Manufacturing Climate Solutions

Carbon-Reducing Technologies and U.S. Jobs

CHAPTER 9

Hybrid Drivetrains for Medium- and Heavy-Duty Trucks

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Summary
The U.S. trucking industry consumes more than 52 billion gallons of fuel each year and accounts for 21% of U.S. greenhouse gas emissions from transport activities. Applying hybrid drivetrain technology to medium- and heavy-duty vehicles can improve fuel economy by 20-50% with a corresponding decrease in greenhouse gas emissions and smog-forming pollutants. The per-vehicle fuel savings and CO_2 reductions possible with hybrid trucks are much more dramatic than those for passenger hybrids, with a medium-duty truck saving 300-700 gallons of fuel per year and saving 3-8 tons of CO_2 emissions. Despite these obvious benefits, the hybrid truck industry is still in a relatively early stage. Hybridizing these large vehicles poses more complex technical challenges because commercial trucks must carry tremendous weight, operate in near-continuous use, make many stops and starts, and often perform tasks not demanded of passenger vehicles (for example, operating the boom on a utility truck). Global market introduction of hybrid commercial trucks is about 10 years behind passenger hybrids.

The United States is well positioned to lead the development of hybrid trucks. At least 25 U.S.-based truck makers and 14 U.S. hybrid system developers are actively involved; many now have prototypes or are producing available hybrid models. A range of U.S. electric hybrids are available for different applications such as package delivery vehicles, beverage haulers, and utility boom trucks. More than 95 U.S. commercial and utility truck fleets have so far purchased or are testing these hybrids, beginning with FedEx Express, which ordered the first hybrid trucks in the United States, United Parcel Service (UPS—total fleet of 73,000 vehicles), and Coca Cola (total fleet of 22,000 vehicles). Other large fleets adopting hybrids include Verizon (59,000 total vehicles) and Pepsi (19,000 total vehicles). In response to this rapidly growing demand, the hybrid truck industry is growing quickly, from only 200 vehicles produced in 2006 to an expected 4,850 in 2010.

Considerable activity, both public and private, is focused on further developing hybrid medium- and heavy-duty truck technologies. In addition to electric hybrids, U.S. industry and government are also developing hydraulic hybrids, a promising new application that uses a hydraulic energy storage and propulsion system instead of an electric battery and motor/generator. Hydraulic hybrids offer fuel economy gains similar to electric hybrids, up to 50% over conventional trucks. They have specific advantages in selected applications, such as city and school buses and refuse trucks, and may have a shorter payback period than electric hybrids. Several U.S. firms and the U.S. Environmental Protection Agency (EPA) are partnering with commercial fleets to produce vehicles in the pilot and road testing phase.

Commercial fleets nationwide have demonstrated ample interest in adopting hybrid trucks, but so far, high production costs have prevented truck manufacturers from offering prices that draw large orders. Fleet orders for hybrid trucks are currently in the 500-1,000 range, yet economic models show that in order to reduce the price premium to an acceptable level, each U.S. supplier

needs sales of 3,000 to 5,000 per year. Government support can help resolve this cost dilemma by providing consistent, long-term help with the costs faced both by manufacturers and truck buyers. Also needed is a continued aggressive effort to establish domestic manufacturing capacity for the next generation of advanced batteries, already a "pinch point" in the industry value chain. These strategies could enable the U.S. hybrid truck industry to take a competitive lead, with a corresponding increase not only in manufacturing jobs but also high-value engineering, design, and electronics/software jobs, as well as employment in service networks, maintenance, and other industry infrastructure to support the vehicles.

Introduction

Hybrid vehicles rely on two or more sources to produce, store, and deliver power. In hybrid electric vehicles these two sources are a conventional internal combustion engine and electricity; in hydraulic hybrids they are the conventional engine and a hydraulic pump/motor with a hydraulic energy storage system. The addition of electric hybrid technology can potentially yield fuel efficiency 2-3 times higher than that of conventional vehicles (U.S. DOE, 2008). Hybrid electric technology has been applied to passenger vehicles with huge commercial success; in 1997 Toyota introduced the Prius, the world's first mass-produced hybrid vehicle, and by 2007 it was one of the 10 top-selling models in the United States (Union of Concerned Scientists, 2007). The same cost-saving and environmental benefits that make hybrid passenger vehicles popular can also be attained by applying hybrid technology to medium- and heavy-duty vehicles, including delivery vans, utility vehicles, buses, and even large, long-haul trucks. In fact, medium- and heavy-duty vehicles stand to benefit particularly from hybrid technology because they consume large amounts of fuel, are in near-continuous operation, and, in many cases, do frequent "stop-and-go" driving, the scenario in which hybrids perform best.

Applying hybrid technology to medium- and heavy-duty vehicles offers obvious benefits. The U.S. trucking industry consumes more than 52 billion gallons of fuel each year (Boyce, December 15, 2008). According to the 2009 U.S. Greenhouse Gas Inventory Report, freight trucks account for 21% of U.S. greenhouse gas emissions from transportation activities (U.S. Environmental Protection Agency, April 2009). Currently, hybrid-electric drivetrains in these vehicles improve fuel economy by 20% to 50% Hybrid delivery trucks used by FedEx, for example, have improved fuel economy by 42% (FedEx).

Hybridizing medium- and heavy-duty vehicles makes a much larger impact, per vehicle, than is possible with passenger hybrids. For example, under a low (20%) fuel savings scenario, a hybrid passenger car would save an estimated 110 gallons of fuel per year, while a hybrid medium-duty truck would save 296 gallons per year (see Table 1). Under a high (50%) fuel savings scenario, a medium-duty truck would save 738 gallons of fuel, reducing CO_2 emissions by 8 tons annually. Since many fleets are seeking hybrid versions for trucks that have higher than average fuel use, these reductions are even greater. In heavy-duty trucks, the high fuel savings scenario would yield particularly dramatic results, saving an estimated 6,421 gallons of fuel and reducing CO_2 emissions by 71 tons.

Table 1. Per-Vehicle Fuel Savings and CO_2 Reduction, Conventional vs. Hybrid Vehicles

Type of Vehicle	**Conventional**		**Hybrid, 20% Fuel Savings**		**Hybrid, 50% Fuel Savings**	
	Fuel Use (gal/yr)	CO2 Emissions (Tons/yr)	**Fuel Saved (gal/yr)**	**CO_2 Reduced (Tons/yr)**	**Fuel Saved (gal/yr)**	**CO_2 Reduced (Tons/yr)**
Passenger Car	547	5.3	110	1	274	2.6
Light-Duty Truck	610	6.8	123	1	306	3.3
Medium-Duty Truck	1,475	16.4	296	3	738	8.2
Heavy-Duty Truck	12,840	14.5	2,569	29	6,421	71.3

Average annual fuel consumption per vehicle type based on (Bureau of Transportation Statistics, 2008). CO_2 emissions per gallon from (U.S. Environmental Protection Agency, 2005).

Source: CGGC.

According to hybrid truck industry estimates, U.S. production of hybrid commercial trucks is expected to reach 4,850 units in 2010 (Van Amburg, 2009). Under the low and high scenarios described above, this would translate into an estimated 4 to 10 million gallons of fuel saved and 47,000 to 116,000 tons of CO_2 reduced per year (see Table 2). By 2020, if the market produces 60,000 hybrid trucks as projected, these low and high scenarios would translate into an estimated 52 to 130 million gallons of fuel saved and .6 million to 1.4 million tons of CO_2 reduced per year.

Table 2. Projected Fuel Savings and CO_2 Reduction with Hybrid Trucks: 2010, 2015, 2020

Projected Number of U.S. Hybrids Produced	Low Scenario: 20% Fuel Savings		Medium Scenario: 35% Fuel Savings		High Scenario: 50% Fuel Savings	
	Fuel Saved 1,000 gal/yr	CO_2 Reduced 1,000 tons/yr	Fuel Saved 1,000 gal/yr	CO_2 Reduced 1,000 tons/yr	Fuel Saved 1,000 gal/yr	CO_2 Reduced 1,000 tons/yr
2010 4,850 Hybrids	4,194	46.6	7,338	81.7	10,482	116.4
2015 20,000 Hybrids	17,265	192.0	30,208	336.5	43,155	479.3
2020 60,000 Hybrids	51,795	576	90,625	1,009.5	129,465	1,437.8

Notes: Average annual fuel consumption per vehicle type based on (Bureau of Transportation Statistics, 2008). CO_2 emissions per gallon from (U.S. Environmental Protection Agency, 2005). Results include an assumed ratio of 3 to 1 for number of hybrid medium-duty trucks versus heavy-duty trucks anticipated in future scenarios.

Source: CGGC.

Hybridizing a medium- or heavy-duty vehicle makes several important improvements possible, for instance substituting a smaller, more efficient engine. Hybrid technology can reduce noise, provide additional acceleration, and make it possible to have “engine-off” operations, running the heating, ventilation and air conditioning (HVAC) and other amenities from stored energy instead of the engine—all benefits that make hybrids attractive not only for commercial vehicles but also for military applications. Hybrids can potentially reduce brake wear, extending maintenance intervals. By reducing reliance on the engine, hybrids could also potentially extend engine service (Technology & Maintenance Council (TMC), 2006).

Despite the considerable promise of commercial hybrid trucks, their technological development and market penetration is about 10 years behind that of passenger hybrids. This is largely because the demands placed on medium- and heavy-duty trucks are very different from light-duty vehicles. For instance, accelerating a large, loaded truck from a dead stop requires an amount of power on a completely different scale from a passenger car. Commercial vehicles typically start and stop dozens of times each day—making them ideal for hybrid systems, which recover and store energy from braking—but at the same time, a considerable amount of power is needed to launch this extra weight. Weight issues in the vehicle design itself are also crucial; it is important for the vehicle, including the hybrid drivetrain, to be as light as possible, to minimize the amount of “unpaid” weight that must be transported.

This report focuses on the U.S. hybrid medium- and heavy-duty truck industry, emphasizing delivery trucks, vocational trucks including utility boom and refuse trucks, and long haul trucks. All commercial trucks are divided into 8 classes based on gross vehicle weight. This value chain analysis will focus on truck classes 4-8. For comparison, all truck categories, along with specific truck types and photos of selected available hybrid models, appear in Figure 1.

Figure 1. Commercial Truck Classes and Descriptions

Truck Types	Gross Vehicle Weight	Example of Available Hybrid
<u>Light Duty</u> • **Compact van** • **Mini-bus** • **Minivan** • **Multipurpose** • **Pickup** • **Step van** • **Utility van** • **Walk-in**	**Class 1** 0 – 6000 lb	 **Consumer Vehicle** Toyota Highlander Hybrid SUV with 4-cylinder hybrid electric engine
	Class 2 6001 – 10,000 lb	 **FedEx** Iveco Daily 35S12, developed jointly by FedEx and Iveco for European use
	Class 3 10,001 – 14,000 lb	 **USPS** Class 3 delivery vans converted into hybrids by Azure Dynamics Incorporated

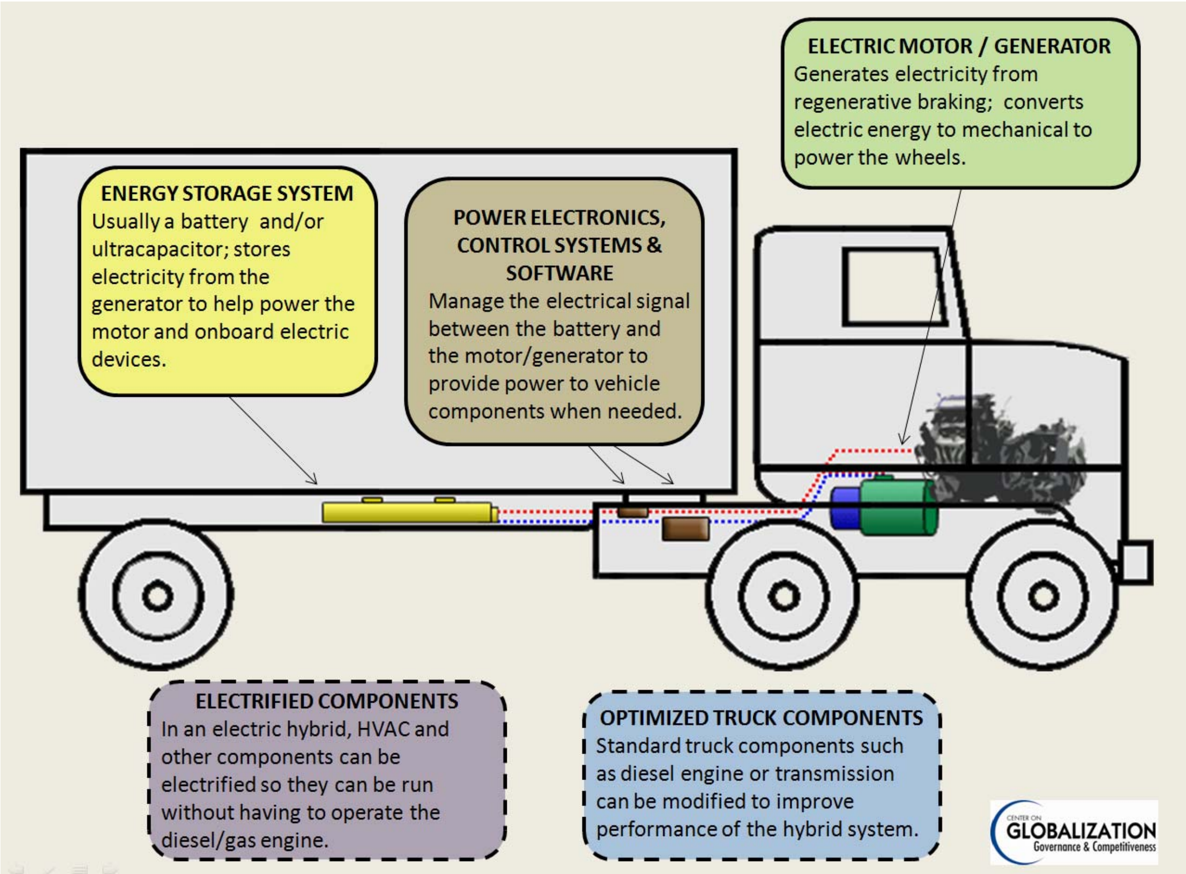
<u>Medium Duty</u> • **Bucket** • **City delivery** • **Landscaping** • **Large walk-in**	**Class 4** 14,001 – 16,000 lb	 **Purolator** Class 4 Ford Motor Company Model E450 Step Van with Azure Dynamics balance parallel hybrid drive
	Class 5 16,001 – 19,500 lb	 **Coca Cola** Kenworth T270 Class 6 Hybrid with Paccar diesel engine and Eaton hybrid system (no Class 5 hybrid image available)
	Class 6 19,501 – 26,000 lb	 **City of White Plains, New York Power Authority** Freightliner M2-106 with Eaton Hybrid Electric Power System and Cummins diesel engine
<u>Heavy Duty</u> • **Cement** • **City bus** • **Dump** • **Fuel** • **Fire engine** • **Furniture** • **Refrigerated** • **Refuse** • **Tow** • **Freight haul** • **Over-the-road** • **Heavy bucket**	**Class 7** 26,001 – 33,000 lb	 **Pepsi** Navistar International DuraStar hybrid tractor with Eaton diesel electric system
	Class 8 33,001 – 150,000 lb	 **Waste Management Inc.** Peterbilt Model 320 HLA with Eaton Hydraulic Launch Assist system

Source: CGGC, based on truck class definitions in (Bridgestone, 2008) and company websites.

Technology Description

Both types of hybrids—electric and hydraulic—improve fuel economy in two basic ways: by recovering energy that is normally wasted, and by capturing and storing energy from the engine's most efficient periods for later use during less efficient ones. The main example of the first process is regenerative braking, in which kinetic energy from the braking process is converted into useful energy. An example of the second process is that, when an engine is operating at a constant speed, part of the energy it produces can be stored and used to run equipment when the vehicle is stopped or slowing (Machine Design, December 13, 2007). In the hybrid medium- and heavy-duty trucks now available and under development, these two basic processes are performed by a large variety of components, applied in different combinations. Electric and hydraulic hybrids each can have parallel or series architectures. In a parallel hybrid, the energy storage system and the internal combustion engine are both connected to the transmission and thus can each provide power to the wheels. In a series hybrid, the conventional transmission and driveshaft system can be eliminated, allowing the engine speed to be decoupled from the vehicle ground speed; thus, the engine can be shut off when not needed (such as when the vehicle is slowing or stopped) and can run chiefly at its highest efficiency, or "sweet spot."

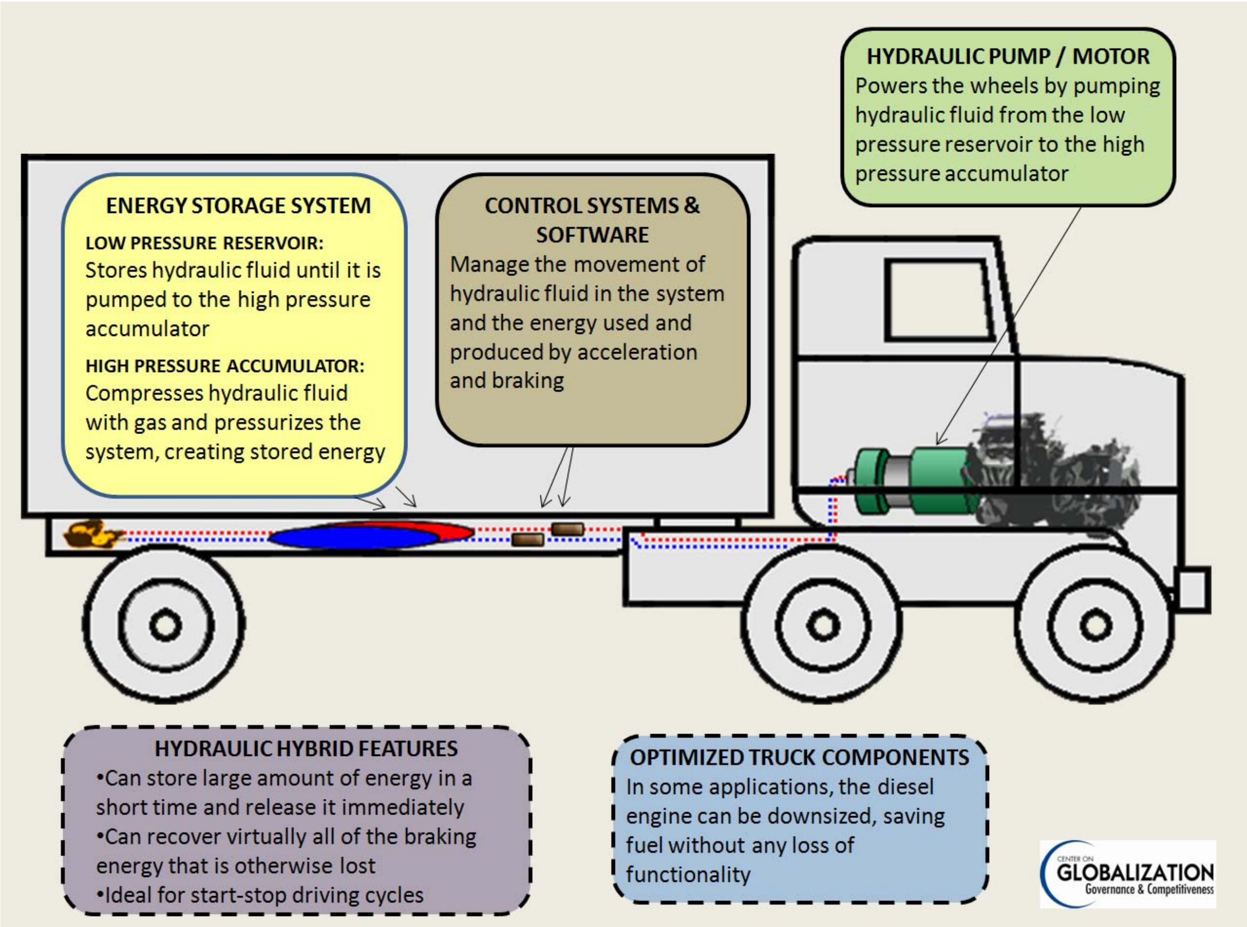
Figure 2. Electric Hybrid Drivetrain for Medium- and Heavy-Duty Trucks



Note: This is an example of a Parallel Architecture.
Source: CGGC, based on (National Renewable Energy Laboratory, 2008).

A visual description of an electric hybrid truck drivetrain is found in Figure 2. Electric hybrid vehicles use both an internal combustion engine and an electric motor/generator to move the wheels. The motor acts as a generator, capturing energy from regenerative braking and from the engine and converting it into electricity—which is then stored in an energy storage system, usually a battery or ultracapacitor. An ultracapacitor is different from a battery in that it stores electrical energy through a physical process, not chemical, and thus can release a high power output quickly. The trade-off, however, is that ultracapacitors have less energy storage capacity than batteries. Because these energy storage systems help power the vehicle, they are larger and must have much greater capacity than a conventional car battery, and the associated weight, volume and cost issues pose the greatest technological obstacle that remains for hybrid trucks. In addition to the motor/generator and the energy storage system, a third component category, the power electronics system, including software and hardware, manages the electrical signal between the battery and the motor/generator.

Figure 3. Hydraulic Hybrid Drivetrain for Medium- and Heavy-Duty Trucks



Source: CGGC, based on (U.S. Environmental Protection Agency, 2006a) and (Eaton Corporation, 2009).

Hydraulic hybrids employ principles similar to electric hybrids, but instead of using batteries, they use alternative components and hydraulic fluid to power the vehicle at low speeds. Hydraulic hybrids use three main components to power a vehicle: a reservoir, a pump, and an accumulator (see Figure 3, above). Fluid is stored in a low-pressure reservoir, and a pump moves the fluid from the reservoir to the high pressure accumulator. Like electric hybrids, hydraulic hybrids collect energy through regenerative braking. This kinetic energy powers the pump, and as the vehicle slows, fluid moves from the reservoir to the accumulator. As pressure builds up in the accumulator, it acts like a fully charged battery—but instead of sending power to an electric motor (as in an electric hybrid), the accumulator sends the accrued energy directly to the driveshaft (Deaton, 2008).

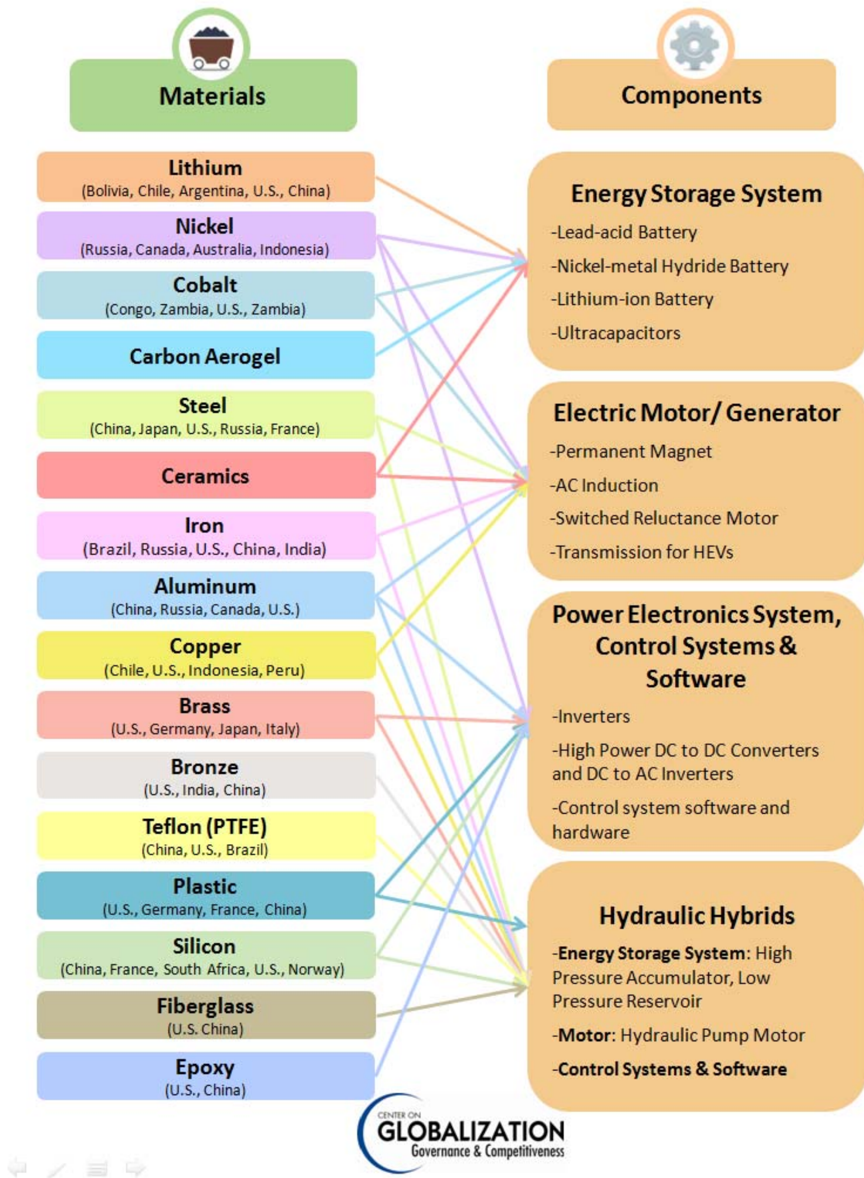
In 2003 an Australian company, Permo-Drive, began working with the Dana Corporation (now Bosch Rexroth) on a hydraulic hybrid project for the U.S. Army (Green Car Congress, October 20, 2004). In 2006 the U.S. Environmental Protection Agency (EPA) unveiled the world's first delivery van with a full series hydraulic hybrid drivetrain. This demonstration vehicle was the result of a partnership with United Parcel Service (UPS), Eaton Corporation, and International Truck and Engine Corporation. Compared with similar conventional vehicles, the UPS demonstration technology achieved 60-70% better fuel economy in laboratory tests. It also reduced emissions of carbon dioxide, the primary greenhouse gas, by 40% or more (U.S. Environmental Protection Agency, 2006).

Despite the basic differences between electric and hybrid technology, it is difficult to generalize about which technology is better suited to which applications. Electric hybrids and hydraulic hybrids each have certain advantages, so that either technology may serve better in any given application, depending on how the vehicle will be used. Hydraulic hybrids are technologically attractive because they have a high power density, enabling them to make use of the large amount of energy generated in regenerative braking. The hydraulic accumulator can charge and discharge this power at much higher rates than an electric battery, giving a large, heavy truck the bursts of power it needs to accelerate quickly in stop-and-go driving. The trade-off, however, is that compared to an electric hybrid, the hydraulic technology has higher *power* density, but lower *energy* density, or less capacity to supply power over an extended time. So, for instance, a hydraulic hybrid may be ideal for a refuse truck that makes many starts and stops because the vehicle can constantly generate the power needed to re-launch its great mass. An electric hybrid, by contrast, is well suited to a utility bucket truck (sometimes called a "cherry picker"). A bucket truck, on average, is parked for half its workday with the engine idling to run the bucket and other electronics (Mims, April 20, 2009). In an electric hybrid bucket truck, the engine could be shut off while the bucket runs on battery power, potentially several hours (Machine Design, December 13, 2007).

Materials and Components

An electric hybrid drivetrain for medium- and heavy-duty trucks can be simplified into three major component categories: an energy storage system, an electric motor/generator, and a power electronics system with control systems and software. Each of these categories offers several options; for example, energy storage in electric hybrids includes a choice among lead-acid batteries, nickel-metal hydride batteries, lithium-ion batteries, and ultracapacitors; in hydraulic hybrids, energy storage is performed by a high-pressure accumulator. For both electric hybrids and hydraulic hybrids, the main components, subcomponents or options, and the associated materials are depicted in Figure 4.

Figure 4. Hybrid Truck Drivetrain: Components and Materials

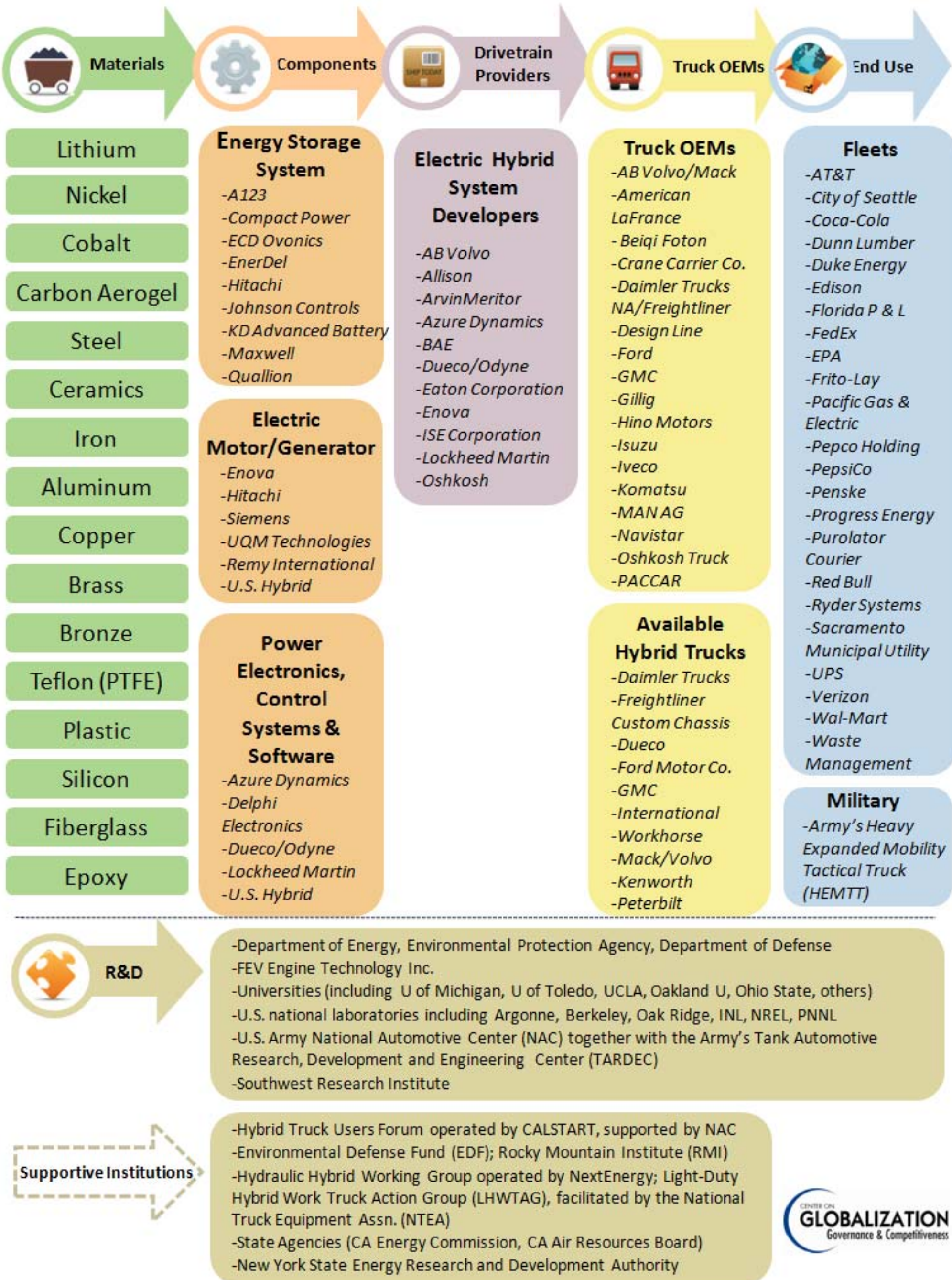


Source: CGGC, based on interviews, industry sources, and (U.S. Geological Survey, 2009).

Value Chains

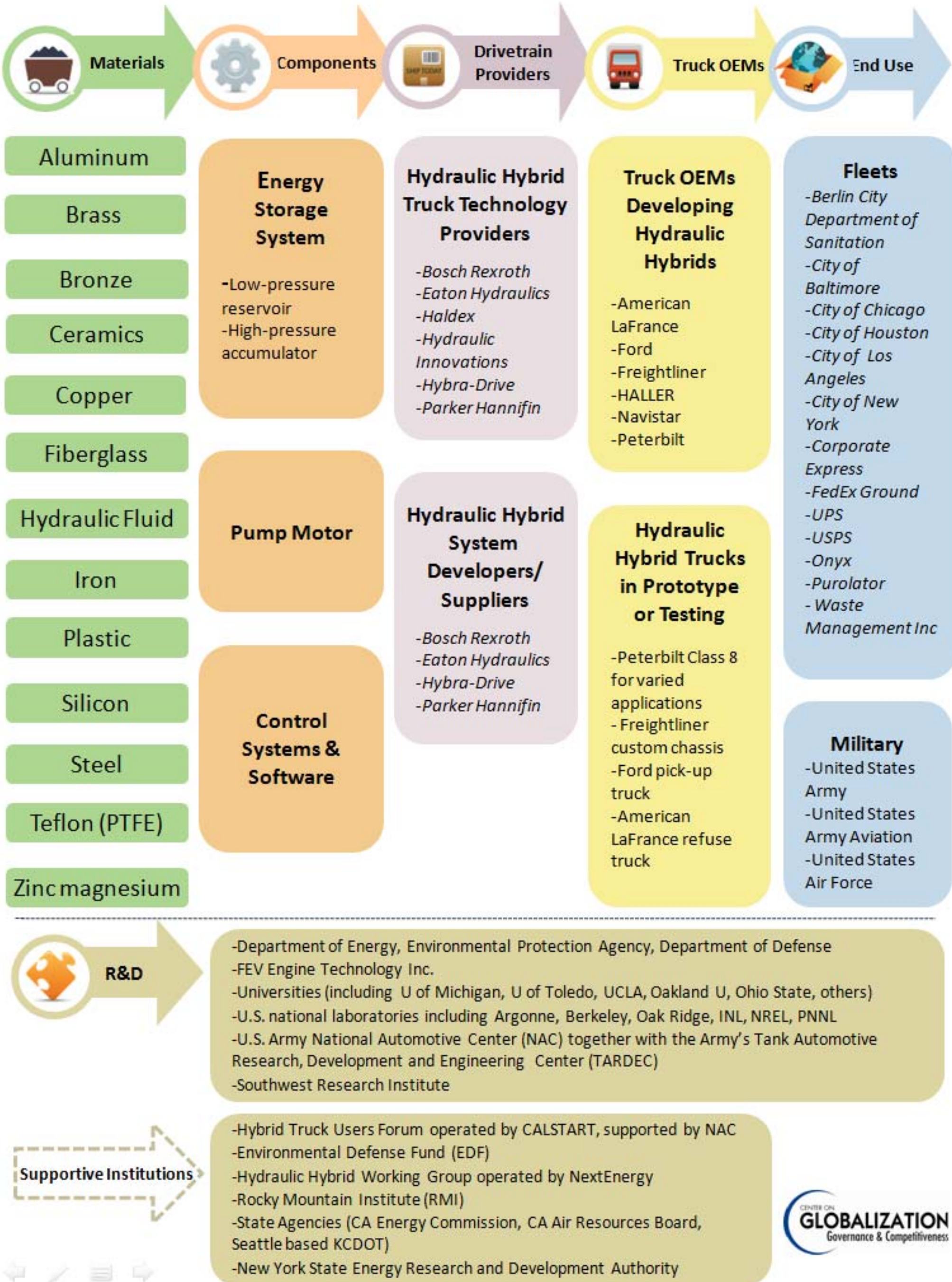
The value chains for the U.S. hybrid medium- and heavy-duty truck industry—one chain for electric hybrids, and one chain for hydraulic hybrids—are found in Figure 5 and Figure 6. For this study we have divided the value chains into five columns: materials, components, drivetrain providers, truck OEMs, and end users. Each of these is described in detail below.

Figure 5. U.S. Value Chain for Electric Hybrid Medium- and Heavy-Duty Trucks



Source: CGGC, based on interviews, company websites, and (CALSTART).

Figure 6. U.S. Value Chain for Hydraulic Hybrid Medium- and Heavy-Duty Trucks



Source: CGGC, based on interviews, company websites, and (CALSTART)

Materials. The motor vehicle industry faces economic risks associated with shortages and price volatility for steel and other metals. In addition to these risks, manufacturers of batteries for electric hybrids are confronted with price and availability issues for several materials. For example, the cost of raw nickel has recently risen dramatically. The price of cobalt, used in Li-ion batteries, nearly tripled between 2003 and 2007 because of demand increases. One-third of world production of cobalt is concentrated in one country, the Democratic Republic of Congo (Hedging, 2007). Similarly, the lithium for Li-ion batteries is increasing in cost. In 2007, the price of lithium carbonate, the main ore from which lithium is extracted, rose nearly 50% over the previous year (Jaskula, 2007). South America has the vast majority of the world's lithium resources, almost half of which are in Bolivia (Romero, 2009, February 3). Control by a single country or region poses the risk that these materials will become too costly or unavailable, a potential "pinch point" in the value chain.

Since hydraulic hybrids do not require batteries, they are not affected by issues related to lithium and other battery materials. Hydraulic hybrid drivetrain components are relatively simple and do not pose any particular materials issues with regard to energy storage.

Components. In electric hybrid trucks, the energy storage system represents the greatest cost challenge, accounting for about one-third of the hybrid system cost. An alternative to batteries, ultracapacitors, store energy physically (not chemically, as batteries do); this allows them to charge and discharge at a much faster rate, but it has the drawback of storing smaller amounts of energy. Ultracapacitors are thus suited best to vehicles where power, not energy storage, is the main objective.

In hydraulic hybrids, several core components—a hydraulic pump/motor, low-pressure reservoir, and high-pressure accumulator—have long been used in applications in construction vehicles. Although hydraulic technology is well-developed, it is still in the early stages of being integrated into a hybrid drivetrain. The hydraulic system's robustness and relatively low cost, however, make it a promising area of hybrid development; while the payback period through fuel savings and improved performance for an electric hybrid truck can be 5-10 years, a hydraulic hybrid truck, priced to high production volumes, may be able to recover its costs in as little as three years (Berg, 2008; Environmental Protection Agency, 2006).

For both electric and hydraulic hybrids, the control systems and software are the heart of hybrid drivetrain technology, the element that makes it possible to maximize the vehicle's energy efficiency and performance. The electronics and control systems provide the ability to connect the engine, transmission, energy storage devices, and electric motor (or in hydraulic hybrids, the pump motor) and configure their functions in many different ways, offering flexibility and optimization.

Drivetrain Providers. At least 10 U.S. companies act as system developers that supply electric hybrid drivetrains to truck OEMs, including Allison Transmission, Arvin Meritor, Azure Dynamics, BAE Systems, Enova, Eaton Corporation and others. An additional system developer, Odyne, went out of business in 2009 and sold its assets to Dueco, with which it had developed class 6-8 aerial lift/bucket trucks. Of the remaining system integrators, only Azure Dynamics builds the hybrid drivetrain directly onto the truck chassis. More typical is the Eaton style arrangement, in which the system developer works with the truck OEM, manufacturing or modifying one or more components and sourcing the rest from other companies. The OEM generally integrates and installs the drivetrain into trucks on its production line.

Eaton is so far the only system developer that offers both hydraulic and electric drivetrains; it is also the hybrid drivetrain provider of the vast majority of hybrid trucks now available on the market. Since 1999 Eaton has produced more than 220 hybrid vehicles for testing and evaluation, including delivery vans, medium-duty delivery trucks, city buses, and utility repair trucks (Machine Design, December 13, 2007). Eaton's hybrid systems are available on truck models from Kenworth, Freightliner, International, and Peterbilt.

Hydraulic hybrid system developers include Bosch Rexroth, Eaton Hydraulics, Hybra-Drive, and Parker Hannifin. Technology providers—companies that provide various relevant hydraulic components—include the above four companies as well as Haldex and Hydraulic Innovations.

Truck OEMs. Each of the four major truck manufacturers in North America—Navistar, Daimler (Freightliner), PACCAR, and Volvo (Mack Trucks)—is involved in hybrid vehicle technology, along with at least 14 others. Hybrid truck models are currently available from at least 10 different U.S. truck makers, including Daimler Trucks North America, Freightliner Custom Chassis, International Truck and Engine, Kenworth and Peterbilt. The first U.S. truck maker to begin assembly line production of electric hybrids was International Truck and Engine Corporation in October 2007 (CALSTART).

At least six truck OEMs are currently developing hydraulic hybrids, including American LaFrance, Ford, Freightliner (Daimler), HALLER, Navistar, and Peterbilt (PACCAR). Hydraulic hybrid trucks now in prototype or testing include a Class 8 truck for refuse trucks and varied other applications, Freightliner Custom Chassis trucks for varied applications, a Ford pick-up truck, and an American LaFrance refuse truck.

End Use. At least 95 companies have integrated hybrid truck technology into their fleets, with that number expected to grow significantly in the next few years. Firms now successfully using Class 5-8 hybrids in their delivery fleets include Coca-Cola, FedEx, UPS, and Wal-Mart. Several entities have either purchased or are testing hybrid utility trucks, including Duke Energy, Sacramento Municipal Utility, and Verizon. In military applications, the Tank-Automotive

Research, Development and Engineering Center (TARDEC) and the National Automotive Center (NAC) are working in partnership with California-based non-profit CALSTART to demonstrate and assess the viability of hybrids via the Hybrid Truck Users Forum (HTUF).

Fleets actively involved in using, testing or developing hydraulic hybrid trucks include Corporate Express, FedEx Ground, UPS, the United States Postal Service, Onyx, Purolator, Waste Management Inc., and sanitation departments in several major cities.

R&D and Supporting Institutions. Government agencies such as the Department of Energy (DOE), Department of Defense (DOD) and the national laboratories have played an important role in developing hybrid commercial trucks, as are universities, R&D firms and manufacturers. The first hydraulic hybrid delivery truck was unveiled by the Environmental Protection Agency (EPA) in June 2006. Supporting institutions include federal and state agencies and several non-profit organizations, including the Environmental Defense Fund, CALSTART, the Hydraulic Hybrid Working Group (operated by NextEnergy) and several state agencies in California, New York, Washington, and other states.

CALSTART operates the Hybrid Truck Users Forum (HTUF), a national program that works with all major U.S. truck makers and system suppliers, together with more than 80 national commercial fleets (representing more than one million vehicles on the road). By sharing information between manufacturers and purchasers, HTUF has created a "fast-track" for assessing and developing vehicles. The program is credited with shortening the product development cycle for hybrid trucks by 1-2 years (CALSTART).

Component Manufacturers, Truck Manufacturers, and System Developers

Table 3 provides a list of companies involved in manufacturing, assembly, and research and development for hybrid medium- and heavy-duty vehicles. These firms range from large multinational corporations such as Siemens and General Electric to small, new firms with fewer than 50 employees, such as Peoria, Illinois-based Firefly Energy. Table 3 includes each company's headquarters and, where available, the U.S. manufacturing, assembly, and R&D locations relevant to hybrid trucks. Total company employees and total company sales, while not reflective of a given company's specific involvement in hybrid trucks, helps provide a sense of relative size of the players involved.

The 70 companies listed in this table are merely representative and do not nearly reflect the full extent of the component supply base, which is rich, varied, and growing quickly. These firms encompass involvement in well-established technologies as well as breakthroughs under development, particularly in the energy storage category. The supply chain consists largely of major new categories not present in conventional truck manufacturing, such as various electric motor types, hydraulic drivetrain components, and modifications to engines, transmissions and other existing components. In the power electronics and control systems segment, many emerging companies are working either independently or in partnership with large multinationals (Continental AG, Hitachi, Lockheed Martin) to develop and manufacture high-value advanced electronic technologies that are crucial to maximizing the performance of hybrid medium- and heavy-duty vehicles.

Table 3. Hybrid Medium- and Heavy-Duty Trucks: Selected Component Firms

Category	Company Name	Headquarters	Hybrid-Relevant U.S. Manufacturing, Assembly, and *R&D Locations*	Total Company Employees	Total Company Sales *(USD mil)*
ENERGY STORAGE SYSTEM					
Lead acid batteries	**Effpower**	Gothenburg, Sweden	n/a	n/a	n/a
Lead acid batteries	**Firefly Energy**	Peoria, IL	Milwaukee, WI	41	n/a
Lead acid batteries	**Johnson Controls**	Glendale, WI	Holland, MI	140,000	$38,062.0
Nickel-metal hydride batteries	**Cobasys**	Orion, MI	Springboro, OH	300	$112.0
Nickel-metal hydride batteries	**LG Chem[1]-Compact Power**	Troy, MI	n/a	n/a	n/a
Nickel-metal hydride batteries	**ECD Ovonics**	Rochester Hills, MI	*Rochester Hills, MI*	1768	$255.9
Nickel-metal hydride batteries	**Panasonic**	Osaka, Japan	n/a	305,825	$90,689.2
Lithium-ion (Li-ion) batteries	**A123**	Watertown, MA	Hopkinton, MA Livonia, MI Midland, MI[2]	1,100	$1.2
Lithium-ion (Li-ion) batteries	**Altair Nanotechnologies**	Reno, NV	Anderson, IN	105	$9.1
Lithium-ion (Li-ion) batteries	**EnerDel**	Indianapolis, IN	Indianapolis, IN	10	$1.0
Lithium-ion (Li-ion) batteries	**Hitachi Maxwell**	Osaka, Japan	n/a	4,881	$2,093.6
Lithium-ion (Li-ion) batteries	**ITRI**	Hsinchu, Taiwan	n/a	6,000	
Lithium-ion (Li-ion) batteries	**Johnson Controls**	Glendale, WI	Holland, MI[3]	140,000	$38,062.0
Lithium-ion (Li-ion) batteries	**KD Advanced Battery Group LLC[4]**	To be announced	MI, to be announced	900 (expected)	n/a
Lithium-ion (Li-ion) batteries	**NEC**	Tokyo, Japan	n/a	152,922	$3,379.0
Lithium-ion (Li-ion) batteries	**Saft Groupe S.A.**	Bagnolet, France	West Palm Beach, FL Valdosta, GA Cockeysville, MD	3,978	$767.4

[1] Compact Power is a U.S. subsidiary of the Korean company LG Chem

[2] A123 currently makes its Li-ion batteries in China (Gustafson, January 12, 2009). Michigan locations are planned facilities in partnership with Dow Chemical Company (Bennett, April 15, 2009)

[3] Planned facility, in partnership with Saft, expected to create 500 jobs (Bennett, April 15, 2009)

[4] KD Advanced Battery Group LLC is a joint venture between Dow Chemical and Kokam America. Facility location is to be announced (Office of the Governor, 2009)

Category	Company Name	Headquarters	Hybrid-Relevant U.S. Manufacturing, Assembly, and *R&D Locations*	Total Company Employees	Total Company Sales *(USD mil)*
			Valdese, NC		
	Sanyo Electric [5]	Osaka, Japan	n/a	29,302	$20,178.2
	SB LiMotive Co.[6]	Suwon, South Korea	n/a	n/a	n/a
	Tesla Motors	San Carlos, CA	San Carlos, CA San Jose, CA	276	$1.5
	Quallion	Sylmar, CA	Sylmar, CA	80	$6.9
Ultracapacitors	**BatScap**	Finistere, France	n/a	33,631	$0.4
	Compact Power	Troy, MI	Troy, MI	n/a	n/a
	EnerDel	Indianapolis, IN	Indianapolis, IN	n/a	n/a
	Maxwell Technologies	San Diego, CA	San Diego, CA	350	n/a
	AFS Trinity	Medina, WA	Livermore, CA	28	$7.3
ELECTRIC MOTOR/GENERATOR					
Permanent magnet	**Bosch Rexroth**	Hoffman Estates, IL	n/a	35,000	$8,235.0
	Hitachi America	Brisbane, CA	Harrodsburg, KY	n/a	n/a
	Raser Technologies	Provo, UT	Provo, UT *Orem, UT*	40	$0.3
	TM4, Inc.	Boucherville, Canada	Boucherville, Canada	110	< $10.0
	UQM Technologies	Frederick, CO	Frederick, CO	54	$7.5
	WaveCrest	Eden Prairie, MN	n/a	108	$9.5
AC induction	**Azure Dynamics**	Oak Park, MI	Woburn, MA	127	$2.8
	Enova Systems	Torrance, CA	Torrance, CA	70	$9.2
	Lockheed Martin	Bethesda, MD	n/a	140,000	$41,862.0
	Siemens VDO [7]	New York, NY	Sacramento, CA	398,000	$99,724.6
Integrated Motor Generators	**EMC**	n/a	n/a	n/a	n/a
	Robert Bosch	Stuttgart, Germany	n/a	282,000	$66,000.0
	Hitachi America	Brisbane, CA	Harrodsburg, KY	n/a	n/a
	Remy International	Pendleton, IN	Indianapolis, IN	n/a	$279.4
Transmission for HEVs	**Aisin Seiki Co. Ltd.**	Kariya, Japan	n/a	73,500	$27,554.0
	Allison Transmission Inc.	Indianapolis, IN	Indianapolis, IN	3,500	$326.6
	Fallbrook Technologies, Inc.	San Diego, CA	Lichfield, KY	50	$9.5
	Freescale Semiconductor Incorporated	Austin, TX	Austin, TX (2) Chandler, AZ Tempe, AZ	24,000	$5,700.0

[5] As of April 1, 2009, Panasonic is in the process of acquiring Sanyo Electric (Reuters, April 1, 2009)
[6] Joint venture between Robert Bosch and Samsung SDI; began operations September 1, 2008 (Bosch, 2008)
[7] Siemens VDO was acquired by Continental AG in 2007 (Continental AG, July 25, 2007)

Category	Company Name	Headquarters	Hybrid-Relevant U.S. Manufacturing, Assembly, and *R&D Locations*	Total Company Employees	Total Company Sales *(USD mil)*
POWER ELECTRONICS, CONTROL SYSTEMS AND SOFTWARE					
Converters and Inverters High-power DC to DC converters & DC to AC inverters	**AC Propulsion**	San Dimas, CA	San Dimas, CA	100	
	AccelRate	British Columbia, Canada	n/a	7	$1.9
	Aerovironment	Monrovia, CA	Monrovia, CA	543	$215.7
	Arens	Arlington Heights, IL	Arlington Heights, IL Carpentersville, IL	n/a	n/a
	Azure Dynamics Corporation	Oak Park, MI	Woburn, MA	127	$2.8
	Continental AG	Charlotte, NC	Huntsville, AL	n/a	n/a
	Delphi Electronics & Safety	Troy, MI	Kokomo, IN	n/a	$18,060.0
	Delta-Q	Burnaby, Canada	n/a	n/a	n/a
	DENSO Corp.	Karlya, Japan	n/a	119,000	$40,174.0
	DUECO Inc.	Waukesha, WI	Waukesha, WI	300	$60.0
	Enova Systems	Torrance, CA	Torrance, CA	70	$9.2
	Hitachi America	Brisbane, CA	Harrodsburg, KY	n/a	n/a
	Robert Bosch	Stuttgart, Germany	n/a	282,000	$66,000.0
	Satcon	Boston, MA	Canada	100-150	$54.3
	Siemens	New York, NY	Sacramento, CA	398,000	$99,724.6
	Tesla Motors	San Carlos, CA	San Carlos, CA	276	$1.5
	TDK	Garden City, NY	Shawnee, OK	74,071	$7,578.9
	UQM Technologies	Frederick, CO	Frederick, CO	56	$7.5
	U.S. Hybrid	Torrance, CA	Torrance, CA	n/a	n/a
Power Electronics, Control Systems and Software	**AC Propulsion**	San Dimas, CA	San Dimas, CA	100	n/a
	Robert Bosch	Stuttgart, Germany	n/a	282,000	$66,000.0
	Eaton	Cleveland, OH	Costa Mesa, CA Williamsburg, VA Youngsville, NC Hartford, CT Los Angeles, CA Sarasota, FL Decatur, AL Gainesboro, TN Los Angeles, CA Union, NJ Auburn, IN Milwaukee, WI Jackson, MS	75,000	$15,400

Category	Company Name	Headquarters	Hybrid-Relevant U.S. Manufacturing, Assembly, and *R&D Locations*	Total Company Employees	Total Company Sales *(USD mil)*
	Efficient Drivetrains, Inc.	Palo Alto, CA	Palo Alto, CA	n/a	n/a
	General Electric Transportation[8]	Erie, PA	Erie, PA Grove City, PA *Niskayuna, NY*	300,000	$183,000.0
	GridPoint	Arlington, VA	Arlington, VA	103	n/a
	Lockheed Martin	Bethesda, MD	Colorado Springs, CO Gaithersburg, MD	146,000	42,700
	Woodward[9]	Columbus, IN	Rockford, IL	n/a	n/a
	U.S. Hybrid	Torrance, CA	Torrance, CA	n/a	n/a
	V2Green[10]	Seattle, WA	Seattle, WA	n/a	n/a
	Valeo SA	Paris, France Troy, MI	Greensburg, IN Jamestown, NY	n/a	$12,891.0
HYDRAULIC HYBRID COMPONENTS					
Energy Storage Systems, Pump Motors, Control Systems and Software	**Bosch Rexroth**	Hoffman Estates, IL	*Rochester Hills, MI* Wooster, OH Bethlehem, PA Fountain Inn, SC	35,300	$8,235.0
	Eaton Hydraulic	Cleveland, OH	Spencer, Iowa Eden Prairie, MN	n/a	n/a
	Haldex	Stockholm, Sweden	n/a	5,489	$1,111.0
	Hybra-Drive	Deerfield, MI	Deerfield, MI	n/a	n/a
	Hydraulic Innovations	Almont, MI	Almont, MI Indian River, MI	3	$0.5
	Parker Hannifin	Cleveland, OH	Haverville, MA Randelman, NC Gardena, CA Redmond, WA Lincolnshire, IL Greenville, TN	57,810	$12,145.6

Company and sales information is from 2008, unless otherwise noted
Source: CGGC, based on company annual reports, company websites, personal communications, OneSource, Dun & Bradstreet, and (CALSTART).

[8] GE Transportation has demonstrated an electric hybrid mining truck for Komatzu (Koller, April 3, 2009)
[9] Woodward acquired MotoTron Control Solutions in 2008 (MarketWire.com, October 6, 2008)
[10] V2Green was acquired by GridPoint in 2008 (Lamonica, September 23, 2008)

Table 4 provides a similar list of truck OEMs involved in manufacture, assembly, and R&D for hybrid medium- and heavy-duty vehicles. These firms include large truck manufacturers such as Daimler, Navistar, PACCAR, and Volvo/Mack, as well as other large manufacturers for whom the truck division is significant even though it may not represent the majority of the company's total sales, such as Ford and GM. Of the 26 truck OEMs listed here, at least 10 are already selling hybrid medium- and heavy-duty trucks that qualify for IRS tax credits. These firms include Daimler Trucks of North America (Freightliner Trucks), Freightliner Custom Chassis, Dueco, Ford Motor Company, General Motors Corporation, International Truck and Engine Corporation (Navistar), Workhorse Custom Chassis (Navistar), Volvo/Mack Trucks, Kenworth (PACCAR) and Peterbilt (PACCAR).

Table 4. Hybrid Medium- and Heavy-Duty Trucks: Selected OEMs

Company Name	Headquarters	Hybrid-Relevant U.S. Manufacturing, Assembly, and *R&D Locations*	Total Company Employees	Total Company Sales *(USD mil)*
TRUCK OEMs				
AB Volvo	Gothenburg, Sweden	Macungie, PA *Hagerstown, MD*	100,000	$32,250.0
Mack Trucks	Allentown, PA	Macungie, PA *Hagerstown, MD*	800	$628.8
American LaFrance	Summerville, SC	Summerville, SC Ephrata, PA Hamburg, NY	7,512	$252.7
Beiqi Foton Motor Co. Ltd	Beijing, China	n/a	21,358	$3,663.6
Crane Carrier	Tulsa, OK	Tulsa, OK	1,600	$204.3
Daimler Trucks NA	Portland, OR		950	$2,799.4
Freightliner Trucks	Portland, OR	Mount Holly Springs, NC	3,100	$126,932.5
Freightliner Custom Chassis		Gaffney, SC	n/a	n/a
Orion Bus	Portland, OR	Mississauga, Ont. Canada Oriskany, NY	259,032	$145,897
Design Line	Charlotte, NC	Ashburton, NZ	n/a	n/a
Ford Motor Company	Dearborn, MI	Avon Lake, Ohio	246,000	$172,500.0
General Motors Corporation	Detroit, MI	Arlington, TX Janesville, WI Kansas City, KS	252,000	$181.1
Gillig	Hayward, CA	Hayward, CA	700	$71.8
Hino Motors	Novi, MI	n/a	n/a	n/a
Isuzu Commercial	Cerritos, CA	Cerritos, CA	23,712	$9,451.0

Company Name	Headquarters	Hybrid-Relevant U.S. Manufacturing, Assembly, and *R&D Locations*	Total Company Employees	Total Company Sales *(USD mil)*
Truck of America				
Iveco	Turin, Italy	n/a	21,358	$14,163.8
MAN AG	Munich, Germany	n/a	55,086	$19,803.7
Navistar International Corporation	Warrenville, IL	Springfield, OH *Fort Wayne, IN*	15,900	$14,724.0
International Truck and Engine Corporation	Warrenville, IL	n/a	1700	$236.1.0
Workhorse Custom Chassis	Highland Park, IL	Union City, IN	400	$54.6
New Flyer	Winnipeg, Manitoba	Winnipeg, Manitoba St. Cloud, MN Crookston, MN	2,319	$961.3[11]
Nissan Trucks	Ageo, Saitama, Japan	n/a	792	$123.5
PACCAR Inc.	Bellevue, WA	n/a	21,800	$15,221.7
Kenworth Truck Company	Kirkland, WA	Seattle, WA Chillicothe, OH *Seattle, WA* *Mt. Vernon, WA*	n/a	$15,221.7
Peterbilt	Denton, TX	n/a	20,000	$15,221.7
Oshkosh Truck Corporation	Oshkosh, WI	McConnellsburg, PA Oshkosh, WI Riceville, IA Dodge Center, MN Killeen, TX Orville, OH	14,000	$7,138.3
Scania AB	Stockholm	n/a	34,777	$10,054.4
Smith Electric Vehicles	United Kingdom	United Kingdom	n/a	n/a
Wu Zhou Long Motors Group	Shenzhen, China	Shenzhen, China	n/a	n/a

Company and sales information is from 2008, unless otherwise noted

Source: CGGC, based on company annual reports, company websites, personal communications, OneSource, Dun & Bradstreet, and (CALSTART).

[11] Total Revenue

A list of 10 firms involved in hybrid system development for electric hybrid trucks, and 4 firms similarly involved in hydraulic hybrid trucks, is found in Table 5. For electric hybrid trucks, five system developers provided drivetrains to the tax-qualifying models currently available; these include ArvinMeritor, Azure Dynamics, Eaton Corporation, Enova, and Odyne (which went out of business and sold its assets to Dueco in 2009). The category also includes Allison Transmissions, the world's leading supplier of hybrid city buses. For hydraulic hybrid trucks, Eaton Hydraulic has provided systems for models now available from International Truck and Engine Corporation (Navistar) and Peterbilt (PACCAR). Other developers currently working with truck OEMs on prototypes and testing of hydraulic hybrids include Bosch Rexroth, Hybra-Drive, and Parker Hannifin.

Table 5. Hybrid Medium- and Heavy-Duty Trucks: Selected System Developers

Company Name	**Headquarters**	**Hybrid-Relevant U.S. Manufacturing, Assembly, and *R&D Locations***	**Total Company Employees**	**Total Company Sales *(USD mil)***
ELECTRIC HYBRID SYSTEM DEVELOPERS				
AB Volvo/Mack	Gothenburg, Sweden	Macungie, PA *Hagerstown, MD*	100,000	$32,250.0
Allison Transmissions Inc.	Indianapolis, IN		3,500	$326.6
ArvinMeritor	Troy, MI	n/a	19,800	$4,819.0
Azure Dynamics	Oak Park, MI	Woburn, MA Wakarusa, IN	127	$2.8
BAE Systems Holdings Inc.	Rockville , MD	Lexington, MA Nashua, NH	88,000	$29,973.1
Dueco/Odyne	Waukesha, WI	Waukesha, WI	300	$60.0
Eaton Corporation	Cleveland, OH	Greenfield, IN *Galesburg, MI*	75,000	$15,400.0
Enova Systems	Torrance, CA	Torrance, CA	70	$9.2
ISE	Cleveland, OH	Maumee, OH	n/a	n/a
U.S. Hybrid	Torrance, CA	Torrance, CA	n/a	n/a

Company Name	Headquarters	Hybrid-Relevant U.S. Manufacturing, Assembly, and *R&D Locations*	Total Company Employees	Total Company Sales *(USD mil)*
HYDRAULIC HYBRID SYSTEM DEVELOPERS				
Bosch Rexroth	Hoffman Estates, IL	*Rochester Hills, MI* Wooster, OH Bethlehem, PA Fountain Inn, SC	35,300	$8,235.0
Eaton Hydraulics	Eden Prairie, MN	Spencer, Iowa Eden Prairie, MN	n/a	n/a
Hybra-Drive	Deerfield, MI	Deerfield, MI	n/a	n/a
Parker Hannifin	Cleveland, OH	Haverville, MA Randelman, NC Gardena, CA Redmond, WA Lincolnshire, IL Greenville, TN	n/a	n/a

Company and sales information is from 2008, unless otherwise noted.
Source: CGGC, based on company annual reports, company websites, personal communications, OneSource, Dun & Bradstreet, and (CALSTART).

Market Overview

In 2004, a multi-year collaboration between Environmental Defense Fund, FedEx and Eaton Corporation resulted in two prototype hybrid delivery trucks, which led to the first U.S. production capability for commercial medium-duty hybrid electric trucks. There has been a great deal of U.S. interest, both public and private, in developing electric and hydraulic hybrid trucks. The EPA and DOE have been closely involved, as evidenced by DOE's technology development projects with the National Renewable Energy Laboratory (NREL) and EPA's leadership in the development of hydraulic hybrids. The truck industry in Europe appears less involved in hybrid commercial vehicles—perhaps due to a greater focus on clean diesel—but several U.S. firms are active in Europe. For example, Bosch Rexroth has been testing hydraulic hybrids with the Berlin Department of Sanitation (Bosch Rexroth AG, September 4, 2008). Other examples of U.S. firms testing hybrid trucks abroad include Eaton Corporation's involvement in Europe with Daimler America/Freightliner trucks, and in Asia with China's Beiqui Foton Bus Company (Machine Design, December 13, 2007).

The U.S. hybrid truck industry has evolved much more quickly than that of Japan, where a single firm, Hino Motors (a Toyota Group company), accounts for approximately 6,000 hybrid trucks on the road (Hino Motors, 2009).[12] Hino has been working on hybrids since 1993, producing at low volumes, taking 15 years to reach the current production volume. In the United States, by contrast, a large number of firms forming a complex supply base have gone from producing the first prototypes in 2004 to early production of trucks in 2007. At least 25 US.-based truck makers and 15 U.S. hybrid system developers are actively involved in developing hybrids; many now have prototypes or are producing available hybrid models. A range of U.S. electric hybrids are now available for different applications such as package delivery vehicles, beverage haulers, and utility boom trucks. More than 95 U.S. commercial and utility truck fleets have so far purchased or are testing these hybrids, beginning with FedEx Express, which ordered the first hybrid trucks in the United States, United Parcel Service (UPS—total fleet of 73,000 vehicles), and Coca Cola (total fleet of 22,000 vehicles). Other large fleets adopting hybrids include Verizon (59,000 total vehicles) and Pepsi (19,000 total vehicles).[13]

Today there are well over 1,000 hybrid trucks on the road in the United States. The Hybrid Truck Users Forum expects U.S. production to reach an estimated 4,850 trucks by 2010, up from just 200 trucks in 2006. U.S. fleets have expressed so much interest in replacing conventional trucks with hybrid models that HTUF anticipates the market to reach an estimated 20,000 trucks by 2015 and 60,000 by 2020 (Van Amburg, 2009).

A combination of several key factors highlights the large market potential for medium- and heavy-duty hybrid trucks. These include the volatility and likely long-term rise of oil prices to a higher range; increasingly stringent emission regulations; emerging regulations to reduce truck engine idling; and the need to meet emissions requirements without reducing diesel engine efficiencies. Hybrid truck technology offers significant opportunities to address each of the above factors. In addition, hybrid vehicles are well suited to military applications. Supplying large amounts of fuel for military vehicles poses huge logistics and safety challenges, so the reduced fuel needs of a hybrid are a significant advantage even beyond the savings in cost and emissions. Especially in military applications, a hybrid’s ability to operate quietly and generate electrical power to operate equipment without the engine running are further market drivers (Technology & Maintenance Council (TMC), 2006).

Hybrid trucks present a unique opportunity for the U.S. industry. Hybrid technology in medium- and heavy-duty applications is still in the early stages, and U.S. manufacturers have a solid start. Since battery development for hybrid trucks involves several issues still to be resolved, U.S. firms have the opportunity to take the lead. Hydraulic hybrids also present a significant

[12] Hino has so far not sold hybrid trucks to the U.S. market, but plans to begin doing so in 2010. In the meantime, the company has begun to sell hybrid trucks on a small scale in Australia and New Zealand (Nikkei Net, 2009).
[13] Fleet sizes from (Fleet-Central.com, 2009).

opportunity, since there are no hydraulic hybrids yet in full production anywhere, but there is considerable advanced activity in U.S. firms. Hybrid Class 8 trucks, including long-haul, are another area of advantage; although there are no long-haul hybrids currently on the road, many are in development by U.S. firms, who are well-positioned to lead in this market through their experience serving the extensive interstate trucking system. Early Class 8 hybrid tractors, used in heavy regional hauling and delivery, are now in production.

One barrier faced by the hybrid truck industry is the need for a well-developed component market, so that truck OEMs have adequate options for sourcing the exact combination of components needed for a given application in a sufficiently short time frame. Fully addressing this problem would include encouraging not only domestic firms but also non-U.S. companies to manufacture components at U.S.-based facilities.

The main barrier to the industry, however, is that production volume has not yet reached a level sufficient to get costs down to a sustainable level for the market. Truck makers confront a chicken-and-egg dilemma, in that commercial fleets are not willing to make large orders until the price of the vehicles falls, yet without large orders the trucks must be priced high in order to recover production costs. Whereas fleet orders for hybrid trucks are currently in the 500-1,000 range, economic models show that each supplier needs sales of 3,000 to 5,000 per year in order to reduce their price premium to an acceptable level (Van Amburg, 2009). Hybrid truck sales thus far do not enable truck makers to do "forward pricing,"—or adjust the vehicle price downward in anticipation of future sales—a strategy that helped account for the rapid market success of Toyota's hybrid passenger car, the Prius. While a large, diversified firm such as Toyota can use more profitable divisions to compensate for losses in an emerging line until the new line gains a foothold, many truck makers do not have this option. Government guarantees or support programs are important for providing consistent, long-term help with the costs faced both by manufacturers and truck buyers.

One such support option is tax credits for the purchase of trucks. A list of currently available U.S. hybrid truck models that qualify to receive federal tax credits appears in Table 6. As of January 6, 2009, the list contained at least 54 trucks, identified by vehicle weight, model, and year. Buyers can obtain tax credits ranging from $3,000 to $12,000 for buying these Class 4 through Class 8 trucks (Internal Revenue Service, 2009). While these tax credits can help boost buyer demand, many truck fleets—and likely the majority of fleet customers for many truck makers—are non-taxpaying entities such as state agencies or utilities, and thus are not incentivized by tax credits. For these fleets, up-front buyer incentives are more effective. Ideally, such support could help shorten the payback time (in which the buyer recoups the extra cost of the hybrid through saved fuel and increased performance) to a more acceptable period, helping the industry reach the crucial tipping point where increased purchases make higher production volumes possible—which in turn brings the purchase price down.

Table 6. Available Tax-Qualifying Models of Medium- and Heavy-Duty Hybrid Trucks

Truck OEM	System Developer	Type of Truck	Commercial Fleet Purchaser	Model Year
Daimler AG				
Daimler Trucks North America LLC (Freightliner Trucks)	Eaton	Class 5-7 Delivery vehicle (** with ePTO and without PTO)		2008, 2009, 2010
		Class 6,7 Tractor		2009, 2010
Freightliner Custom Chassis Corporation	Eaton	Class 5-6 Step van and Utility truck	FedEx UPS	2006
		Class 4-6 Walk in truck		2006, 2007
Dueco				
	Odyne*	Class 6-8 Utility truck		Under development
Ford Motor Company				
	Azure	Class 2-4 Step Van, Strip-chassis, Cut-away chassis	FedEx, Purolator, AT&T, Refrigerated	2008
General Motors Corporation				
	Enova	Class 2-3 Van	Verizon	Under development
Navistar International Corporation				
International Truck and Engine Corporation	Eaton	Class 4-7 Utility		2006, 2007,2008, 2009
		Class 6-7 Step Van		In production
	ArvinMeritor	Class 8 Long haul	Wal-Mart	2009
	Eaton Hydraulic	Class 5 Delivery (Hydraulic)	EPA (Class 5 delivery)	2006
Workhorse Custom Chassis	Azure	Class 3-4 Step Van, Strip-chassis		2008
	Eaton	Class 5-6 Step In	UPS	2007
Mack Trucks/Volvo				
	Enova	Class 8 Refuse		Under development
PACCAR Inc.				
Kenworth	Eaton	Class 5-7 Utility	Dunn Lumber (Class 6)	2008, 2009, 2010
		Class 5-7 Delivery		2008, 2009, 2010
Peterbilt	Eaton	Class 6-7 Utility		2008, 2009, 2010
		Class 6-7 Delivery		2008, 2009, 2010
		Class 8 Long Haul	Wal-Mart	2008
	Eaton Hydraulic	Class 8 Refuse, (Hydraulic)		2008

Note: All these trucks qualify for an IRS tax credit ranging from $3,000 to $12,000.

*In January 2009, DUECO, Inc. and Utility Equipment Leasing Corporation acquired Odyne's assets to continue production of plug-in electric hybrid drive systems for medium and heavy-duty trucks.

** The Eaton ePTO (power take-off) reduces idling time.

Source: CGGC based on (Environmental Defense Fund, 2008) and (U.S. Department of Treasury, 2009).

As an alternative to tax credits, the Hybrid Truck Users Forum has proposed a government rebate structure for hybrid trucks that have demonstrated fuel efficiency gains. Under HTUF's proposal, truck purchasers would receive a rebate ranging from $5,000 to $40,000, depending on the size of the vehicle and its fuel efficiency gain over conventional models (see Table 7). Trucks would qualify for the rebate by demonstrating fuel efficiency gains through existing IRS or EPA guidelines. Rebate amounts would drop each year of the five-year program. Similarly, California's Air Resources Board, in its efforts to reduce criteria and toxic air pollutants, is now considering implementing a $25-million incentive program to offer qualifying truck purchasers vouchers of $10,000 to $35,000, plus an additional $5,000 voucher for the first hybrid truck or bus purchased by any fleet (Air Resources Board, 2009).

Table 7. Rebates to Purchasers of Hybrid Trucks (first year of rebate program*)

Vehicle Weight (pounds)	Demonstrated Fuel Efficiency Gain			
	20%	**30%**	**40%**	**50%**
8,500 - 10,000	$5,000	$10,000	$15,000	$20,000
10,001 - 14,000	$10,000	$15,000	$20,000	$25,000
14,001 - 33,000	$15,000	$20,000	$25,000	$30,000
	10%	**20%**	**30%**	**40%**
33,000 and up	$20,000	$27,500	$32,500	$40,000

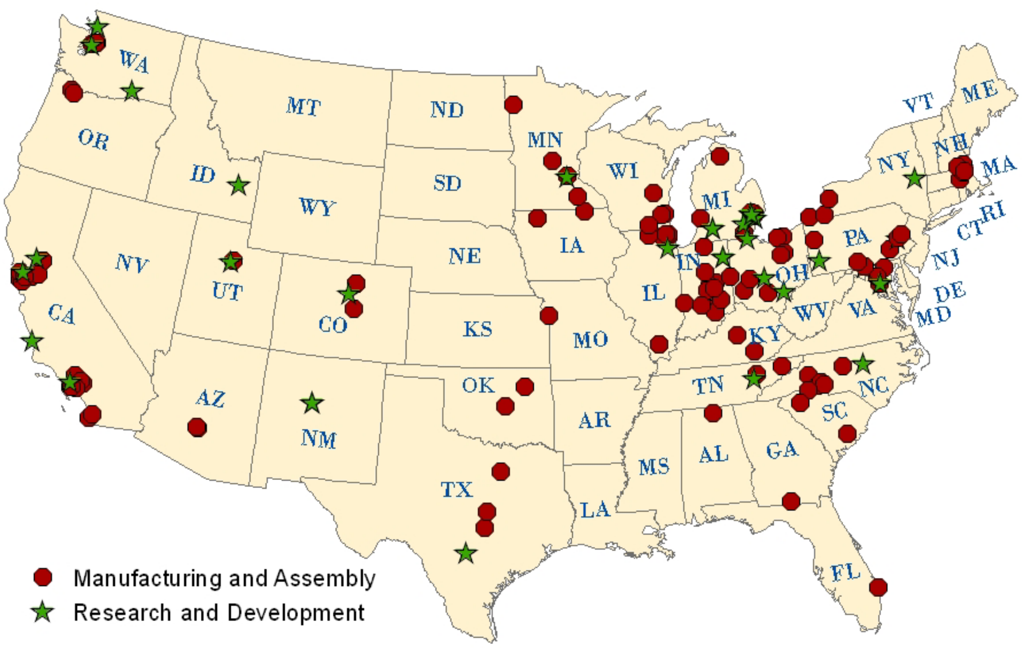
*Rebate amounts would drop each year of the five-year program.
Source: (Van Amburg, 2009)

Job Opportunities

Auto and truck manufacturing involves more linkages than almost any other industry, pulling together many components from several tiers of firms. Unlike passenger cars, trucks are manufactured a la carte—made piece by piece, often based on specifications for a specific fleet client. Hybrid trucks represent a diverse and complex array of component options, combined in many different ways according to the size and function of the vehicle and the manner in which it will be operated. Hybrid development is rapidly evolving to include not just hybrid components that are added to existing trucks, but new configurations for optimizing conventional components such as fuel tanks and engines, and electrification of others such as cooling systems. Although to date, hybrid truck makers have largely been able to use the same personnel on the same production lines as conventional trucks, any significant increase in production volume would likely translate not only into a commensurate increase in employment but also ripple effects among a wide range of component suppliers.

Existing jobs related to manufacturing, assembly, and research and development of hybrid trucks are dispersed among at least 143 locations nationwide, as shown in Figure 7. Much of this activity is found in the industrial states hardest hit by manufacturing unemployment; thus the infusion of capital and manufacturing jobs associated with the rapidly growing hybrid truck industry is occurring exactly where most needed. Research and development is most heavily represented in Michigan and neighboring states, with significant additional activity at several national laboratories and other federal and state agencies. A number of universities are involved in hybrid truck research, including University of Michigan, University of Toledo, and University of California Los Angeles. Manufacturing and/or assembly is largely concentrated in the Great Lakes region including Michigan, Wisconsin, Illinois, Indiana, Ohio, Pennsylvania and New York, with additional concentrations in Massachusetts, California, North Carolina, South Carolina, and Texas. Although many truck companies' sales are declining as would be expected from the current economic downturn—with some layoffs and plant closings—the long-term growth trend in hybrid trucks appears to be intact. For example, in March 2009, Kenworth Truck Company (a division of PACCAR) received its largest hybrid truck order to date, 150 diesel-electric tractors and 35 hybrid trucks (Puget Sound Business Journal, March 5, 2009).

Figure 7. U.S. Hybrid Medium- and Heavy-Duty Trucks: Manufacturing, Assembly, and R&D Locations



Source: CGGC, based on Tables 3, 4, and 5 above; company interviews and websites.

An expanding U.S. hybrid truck industry, particularly under the rapid growth scenarios expected by HTUF with volume reaching some 60,000 units by 2020, would mean not only additional truck manufacturing jobs but also a significant number of high-value design, engineering, electronics and software jobs. Hybrid trucks depend critically on these advanced technology systems to optimize fuel efficiency and performance, and given the wide range of configurations used in available models and those underdevelopment, this area promises to grow substantially in the future. In addition, the industry will also include employment in service networks, maintenance, and other industry infrastructure to support the vehicles. An example of such a facility is a new 18,000-foot service center opened by Peterbilt in December 2008 in Norfolk, Nebraska, where it is intended to serve a rapidly-growing transportation industry in the northeastern part of the state (Trucker.com, April 9, 2009).

The U.S. truck industry and federal and state governments are placing special emphasis on establishing domestic capacity in battery manufacturing despite the lead that Asian manufacturers have in the current generation of batteries. The United States is a leader in advanced battery research, and Michigan and other states recognize this as a strategic opportunity to lead the world in the next generation of energy storage systems for hybrid vehicles. On April 14, 2009, Michigan Governor Jennifer M. Granholm announced that four companies plan to invest more than $1.7 billion to establish advanced battery manufacturing plants, creating 6,683 new jobs in Michigan. The four companies are Johnson Controls-Saft Advanced Power Solutions LLC, LG Chem-Compact Power Inc., KD Advanced Battery Group LLC, and A123Systems Inc. (Office of the Governor, 2009).

Conclusion

The manufacture of hybrid medium- and heavy-duty trucks appears to be a significant competitive opportunity for the United States. U.S. truck makers, component manufacturers and system developers are well-positioned to command a future lead, having doubled U.S. production yearly in the first few years of entering the market. Dozens of models are available today and many additional ones are currently in field testing. U.S. firms have considerable momentum in developing not only new electric hybrid trucks, but also hydraulic hybrids, a newer technology in which, to date, domestic firms are leading. Several U.S.-made hydraulic hybrid trucks are now available or in testing, with others expected to become available as early as 2010.

The rapidly growing hybrid truck market promises to maintain and expand job opportunities in the truck industry even as the market for conventional trucks has dipped in recent years. Manufacturing, assembly and R&D for hybrid trucks are associated with traditional truck manufacturing jobs as well as advanced technology jobs in electronics and software. Much of this employment is concentrated in the industrial states that have been most affected by unemployment in manufacturing, including Michigan and surrounding states.

A particularly important opportunity for electric hybrids is the manufacture of advanced batteries, which constitute a “pinch point” in the value chain for technological and cost reasons that are yet to be fully resolved. Federal and state agencies and the industry are making efforts to establish manufacturing capacity in advanced batteries, emphasizing the next generation of devices that have yet to be used in hybrid vehicles. While additional breakthroughs in energy storage are likely, U.S. truck makers meanwhile have a number of hybrid models ready and are only in need of sufficient volume orders to scale up production. To bring down production costs in order to achieve the necessary volume, also needed is a multi-year commitment of continued government support for research and development, accompanied by assistance with purchase costs for interested truck fleets.

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