of intermittent operation)
- Ability to operate on diesel fuel
- Rapid start-up (<10 minutes) or continuous operation
- Reliability and durability comparable to that of the truck engine

- Low maintenance
- 115 volts AC and 12 volts DC; possibly 36/42 volts DC as well

A similar set of requirements that has been developed by TIAX[12] is as follows:

- Power: 5 to 15 kW
- Power density: 0.08 kW/kg by 2006 and 0.15 kW/kg by 2010
- System volume:12.5 liters/kW by 2006 and 6.7 liters/kW by 2010
- Lifetime: 40,000 hours for SOFC
- Cycling capacity: not less than 10 cycles/year

For refrigeration trailer units, the power requirement would be 10 to 30 kW and the power density should be at least 0.22 kW/kg including batteries.

Solid-Oxide Fuel Cells

In a SOFC, oxygen molecules from the air dissociate into atomic oxygen in the cathode, and the atomic oxygen diffuses through a solid-oxide electrolyte (that has a high oxygen mobility) to react with hydrogen and carbon monoxide to produce electricity and heat. As is shown in Figure 7, the products of the reaction are water vapor and carbon dioxide. Temperatures on the order of 800°C to 1000°C are required to allow for satisfactory functioning of the cathode. SOFCs are constructed in tubular and planar configurations, the latter being preferred for truck applications because of greater power density and durability. A schematic of a planar SOFC is shown in Figure 8.

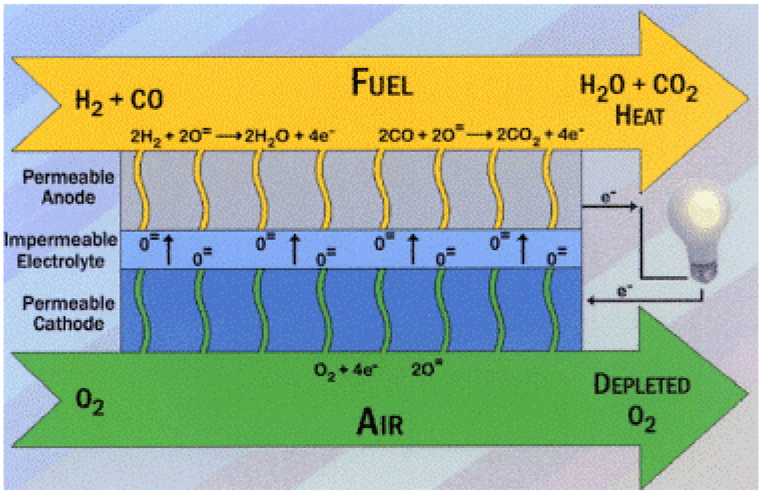


FIGURE 7 Physics of a Solid-Oxide Fuel Cell

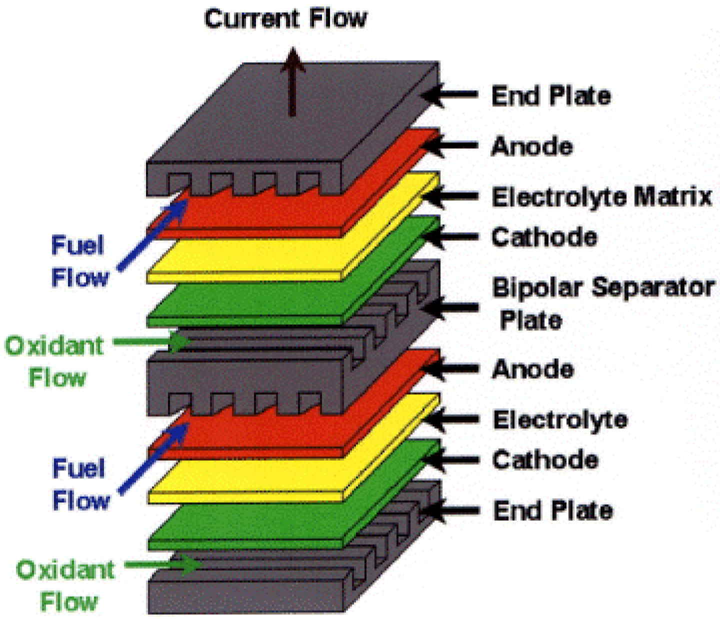


FIGURE 8 Schematic of a Planar SOFC[13]

Currently, SOFCs are prohibitively expensive, costing more than $10,000 per kilowatt. The key to lower costs is believed to be higher production volumes, which are expected to increase sufficiently to lower the manufacturing cost to $800–$1500 per kilowatt by 2005 and to about $400/kW by 2010, when more than 50,000 units are predicted to be manufactured.[13]

The major technical challenge with SOFCs is to improve the durability of the ceramic components, which must withstand severe shock and vibrations on a moving truck. Research in the following areas is needed to improve the robustness of the SOFC:[13]

- Develop a cathode material that will function satisfactorily at 700°C or below. At that temperature, metallic materials could replace some of the ceramic components.
  - Substantial work currently is being directed at modifying the current cathode material, lanthanum-strontium-manganite.
  - Little work is directed at understanding the surface exchange mechanism in order to introduce new, more active cathode materials

- Develop a substitute for the current anode material (nickel/yttria-stabilized zirconia cermet) that would be less susceptible to sulfur poisoning and carbon deposition or develop an economical way to remove sulfur from the fuel before it reaches the anode.

- Develop a more conductive electrolyte than the current material (yttria-stabilized zirconia) that would allow a broader range of compatible cathodes for lower-temperature operation.

- Develop a low-cost, metallic substitute for the traditional interconnect material ($LaCrO_3$), which does not work well in planar designs due to high sintering temperatures and a tendency to warp in a reducing environment and is too expensive. Corrosion film on the metal at 800°C must remain conductive and may not cause significant structural deformation.

- Develop computer models to optimize SOFC stack configurations.

- Characterize candidate new materials in terms of fracture toughness, thermal-expansion coefficient, Young's modulus, Poisson's ratio, etc.

- Develop more robust sealing materials and design approaches.

The above topics are currently being addressed for a variety of applications in a major DOE effort, the Solid-State Energy Commission Alliance (SECA), which is focusing on cell and stack performance, reliability, and cost. However, additional work may be needed to focus specifically on heavy-vehicle issues. Of particular importance would be focusing the material characterization and computer modeling activities on heavy vehicles as well as defining the material properties that are needed to withstand the typical vibrations and shocks experienced by heavy vehicles, defining the real-time power requirements for heavy-vehicle APUs, and demonstrating a SOFC as a heavy-vehicle APU.

Concern also was expressed about thermal cycling, which can degrade the ceramic components, and about start-up time. However, it was felt that those problems could be minimized by running SOFCs continuously.

Other areas of important research include the following:

- Develop efficient methods and integrated system designs for using the high-grade waste thermal heat from a SOFC.

- Develop higher-current-density electrode designs.

Proton-Exchange Membrane Fuel Cells

Proton-exchange membrane (PEM) fuel cells — sometimes called polymer-electrolyte membrane fuel cells — operate at a much lower temperature (about 80°C), but their dependence on very pure hydrogen as the fuel makes them impractical for APUs on trucks. PEMs are very intolerant to both sulfur and carbon monoxide. Whereas reforming diesel fuel to produce hydrogen and carbon monoxide for a SOFC is relatively straightforward, the reforming process for PEMs is very complicated. As is shown in Figure 9, it requires a complex, multi-stage reformer that must be carefully thermally managed at each step and that occupies an unacceptably large volume. Carrying tank hydrogen on the truck also is considered unacceptable because of the space required, plus the lack of infrastructure to supply it.

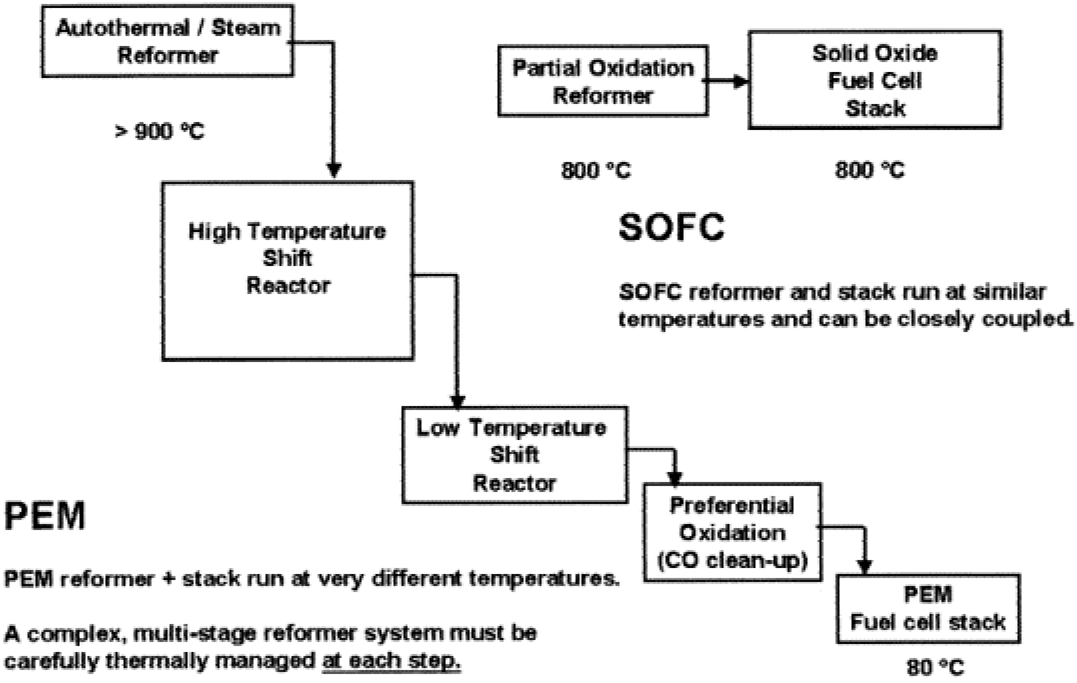


FIGURE 9 Comparison of Reformer Processes for PEMs and SOFCs[14]

Other problems with PEMs include the high cost of the platinum catalyst, the high cost of the ion-exchange membrane, and the difficulty of water management. As progress is made in the DOE Office of Hydrogen and Infrastructure towards increasing hydrogen storage on vehicles and reducing the cost of PEM fuel cells for passenger cars, the feasibility of using a hydrogen-fueled PEM for a heavy-truck APU will be revisited.

Alkaline Fuel Cells (AFC)

The alkaline fuel cell has been developed to a high state of reliability for the U.S. aerospace program, where pure hydrogen is used as the fuel. For automotive applications, the AFC is unsuitable unless pure hydrogen is used as the fuel. The AFC is intolerant to carbon dioxide, which results in the formation of carbonate in the electrolyte, with loss of performance. AFCs cannot be used directly with reformed carbonaceous fuels because of large amounts of residual carbon dioxide in the hydrogen produced. Pure hydrogen must be produced from these gases for AFC use. It also is necessary to remove essentially all the carbon dioxide from the air, which contains 350–400 ppm carbon dioxide. For these reasons, the AFC is not a practical fuel cell type for application with gasoline and diesel-fueled trucks in the time period of interest for EPS development.

Phosphoric Acid Fuel Cells (PAFC)

The PAFC, operating at about 200°C, is being developed for on-site power in the 200 kW and above power range. An attempt to develop the PAFC for transportation application culminated in the demonstration of a 50 kW PAFC-powered transit bus at Georgetown University in 1994. The demonstration was of limited success and led to the 1998 testing of a bus powered by a 100 kW PAFC supplied by International Fuel Cells corporation. Because material costs are high, a typical PAFC costs between $4,000 and $4,500 per kW, which is outside the range of consideration for an EPS.

Molten-Carbonate Fuel Cells (MCFC)

The MCFC, operating at about 650°C, also is being developed for on-site and central power applications in the 200 kW to 1-megawatt power range. No known attempts have been made to develop a MCFC system for transportation application. As with the PAFC, the complexity and high system cost preclude consideration in the low-kilowatt range of interest for EPS.

Thermoelectrics

In principle, it would be possible to generate both heat and electricity by coupling a thermoelectric (TE) device to a direct-fired heater. In fact, one such system is under development in a joint project between Hi-Z Technology, Inc. and PACCAR Technical Center for waste-energy power production in a heavy-duty vehicle. Another TE system is under development for automotive applications by OmniNove in Sweden.[7] The Hi-Z/PACCAR system is designed to deliver 1–3 kW of power and has demonstrated up to 900 W according to the latest literature. The OmniNove system has only produced 95–100 watts of power from a thermal input of about 6.3 kW, which is far short of the requirements to replace truck idling. Both of these systems, and all other such systems to date, have utilized “old” TE materials, like bismuth telluride and lead telluride, in the TE device. These materials are simply not capable of producing the power or the system efficiencies required in light-duty and heavy-duty vehicles. The highest efficiency for TE devices using these “old” TE materials is only about 5 percent. New classes of TE materials are creating much better opportunities and possibilities for achieving the power production, system efficiency levels, and costs required for heavy-duty-vehicle APUs. The new TE materials include skutterudites (developed and characterized at NASA-JPL, thin-film superlattice materials (developed and characterized at Research Triangle Institute), and quantum-well materials (investigated and researched at a number of organizations such as MIT, Hi-Z Technology, Inc., and PNNL).

Recent heavy-duty TE design studies at NREL have shown the new skutterudite TE materials in properly integrated and optimized designs could produce system efficiencies of 10–13% and power outputs approaching the heavy-duty vehicle APU requirements. Diesel-fired burners in heavy-duty vehicles could provide a significant amount of thermal energy at operating temperatures (~650°C) that are very close to the optimum working temperatures for these new

TE materials. NREL's design studies to optimize the integrated heat exchanger/TE device designs have laid a good foundation in quantifying their design and performance characteristics in an actual device. However, further work is required to optimize materials and to integrate TE devices with heat exchangers for heavy-truck applications. This should include investigation with a cool-side working fluid. With proper funding, these TE devices probably could become commercial realities in about 5 years.

In the future, higher power levels should be attainable from the quantum-well (QW) devices that are under development, but their development, thermoelectric characterization, and implementation into a working device are at least 10 years into the future. There is much research and development work that must be funded and executed before QW TE devices become a reality. However, if their development, characterization, and implementation are successful, such QW TE systems could provide substantially enhanced system efficiencies and power production, compared to current TE materials, required for truck electrification. QW work is being conducted within another DOE program, but it should be monitored and guided by the EPS program requirements. The EPS program should help establish TE material and system-level requirements, technically coordinate TE material research, and provide the potential final applications for advanced TE systems.

Truck-Stop Electrification

A number of people at the workshop expressed the belief that truck-stop electrification is the ultimate solution to reducing idling. The trucker would simply plug a power cord into an outlet at the truck stop to power heating, air conditioners, marker lights, and accessories like microwave ovens and refrigerators. Although the trucks would not have to carry an extra engine or special fuel, some modifications to the truck would be necessary to enable the accessories to be run on 110 volt AC.

Currently, very few truck stops are equipped to provide shore power, and very few trucks are equipped to accept it. This has been described as a "chicken-and-egg" situation, where truck stops cannot justify the cost of installing shore power because not enough customers would use it, and truckers cannot justify the cost of the necessary truck modifications because not enough truck stops offer the service. However, the situation is gradually improving and probably will continue to do so. One truck manufacturer has sold over 5000 trucks equipped for shore power since 1997,[15] and several truck stops have recently installed equipment to furnish power. Fleets with repeatable destinations could be the initial market for shore power. Expanded use of APUs may encourage the transition to shore power, because they will drive the demand for electric HVAC, so eventually the market may shift from APUs to shore power.[4]

Even if all truck stops were equipped to supply shore power and all trucks were equipped to accept it, truck-stop electrification would not solve the entire problem because there is a critical shortage of parking space at truck stops, there being less than 300,000 spaces for over 450,000 trucks. Furthermore, many truckers find it necessary to spend the night at locations away from truck stops, and a significant amount of idling also occurs near loading docks.

As discussed above, significant energy savings could be achieved while the truck is moving if pumps, fans, compressors, and other accessories were electrified.[4,5] Any future moves to electrify trucks for that purpose also will reduce the barriers to truck-stop electrification.

DISCUSSION

Truck Electrification

Significant improvements in fuel efficiency could be accomplished by electrifying many of the accessories in a truck in a systematic, system-wide fashion. However, research is needed in system development, modeling, component development, and technology demonstration.

Idle Reduction

In view of the importance of air conditioning and electrically driven appliances to a large majority of U.S. truckers and the general unavailability of shore power, it appears that a diesel-powered APU, or the equivalent, is the only viable, near-term alternative to enable a significant decrease in the amount of idling. It also appears that incorporation of such a unit into the truck by the truck OEM would go a long way toward improving the reliability, reducing the weight, and lowering the cost to the point where an APU would be welcomed in the marketplace. Some research into use of light-weight materials, system integration, and noise reduction would be useful.

Direct-fired heaters, with or without thermal-storage systems, might be adequate in certain locations. These are well-developed technologies and should not require additional R&D.

In the longer term, some combination of truck-stop electrification and fuel-cell-powered APUs probably will be employed to reduce idling. The barriers to truck-stop electrification are more economic than technical, but development of standards for voltages, currents, and connectors would be helpful.

A large number of technical barriers exist for fuel cells, but on-going and planned research in other parts of DOE and the Department of Defense (DOD) should eventually solve those problems. However, coordination with the EPS program will be important.

Batteries with greater power densities, higher specific power, and longer lives always will be important for idle reduction and truck electrification, as well as many other areas of the transportation sector. On-going research in other parts of DOE and in industry should be encouraged and coordinated with the EPS program.

In addition, to these “supply-side” activities, efforts to reduce the “demand” or power requirements of accessories (i.e., auxiliary-load reduction) will be important, because a reduction in power requirements will reduce the size, weight, and cost of the power source and thus make the use of these technologies more appealing to the trucking industry.

SCHEDULING AND RESOURCE REQUIREMENTS

A schedule and anticipated budgets for the main research areas in the EPS program are given in Table 3.

TABLE 3 Budget Projections for the EPS Program

	Budget, $1000							
Research Area	FY02	FY03[a]	FY04	FY05	FY06	FY07	FY08	TOTAL
Diesel-Powdered APU								
Technology Assessment	100							100
Hardware Development	400		700	700	600	200		2600
Truck-Stop Electrification			200	200				400
Truck Electrification								
System Development	400		800	1000	1000	700	400	4300
Modeling	100	100	400	500	500	400	300	2300
Component Development	300		800	1000	1000	600	400	4100
Technology Demonstration			400	800	1000	1200	800	4200
Coordination with Other Programs[b]		200	350	400	400	350	300	2000
Total	1300	300	3650	4600	4500	3450	2200	20000

[a] Budget for FY03 is low because of carry-over funds from FY02

[b] Fuel cells, Batteries, Parasitic Energy Losses, Heavy Hybrids, Power Electronics, Thermoelectrics (DEER)

IMPLEMENTATION AND MANAGEMENT PLAN

The Office of FreedomCAR and Vehicle Technologies (OFCVT) maintains overall authority and responsibility for managing and implementing DOE's Heavy Vehicle Systems R&D technology area, which includes the Essential Power Systems (EPS) projects. Management responsibility for the program resides with the program manager of OFCVT, who reports to the DOE Deputy Assistant Secretary for Technology Development. OFCVT is responsible for program coordination, establishing priorities among project activities, evaluating progress, coordinating with other government and private-sector organizations, and reporting to senior DOE management. Contract execution and administrative authority for the EPS activities have been delegated to DOE's Albuquerque Operation Office.

Implementation of R&D efforts with industry will be accomplished through competitive solicitations and cooperative agreements. National laboratories will be funded directly based upon their capabilities and performance. Awards will be made based upon expertise and facilities required to accomplish the desired work, the track record of responsiveness and results, and involvement of organizations expected to use the results of the work.

Projects are controlled through multi-year program plans, Program Execution Plans and national laboratory Annual Operating Plans, which contain clear statements of goals, objectives, approaches, and milestones. Contractor quarterly progress reports are submitted outlining technical and cost status versus projections, problem areas, and outstanding issues. Periodic site reviews also are conducted to assess the status of each project and identify issues that may require OFCVT resolution.

The EPS is expected to provide a possible pathway for future truck electrification, and it is envisioned that this technology will be linked to the advanced heavy-hybrid program, which recently initiated a solicitation and subcontracts for advanced heavy-hybrid propulsion components and systems.

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7. A. Kushch, J. Bass, S. Ghamaty, N. Elsner, R. Bergstrand, D. Furrow, and M. Melvin, "Thermoelectric Development at Hi-Z Technology," 2001 DEER Conference.

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12. DOE Project DE-FC04-01ALL 67604, "Fuel Cell Auxiliary Power Systems for Transportation Applications," being conducted by TIAX LLC. Draft report expected February 2003.

13. J. Strakey, "Status of the Solid State Energy Conversion Alliance Program," Presentation at the Essential Power Systems Workshop, Washington, DC, December 12–13, 2001.

14. J. Weber, "Solid Oxide Fuel Cell Auxiliary Power Unit," Presentation at the Essential Power Systems Workshop, Washington, DC, December 12–13, 2001.

15. S. Yeakel, “Truckstop—and Truck!—Electrification,” Presentation at the Essential Power Systems Workshop, Washington, DC, December 12–13, 2001.

APPENDIX A

Agenda from Essential Power Systems Workshop

December 12–13, 2002
Washington, DC

U.S. DEPARTMENT OF ENERGY
OFFICE OF HEAVY VEHICLE TECHNOLOGIES

ESSENTIAL POWER SYSTEMS WORKSHOP

December 12–13, 2001
Hilton Washington Embassy Row Hotel, Washington, DC

AGENDA

DAY 1, WEDNESDAY, DECEMBER 12, 2001

7:30 am	**Registration** **Continental Breakfast**
8:30 am	**Welcome, Introductions and OHVT Overview** *James Eberhardt*, Director, Office of Heavy Vehicle Technologies, U.S. Department of Energy
8:45 am	**EPS Program Overview and Workshop Expectations** *Susan Rogers*, Program Manager, Heavy Vehicle Systems R&D, Office of Heavy Vehicle Technologies, U.S. Department of Energy
9:00 am	**OEM Perspective** *Bill Gouse*, Executive Engineer, Technology Planning, Freightliner
9:20 am	**End Users' Perspectives** Speakerphone talks and Q&A monitored by *Mark Kachmarsky*, Highway Vehicle Architect, Mack Trucks ***9:20 am Marty Fletcher*, Director of Technical Maintenance and Training, U.S. Express** ***9:35 am Jim Kennedy,* Fleet Manager, McKenzie Tank Lines** ***9:50 am Mike Swiger,* President, Swiger Trucking**
10:05 am	**Break**
10:25 am	**Diesel-Powered Gen Sets** *Paul Plahn*, Director, Advanced Product Development, Cummins Power Generation
10:45 am	**Cab/Engine Heaters** *Joe Kirby*, Director, Truck Group, Webasto
11:00 am	**Solid-Oxide Fuel Cells** *John Weber*, Director, Advanced Energy Products, Delphi
11:20 am	**Status of the Solid-State Energy Conversion Alliance (SECA) Program** *Joe Strakey*, Associate Director, Strategic Center for Natural Gas, DOE NETL

11:40 pm **Energy Storage (Batteries)**
Dell Crouch, Lead Development Engineer, Advanced Lead-Acid Batteries, Delphi

12:00 pm **Luncheon**

1:00 pm **Parasitic Energy Loss Reductions and Enabling Technologies for Class 7/8 Trucks**
David Orr, Commercial Manager, Electrical & Electronic Systems, Caterpillar
John Duffy, Senior Project Engineer, Kenworth Truck

1:30 pm **Intelligent Cooling & Lubricating Components for Next Generation Vehicles**
David Allen, Vice President, New Product Development, EMP

2:00 pm **Turbogeneration and Electrification**
Carl Vuk, Program Manager, John Deere

2:10 pm **Truck-Stop Electrification**
Skip Yeakel, Principal Engineer, Advanced Engineering, Volvo

2:30 pm **Thermoelectrics**
Jack Bass, Vice President, Hi-Z

2:50 pm **Instructions for Breakout Sessions**
Ray Fessler, Principal Consultant, BIZTEK Consulting, Inc.

2:55 pm **Break**

3:15 pm **Concurrent Breakout Sessions – Systems Perspective**
Benefits, Options, Requirements, Issues

- Idling Reduction
- Truck Electrification

4:45 pm **Breakout Session Reports**

5:15 pm **Adjourn**

DAY 2, THURSDAY, DECEMBER 13, 2001

7:00 am **Continental Breakfast**

8:00 am **Concurrent Breakout Sessions – Technical Details**
Goals, Barriers, R&D Approaches, Magnitude of Effort, Priorities

- **Near-Term Technologies**
  (Direct-fired heaters, diesel engines & gen sets, truck-stop electrification)
- **Fuel Cells**
  (SOFC, PEM, etc.)
- **Truck Electrification**
  (Including component electrification and energy storage)

10:00 am **Break**

10:20 am **Resume Breakout Sessions**

12:00 pm **Luncheon**

1:00 pm **Reports from Breakout Sessions**

2:30 pm **Next Steps**

2:45 pm **Closing Comments**
Sid Diamond, Vehicle Materials Technology, Office of Heavy Vehicle Technologies, U.S. Department of Energy

3:00 pm **Adjourn**

APPENDIX B

Participants in Essential Power Systems Workshop

December 12–13, 2002
Washington, DC

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