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FEDEX AND ENVIRONMENTAL DEFENSE: BUILDING A HYBRID DELIVERY FLEET

When Environmental Defense has seen a problem, we don't just oppose it—we propose an alternative and work directly with those involved to find answers. Often such solutions require uncommon alliances.

—Fred Krupp, President of Environmental Defense[1]

On April 22, 2005, FedEx Express announced that it planned to buy 75 hybrid delivery trucks for its U.S. fleet. Since 2000, Environmental Defense and FedEx had been collaborating to source a new generation of delivery trucks with dramatically improved fuel efficiency and environmental impact. At the time of the April announcement, FedEx had 18 prototype trucks in operation. The order for 75 more was an important intermediate step in bringing the project from the prototype stage into large scale production.

Gwen Ruta, Environmental Defense's director of corporate partnerships, viewed the FedEx announcement with satisfaction. The FedEx purchase of a significant number of clean, energy efficient trucks indicated that the project had succeeded in developing a vehicle that met the project's objectives: dramatically improved environmental performance, while meeting FedEx's functional and operational requirements. But, how should she define success? Reducing the environmental impact of the FedEx delivery truck fleet was important, but this was only a small fraction of the total number of delivery trucks in the U.S.—let alone the world.

THE PLAYERS

Many organizations were involved in developing a hybrid delivery fleet. The project began when Environmental Defense and FedEx began discussions about forming a partnership to investigate ways to improve the emissions and fuel economy of the FedEx fleet. FedEx invited companies to submit proposals to meet a set of performance requirements. Two teams submitted

[1] Environmental Defense Annual Report, 2004, p. 2. http://www.environmentaldefense.org/documents/4186_AR2004.pdf (June 28, 2005).

David Hoyt prepared this case under the supervision of Professor Erica Plambeck as the basis for class discussion rather than to illustrate either effective or ineffective handling of an administrative situation.

hybrid prototypes for evaluation, and a team led by Eaton Corporation (which would make the transmission), and Freightliner (which would make the chassis) won the competition.

Environmental Defense

Environmental Defense was a nonprofit organization formed in 1967 by a small group of scientists. Initially known as the Environmental Defense Fund, its first project was to help ban the pesticide DDT, which was causing serious harm to wildlife. The organization attempted to develop fair, non-partisan, and cost-effective solutions to environmental problems by using science, economics, and law. As a key part of this approach, it worked closely with select corporations on some of its environmental projects.

Environmental Defense believed that corporations had the ability to have a large positive impact on the environment, and developed partnerships with leading companies to accelerate positive environmental change, while at the same time bringing benefits to the companies. President Fred Krupp noted: "The American public does not want conflict between improving our economic well-being and preserving our health and natural resources. The early experience suggests it can have both."[2]

Environmental Defense initiated partnerships by identifying an important environmental issue, then approaching a leading corporation with a plan to work together to address the issue while simultaneously providing business benefits to the company. The first such partnership, begun in 1990, focused on packaging waste in the fast food industry. Environmental Defense worked with McDonald's to evaluate its packaging and design improvements, eliminating the use of polystyrene "clamshell" containers, and eventually reducing packaging waste by 150,000 tons over a 10-year period. It later worked with McDonald's to reduce the use of antibiotics in meat production. In 1998, it worked with UPS to improve the environmental profile of its overnight packaging. Other prominent corporate partners included Citigroup, BP, Bristol-Myers Squibb, and DuPont.

Environmental Defense had a staff of 260 scientists, economists, attorneys, and other professions, who provided technical, legal, and project management expertise to its corporate partners. In developing its partnership projects, Environmental Defense had two critical requirements: that any solution be made available to all other companies, and that Environmental Defense would accept no financial contributions from its corporate partner.

Environmental Defense received almost all of its financial support from individuals and foundations, with less than 1 percent coming from corporations. In 1999, the year before the FedEx partnership began, revenue was $31.4 million. By 2004, revenue was $50.5 million.[3,4]

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[2] Fred Krupp, "New Environmentalism Factors in Economic Needs," *The Wall Street Journal*, November 20, 1986.

[3] Environmental Defense Annual Report, 2004.

[4] Other organizations that worked with companies on environmental projects and other social responsibility initiatives charged consulting fees for their services or accepted donations from corporate partners. For instance Conservation International (www.conservation.org) worked with companies on projects to improve the environment and also provide economic value to their corporate partners, such as a program with Office Depot, the world's largest reseller of paper, to develop environmentally friendly paper sources. Another organization, Business for Social Responsibility (BSR, bsr.org), provided paid consulting services to companies related to social issues, including environmental issues. Conservation International had no restriction on corporate donations, and BSR

FedEx Express

FedEx Express began in 1971 as Federal Express, the product of a 1965 term paper by Yale University undergraduate Frederick Smith. In his paper, Smith criticized the practice of existing airfreight carriers that used passenger route systems—a practice he viewed as uneconomical. His paper described a system designed specifically for airfreight that could be used for time-sensitive shipments. After serving in the military, Smith launched FedEx to provide rapid shipment of high-priority goods.[5] Among FedEx's many innovations, it was the first company dedicated to overnight package delivery, the first to offer next-day delivery by 10:30 a.m., the first to offer Saturday delivery, and the first to offer a money-back guarantee. In 1990, FedEx was the first company to win the Malcolm Baldridge National Quality Award in the service category.[6]

FedEx Express had a strong position on environmental protection, and was one of the best Fortune 500 companies tracked by the Council on Economic Priorities (CEP) in environmental issues. In addition to the hybrid truck project, it had redesigned its packaging to decrease waste and greenhouse gas production and increase recycling, reduced the noise and pollution from its aircraft fleet, and replaced some ground vehicles with alternate fuel vehicles and low-emission vans. In 2005, FedEx completed the largest corporate solar energy project in California, on top of its Oakland regional hub facility.[7]

FedEx Express was one of the operating companies of FedEx Corporation, based in Memphis, Tennessee. It grew rapidly and expanded to more than 220 countries and territories by 2005. Its FY 2005 revenue was $19.5 billion, and its 139,000 employees transported more than 3.3 million packages daily. It had 670 airplanes, and a surface fleet of about 40,000 vehicles.[8]

By 2005, FedEx Corporation consisted of four core operating companies. In addition to FedEx Express, other operating companies included FedEx Ground, FedEx Freight, and FedEx Kinko's. In 2004, FedEx had acquired the Kinko's chain of 1,200 stores which provided copy and other office services, as well as selling office supplies, creating FedEx Kinko's Office and Printing Services. A year later, the company was considering establishing an Internet store, selling a wide range of office supplies and furniture. This would put FedEx into direct competition with its large office supply customers: Staples, Office Depot, and OfficeMax.[9] These companies, however, had already begun competing with FedEx Kinko's, providing printing, copy, and delivery services.

By 2005, FedEx Corporation grown to 250,000 employees and contractors in more than 220 countries. It moved more than 6 million shipments daily, using its fleet of 670 aircraft and more

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charged a consulting fee for its work. Rocky Mountain Institute also charged a fee for consulting. One of its areas of focus was on energy and environmental issues, and it worked with Wal-Mart to increase the efficiency of its heavy truck fleet (See http://walmartstores.com/GlobalWMStoresWeb/navigate.do?catg=348&contId=5626 for details (November 30, 2005)).

[5] Federal Express adopted the brand name "FedEx" in 1994.

[6] FedEx Corporate History, http://www.fedex.com/us/about/today/history/?link=2 (June 28, 2005).

[7] For more on FedEx's environmental policy, projects, and awards, see: http://www.fedex.com/us/about/responsibility/environment.html?link=4 (November 30, 2005).

[8] FedEx Express Facts, http://www.fedex.com/us/about/today/companies/express/facts.html?link=4 (June 28, 2005).

[9] Bob Tedeschi, "New Level of Competition: When a Supplier Gets Into Its Customer's Business," *The New York Times*, September 26, 2005, p. 8.

than 70,000 ground vehicles. Revenue in the fiscal year ending May 31, 2005 was 29.4 billion.[10] (For simplicity, in the balance of this case, "FedEx" will refer to FedEx Express.)

Eaton Corporation

Eaton was a diversified manufacturer with 2004 revenues of $9.8 billion from a wide range of industrial products for the aerospace, automotive, trucking and electrical industries. Eaton's Truck Components Division, headquartered in Kalamazoo, Michigan, had 11 plants in 9 countries. It made a wide range of drivetrain components for trucks, including axles, clutches, transmissions, driveshafts, and brakes. This group had $1.8 billion in 2004 revenues. Eaton made the transmission, the heart of the hybrid system, for the FedEx hybrid truck.

THE PROBLEM

Delivery vehicles were significant sources of pollution, and also large consumers of fuel. They traveled short distances between their many pick-ups and deliveries. Package delivery companies, the U.S. Postal Service, uniform delivery companies, and food companies such as Coca-Cola and Pepsi, all had fleets that ran delivery routes consisting of frequent short stops. These fleets typically used diesel powered vehicles, which provided substantially better fuel economy and performance than gasoline for the demands placed on delivery vehicles.

Diesel exhaust, a mixture of gas, liquid, and solids, is deemed dangerous to humans. Very small particulates, which include many toxic compounds, are emitted from diesel engines, and are easily breathed deep into the lungs of people in the vicinity of the emissions. In addition to particulate pollution, nitrogen oxides (NOx) and other compounds in diesel exhaust combine in the presence of sunlight to form ozone, which is also harmful to human health and the environment. Exposure to diesel exhaust has been linked to many health problems, including cancer, neurological problems, weakened immune systems, and respiratory and cardiovascular disease.[11] Environmental Defense estimated that for every 10,000 conventional FedEx delivery trucks that were replaced by hybrids, smog-causing pollution would be reduced by 2,000 tons a year—an amount equivalent to taking all passenger cars off New York City roads for one month. In addition, diesel fuel usage would be reduced by 6.5 million gallons per year, the equivalent of 930,000 barrels of crude oil.[12]

In addition to health problems caused by local pollution, combustion of diesel fuel generated carbon dioxide, a greenhouse gas. From a strictly economic perspective, consumption of diesel fuel was an important operating cost for delivery fleets. Reducing the amount of fuel consumed would simultaneously reduce costs and reduce emissions that harmed health and the environment.

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[10] FedEx Corporation Facts, http://www.fedex.com/us/about/today/companies/corporation/facts.html (June 28, 2005).

[11] Yewlin Yee, Cindy Copeland, Mark MacLeod, Jana Milford, Vickie Patton, Janea Scott, Nancy Spencer, "Cleaner Air For America: The Case For a National Program to Cut Pollution from Today's Diesel Engines," Environmental Defense, 2005, pp. 8-9.
http://www.environmentaldefense.org/documents/4488_cleanerairamerica.pdf (November 28, 2005)

[12] "Getting in Gear: Environmental Defense and Federal Express, Transforming Truck Technology in America," Environmental Defense Web site: http://www.environmentaldefense.org/partnership_project.cfm?projectID=3 (November 28, 2005)

Environmental Defense viewed developing new technology for delivery fleets as a way of making substantial improvements in total vehicle emissions and fuel consumption. In 2002, there were about 400,000 Class 4 vehicles, the class that included the FedEx W700 delivery truck, in the U.S.[13] About 75 percent of FedEx's total fleet of 40,000 trucks were Class 4 vehicles.

DEVELOPING A HYBRID DELIVERY VEHICLE

In early 2000, Environmental Defense contacted FedEx to see if it was interested in working together on a new project that would speed development of improved technologies for delivery vehicles. Environmental Defense had observed the development of cleaner and more efficient passenger vehicles, and noted that while there were important opportunities for improvements in commercial delivery fleets, development of cleaner and more efficient delivery vehicles was lagging. Delivery fleets were significant sources of pollution, and partnering with an industry leader offered the opportunity to achieve significant improvement.

Environmental Defense had already been introduced to FedEx in the late 1990s, when the two organizations had discussed an overnight packaging project.[14] FedEx was open to working with Environmental Defense, provided the project was something that was of major importance to the company. Developing a new generation delivery vehicle—one with dramatically reduced emissions and lower fuel consumption—was such a project.

In the early 1990s, FedEx had done a clean air project in which it evaluated several alternative fuel technologies. This project involved a fleet of more than 100 vehicles, which were operated in revenue service and evaluated over a period of several years. The results were mixed, in terms of vehicle performance, environmental performance, and infrastructure requirements. Many issues would have to be resolved before any of the alternative fuel technologies would be acceptable for use. Although the study failed to identify a viable alternative technology, FedEx continued to make incremental improvements to its fleet that resulted in improved fuel efficiency and lower environmental impacts.

The FedEx/Environmental Defense initiative focused on the standard FedEx medium delivery truck, the "W700." The company had about 30,000 of these in service.

At first, there was skepticism among some of the FedEx personnel regarding a partnership with an environmental organization. Jim Steffen, the FedEx chief engineer at the time, commented on the first meeting between FedEx and Environmental Defense: "We exchanged business cards, and I looked at the business cards and saw 'Environmental Defense' and I thought to myself, why are we ever meeting with these people?"[15] It became clear, though, that both parties were working toward common goals.

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[13] U.S. Census Bureau, "2002 Economic Census: Vehicle Inventory and Use Survey" ('VIUS Survey'), December 2004, pg. 14.

[14] FedEx had a project underway at the time to redesign their packaging to be more environmentally friendly, so did not work with Environmental Defense on that project. Environmental Defense worked on the packaging project with UPS.

[15] Environmental Defense, "Getting in Gear: Environmental Defense and FedEx Express: Transforming Truck Technology in America," DVD.

Mitch Jackson, head of environmental activities at FedEx Express, described the working relationship between the two organizations as the project progressed. He noted the traditional tension between environmental organizations and companies, and told of a meeting that he had briefly left. Reentering the room, he paused to observe the group interaction:

> If you had come into that meeting cold, and didn't know who was employed by whom—you had the manufacturing team, the environmental team, the ED [Environmental Defense] folks, and the FedEx folks—it would have taken you 10 or so minutes to figure out who worked for what organization. We were focused on the initiative at hand, and trying to get through the issues, not stating positions or policy points. It was very telling to me that there was, in fact, a lot that we had in common in trying to get real results.[16]

Specifications and Supplier Selection

The first step was to develop a set of specifications for the new truck. FedEx and Environmental Defense solicited proposals based on performance requirements, without reference to technology. This was intended to stimulate respondents to look for the best solution, rather than pre-judging which technology would be most appropriate. Jackson noted, "We looked at the … technology landscape, to see where solutions were at that point in time. We thought that there would be innovations occurring over that period, but if not, we wanted to spur innovation."[17]

The two partners established cross-functional teams that researched available technologies with the objective of developing a set of performance goals. The intent was to make these goals "aggressive yet potentially achievable."[18] Working together, they developed goals: increase fuel economy, measured in miles per gallon, by 50 percent (equivalent to a fuel consumption savings of 33 percent); decrease both NOx and particulate emissions by 90 percent; and maintain or improve on functional and operational performance when carrying out normal delivery operations. The economic goal was to achieve lifetime costs (procurement plus operating costs) that were no higher than those for an existing W700 delivery truck. The new truck was to be available within four years. The two partners then vetted these goals with FedEx's existing suppliers and with others in the industry. While many thought the objectives were overly aggressive, none thought that they were ridiculous. When an important existing supplier said to FedEx, "You're our biggest customer. If that's what you want, we'll work with you," the partners knew that the project was realistic.

FedEx and Environmental Defense then prepared a "Request for Information" (RFI) that they sent to many manufacturers in February 2001.[19] This short document gave the goals of the project and the basic specifications, and asked for non-binding proposals from interested

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[16] Quotations from interviews with the author, unless otherwise specified.

[17] "Getting in Gear (DVD)," loc. cit.

[18] Jackson noted that the partners decided that it was preferable to be too aggressive, and ultimately relax the requirements, if needed, than to underestimate what could be accomplished and try to make the goals more stringent as the project progressed.

[19] The RFI is available on the Environmental Defense Web site, at http://www2.environmentaldefense.org/documents/3529_FedEx-AllianceRFI.pdf (July 5, 2005).

suppliers. When they sent out the RFI, there was no assurance that any qualified suppliers would bid. As Ruta recalled, "We really didn't know for sure if anybody was going to be able to build a truck that met our goals. It was sort of like sending out invitations to a party, and you didn't know if anyone was going to come."[20]

There were over 20 replies to the RFI, some of which were not viable.[21] The partners narrowed the replies to four, each of which had been submitted by a team consisting of a transmission, engine and chassis manufacturer. Each of these teams proposed diesel-electric hybrids, which they viewed as the only way to meet the performance requirements within the four-year time horizon. The teams were led by the transmission manufacturers, since the power management systems were the key new technology being developed. One of the four finalists was led by Eaton, which had not previously developed hybrid systems, and had been viewed as a dark horse in the competition.

While many environmental organizations, and the public, viewed diesel engines as environmentally undesirable due to high particulate emissions, the technology for controlling particulates had greatly improved in recent years. The testing and validation of diesel-electric hybrids by Environmental Defense was important in gaining the environmental community's acceptance of this technology for delivery vehicles. Greenpeace later cited the FedEx/Environmental Defense project favorably in a study on improving the environmental performance of the Canadian delivery fleet.

The Development of a Hybrid Transmission at Eaton

In the summer of 1999, Eaton conducted a strategic planning exercise that identified commercial pickup and delivery vans as an important future market for hybrid electric vehicles. The duty cycle of these vehicles appeared to be perfectly suited to hybrid technology, as the frequent stops and starts would maximize the advantage of regenerative braking and use of an electric motor for starts. Also, package delivery companies were making more trips into neighborhoods, resulting in pressure to reduce local pollution and noise (the electric motor in the hybrid-electric powertrain was silent). The market was large, as there were many large commercial fleets, and new production (for fleet expansion and replacement of older trucks) was expected to be many thousands each year in North America alone.

To address this strategic opportunity, Eaton launched a hybrid program in early 2000, beginning by working on the technology at its Innovation Center. At the same time, the company talked to fleet customers and observed what competitors were doing. Eaton needed to carefully ascertain the market potential and proceed cautiously in its research and development expenditures. As in most advanced-technology projects, development costs could be of the same magnitude as lifetime product production costs, or even greater.

Eaton also participated in forming an industry-government collaboration, led by the U.S. Department of Energy. This group, the 21st Century Truck Partnership, included leading truck OEMs, engine manufacturers, and drive train manufacturers. There were 16 companies, 4

[20] "Getting in Gear (DVD)," loc. cit.

[21] For instance, the respondent might not have the capability to scale up to fleet production requirements, or the proposal might use a technology such as hydrogen that would not be practical within the four year time objective.

federal government agencies, and 12 national laboratories involved in the partnership (**Exhibit 1**). This group met monthly in Washington, D.C., starting on April 19, 2000.

The group's objective was to promote government/industry programs to improve fuel efficiency, reduce emissions, enhance safety, reduce ownership and operating costs, and maintain or enhance performance.[22] The participants believed that the government could help with fundamental research that would position U.S. companies favorably compared with foreign manufacturers. Eaton used these meetings to network and to understand the state of the industry, in addition to contributing its expertise to the partnership.

In the fall of 2000, Eaton met with FedEx to describe its vision for hybrid delivery vehicles, and to see if the company would accept prototypes to test. Eaton wanted feedback on what the users liked and didn't like about the hybrid prototypes, and planned to build a final product based on that feedback.

However, at this time FedEx was working with Environmental Defense to define the specifications for a next generation delivery vehicle. Eaton was not yet viewed as a serious player in hybrid technology, as other companies had more experience in this field. Kevin Beaty, the manager of Eaton's hybrid business unit recalled FedEx's response, "Please don't waste your time and money on this. You're already way behind. There are lots of other things you can do for us [with other products]. Please don't bother [with a hybrid system]."

Eaton told FedEx that it was committed to hybrids, would continue to work on the technology, and would like to keep FedEx informed of its progress. Eaton also asked to be sent a copy of the upcoming RFI, which FedEx agreed to do. Elizabeth Sturcken, the Environmental Defense project manager for the FedEx project, recalled, "When FedEx and Environmental Defense were sitting around the table handicapping this thing, we put Eaton in last place, frankly."[23]

Eaton, however, badly wanted to be part of this project. Beaty commented, "We were hungry. We were very hungry … We didn't have hundreds of engineers. We didn't even have dozens of engineers. So, we were trying to keep ourselves motivated to squeeze every ounce of creativity, every ounce of energy from within ourselves."[24]

Eaton's response to the RFI demonstrated the company's understanding of the technical and commercial issues, as well as its capability to perform, and Eaton was selected as one of four respondents invited to continue to the next round of the competition. By the time FedEx made the invitation, in May 2001, Eaton was already well along in building the first prototype of a medium delivery hybrid truck as part of its strategic initiative—a truck that was essentially the same as the one to be used for the FedEx competition—thus providing a great deal of time for testing and design improvements before the September 2002 tests.

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[22] "Technology Roadmap for the 21st Century Truck Program: A Government-Industry Research Partnership," December 2000, p. xv. Online at http://www.eere.energy.gov/vehiclesandfuels/pdfs/program/21ct_roadmap.pdf (Sept. 7, 2005)

[23] "Getting in Gear (DVD)," loc. cit.

[24] Ibid.

Selecting the Winner

For the next phase, FedEx and Environmental Defense had defined a series of tests that would establish the current vehicle's performance, and would be used to test proposed new vehicles. They ran the standard W700 through these tests at the Southwest Research Institute, an independent testing company, to determine the baseline performance of the existing truck.

Under confidentiality agreements, FedEx provided each of the finalists with operating cost objectives per vehicle mile (including maintenance costs). FedEx also fielded specific questions from each design team. These discussions were conducted under non-disclosure agreements.

The informal nature of the process required that the finalists take the initiative to fully understand FedEx's needs. The Eaton team was particularly involved in gaining a thorough understanding of all aspects of their potential customer's requirements. This understanding was important in the company's ultimate success.

The final selection was based on three factors: meeting the fuel efficiency and environmental objectives, an economic analysis, and a rigorous test of the vehicle's driving performance on the test track. The economic analysis included both the projected costs of the initial prototypes, as well as costs for a range of production volumes. FedEx intended to be a "launch customer" for the technology, stimulating manufacturers to develop products that could be sold to a broad range of fleets. It recognized that it would not purchase enough units to justify a manufacturer's product development and scale-up to economic production—manufacturers would have to sell to other fleets as well in order to have a successful business in hybrid delivery trucks.

Participants were required to deliver a prototype for testing in September 2002, and also to present their economic analyses. Eaton and one other company delivered prototypes for testing. Two additional companies had been invited to build prototypes, but dropped out—one because it wanted a purchasing commitment from FedEx prior to beginning prototype development.

Eaton had already been developing a prototype as part of its strategic move into the hybrid delivery truck market, and its truck was ready well in advance of the testing. The company took it to the Southwest Research Institute for pretesting in June and July 2002. The prototype was put through the same tests as would be used in the competition, thus providing Eaton with valuable information about vehicle performance. The other competitor had been busy with other hybrid projects, and did not start building a vehicle for the FedEx tests until it received word that it would be included in the September 2002 tests. This, combined with a more complicated design, meant that the competitor completed its prototype just prior to the delivery deadline.

One of the critical decisions that Eaton had to make was whether to try and meet every performance specification, or to trade off some of the fuel consumption and emissions specifications in order to make the truck less expensive and more reliable. The highest performance design, a "full hybrid," system used an engine which ran at a fixed speed. A device similar to a continuously variable transmission (CVT) provided the interface to the wheels, delivering the required speed and torque.[25] This decoupled the engine speed from the vehicle speed. One competitor announced in the fall of 2001 that it was working on a CVT-like approach that involved 43 different power flow paths (combinations of speed and torque). Eaton

[25] This is the technology used in the popular Toyota Prius passenger car.

had worked on this design in 2000, and understood the difficult technical issues, and high cost, involved in this CVT-like approach. Long term, Eaton believed that CVT functionality was the best solution. But they needed to introduce a practical powertrain in a relatively short time.

An alternative was a "direct hybrid" design, which was less complicated, as the engine drivetrain components were directly coupled, using just four or five power flow possibilities. Most of the efficiency and emissions gains could be achieved with this approach. However, the FedEx-Environmental Defense team had given no indication that it was open to compromise on its efficiency and emissions specifications. Eaton selected the "direct hybrid" technology for its submission, believing that it was a better overall combination of practical and performance considerations than a solution that relied on the more complex CVT technology.

In trying to meet the NOx requirements, Eaton faced a similar dilemma. They investigated options for reducing NOx emissions by the requested 90 percent, but the technologies that appeared to have this capability (including a NOx adsorber, and a catalyst to degrade NOx) were unproven, had unknown reliability, and were prohibitively expensive. Ultimately, Eaton did not incorporate these into its proposal.

The two finalists' prototypes were tested by the Southwest Research Institute in September 2002. The team led by Eaton, with a Mercedes (owned by DaimlerChrysler) engine and Freightliner chassis, was selected based on the results of these tests. The vehicle reduced particulate pollution by 93 percent, NOx emissions by 54 percent, and increased fuel efficiency by 45 percent compared to the standard delivery truck.[26] As part of its presentation, Eaton provided a series of potential improvements to the truck, and the expected increases in economy associated with these improvements. As team leader, Eaton provided information to FedEx about how much funding would be required to support initial field placement of pre-production test vehicles. (In a normal negotiation, the system integrator, in this case Freightliner, would negotiate prices directly with the end user — subsystems suppliers would not discuss prices with the end user.)

Sturcken observed that Eaton's performance thoroughly overcame the initial skepticism about the company's lack of hybrid experience. She noted, "We drove them hard … and the truck we ended up with performed best across all parameters. And that was Eaton Corporation."[27] Eventually, the Eaton truck would reduce particulate emissions by 96 percent, NOx by 65 percent, and increase fuel efficiency by 57 percent compared to the baseline truck.[28]

FedEx publicly introduced the hybrid electric truck on May 20, 2003. In its press release, the company indicated its intentions: "FedEx Express expects to purchase hybrid electric vehicles on the company's normal purchasing schedule for routes in the U.S. and Canada, where medium-sized trucks are used. This program has the potential to replace the company's 30,000 medium duty trucks over the next 10 years."[29] That potential could only be achieved, however, if

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[26] "FedEx-Alliance Future Vehicle Program: Eaton Hybrid Electric Vehicle Description & Measured Performance," March 24, 2003.

[27] "Getting in Gear (DVD)," loc. cit.

[28] http://www.environmentaldefense.org/partnership_project.cfm?subnav=project_fullstory&projectID=3 (July 5, 2005).

[29] FedEx Express press release, "FedEx Express Introduces Hybrid Electric Truck," *Business Wire*, May 20, 2003.

manufacturers could provide the vehicles in quantity, and at an economically viable price. (**Exhibit 2** provides a comparison of the standard W700 FedEx truck, and the hybrid vehicle.)

HYBRID-ELECTRIC TECHNOLOGY

A hybrid vehicle uses both an internal combustion engine (ICE) and an electric motor for power. The electric motor is powered by a battery storage system, which is recharged by the ICE and during braking. The vehicle is powered by the electric motor on start-up and at low speed. As speed increases, the ICE begins to provide power, taking over at speeds of more than 10-30 miles per hour.

In a conventional ICE vehicle, brakes convert the energy of the vehicle's motion into heat, which is lost to the atmosphere. In a hybrid vehicle, the wheels turn a generator when the driver releases the accelerator or applies the brake, recharging the batteries and slowing the vehicle. Brake use is reduced, used when deceleration produces more energy than the batteries can absorb, or in emergency situations. In addition to generating electric energy, this "regenerative braking" reduces wear on the brakes, and the associated maintenance costs. (See **Exhibit 3** for a diagram of a hybrid powertrain.)

By the early 2000s, a number of passenger cars employed hybrid technology, using gasoline engines as the ICE. For the delivery vehicle application, a diesel engine was used, as it was far more fuel-efficient and durable. As a result of federal government regulations, recent advances in emissions control technology had greatly alleviated the particulate emissions problems historically associated with diesel engines.

For delivery vehicles, hybrid power offered many attractive benefits:[30]

- Use of electric power from the battery enabled a smaller, more efficient ICE to be used. In the FedEx case, a 4.3 liter, 4-cylinder engine was used in the hybrid, replacing a larger 5.9 liter, 6 cylinder engine. Use of a smaller ICE reduced fuel usage and emissions.
- Brake maintenance costs were reduced due to regenerative braking.
- Acceleration at lower speeds (and from a stop) was better, as torque from the electric motor was highest at low speeds (as compared to an ICE, which had maximum torque at relatively high engine speeds). This was particularly useful for delivery vehicles, which made frequent starts, and generally traveled at slower speed.[31]

The key to making a hybrid vehicle work was the power management system, which controlled the ICE and electric motor, determined how much power to use from each source at any given time, and seamlessly used this power to drive the vehicle. When engineered correctly, the vehicle would start, accelerate, and cruise smoothly, even as the power was converting from full electric, through a combination of ICE and electric, to full ICE power.

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[30] http://www.environmentaldefense.org/documents/3530_Hybrids_FactSheet.pdf (July 5, 2005).

[31] Torque is a measure of the amount of force applied to cause an object to rotate. When starting from a stop, a relatively large amount of torque is needed to begin turning the wheels.

MOVING FROM PROTOTYPES TO PRODUCTION

In the spring of 2003, FedEx placed an order for 18 hybrid-electric delivery trucks.[32] The first two hybrids began service in Sacramento, California in March 2004, followed by ten in New York City and four in Tampa, Florida in October 2004, and two in Washington, D.C. in April 2005. These were largely hand-built, intended to prove out the basic design in actual delivery service.

On April 22, 2005, FedEx Express announced that it would add an additional 75 hybrid vehicles to its delivery fleet by the end of May 2006, contingent on price and availability. The new hybrids were expected to be placed in New York City and other cities.[33] The focus now turned to the production process.

Manufacturing a hybrid delivery truck differed in two respects from manufacture of conventional trucks. First, the hybrid transmission system had to be produced. Then, it had to be integrated into the chassis assembly.

Eaton designed the hybrid transmission, and built the prototypes in its product development facility in Galesburg, Michigan. The company planned for volume production of hybrid transmissions to be done in Greenfield, Indiana. The initial production was done using a job shop process, due to the low production volumes, with relatively high unit costs and low fixed investment. Only when demand increased to the point where production volumes were 500-1,000 units per year could the substantial investment in tooling be justified to achieve production economies. Using the simpler direct hybrid design enabled Eaton to manufacture the hybrid drivetrains using existing production capacity.

The standard delivery truck production process was for all components to be shipped to the chassis manufacturer, Freightliner Custom Chassis Corporation (FCCC), part of the Commercial Vehicles Division of Daimler Chrysler. In 2005, FCCC was the largest producer of trucks and specialty vehicles in North America. FCCC manufactured chassis for school buses, motorhomes, delivery vans, and shuttle buses. The company employed more than 750 people in its plant in Gaffney, North Carolina, and produced nearly 200 chassis daily, in one eight-hour shift. FCCC had been the sole supplier of delivery trucks to FedEx since 1995, and had worked with Eaton on the FedEx project, making the chassis for the hybrid truck.

Each chassis passed down a production line that was controlled by a moving chain, taking about 25 minutes from start to finish. The various components were added to the chassis at stations along the line, the most involved being the installation of the engine and drive train.

Each vehicle was built to order, and vehicles destined for several customers might be interspersed along the line, with the first being for one customer, the second for another customer, and so on. Computer monitors at each station provided instructions as to the specific requirements for each vehicle. After the chassis was fully assembled and tested, it was sent to another company to have the body added, then on to the customer.

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[32] FedEx bought an additional two hybrid powertrains as a reserve.

[33] FedEx press release, "FedEx Announces Plans to Add Up to 75 'Clean Air' Hybrid Trucks to Fleet," April 22, 2005.

The chassis used for the hybrid vehicle was developed collaboratively. FCCC sent a standard chassis to Eaton, which modified the chassis for the hybrid powertrain. FCCC and Eaton then reviewed the modified chassis, and developed a prototype.

When any new chassis design was first developed, one unit was built and extensively tested. The next step was to set up the production line for a "pre-production series" of 1-10 units. Engineers walked down the production line with each chassis, noting any problems, or assemblies that needed additional tools or fixtures. If any parts did not fit, or were missing, the chassis continued down the line, and the problems were fixed later.

The first 18 FedEx hybrids ("Gen 1") were produced by a modified version of this pre-production process. Because of the unique requirements of the hybrid system, particularly the batteries and high voltage circuitry, the first two Gen 1 units were assembled by FCCC without the hybrid drivetrain and batteries, which were installed by Eaton. For the remaining 16 Gen 1 units, FCCC installed the hybrid drive unit (motor, clutch, and transmission), but without the battery system. The chassis were shipped to Utilimaster, where the body and hybrid battery systems were installed.

After the Gen 1 units were completed, FCCC gave recommendations to Eaton for changes that could improve the ability of the vehicles to be mass produced. FCCC found design issues that required extensive production time, but with small changes and additional fixturing the required time could be dramatically reduced. For instance, in the Gen 1 design, the mounting of the hybrid powertrain and batteries interfered with the installation of the standard Utilimaster body, so that a redesigned cab floor was needed for the hybrids. Eaton then explored design changes so that Utilimaster would be able to install a standard body on the hybrid units.

Eaton and FCCC met weekly to plan these design changes, which were to be incorporated into the next order for 75 units ("Gen 2"). After making the changes, Eaton validated the performance of the modified truck.

The production of the Gen 2 vehicles would follow the normal production flow. Eaton would send the hybrid systems, including the batteries, to FCCC. FCCC would do the full chassis production using its standard production line process. Utilimaster would then add the body and ship the completed vehicle to FedEx. The first Gen 2 vehicle, however, would be used to prove out the design and durability. It was planned for evaluation at a test track in late 2005, in order to ensure that the brackets used to mount the batteries and other components were sufficiently strong, and that all the modified parts worked properly as a system. This testing was expected to be completed prior to the production of the 75 customer units scheduled to begin in early 2006.

CARS, TRUCKS, AND FUEL CONSUMPTION IN THE UNITED STATES

In 2002, there were about 223 million light duty vehicles (cars, motorcycles, pickup trucks, and SUVs), and about 6 million commercial trucks in the U.S. Of these, about 396,000 were in the 14,001 to 16,000-pound range ("Class 4")—the class of the FedEx truck, which had a rated weight of 16,000 pounds. However, the environmental impact and potential fuel savings from using hybrid technology is related to fuel consumption. Light duty vehicles consumed 137 billion gallons of gas, while medium and heavy commercial trucks consumed about 37 billion

gallons of gas and diesel fuel annually. Thus trucks, while comprising just 3 percent of the vehicle population, accounted for more than 21 percent of fuel consumption.[34] The useful life of a car was somewhat higher than for a medium delivery truck. FedEx planned to use its trucks for 10 years, while the EPA assumed a 14 year lifetime for passenger vehicles when evaluating alternative powertrain technologies.[35]

Though hybrids had become popular for passenger cars, the benefits appeared more compelling when applied to delivery vehicles. Cars were rarely used in the intensive stop-start mode that was the norm for delivery vehicles. The normal pattern of usage for delivery trucks, consisting of frequent stops and short drives between stops, meant that the relative improvement in fuel consumption and emissions would be much greater for trucks than passenger cars.

ISSUES IN FLEET DESIGN AND PROCUREMENT

FedEx had a U.S. delivery fleet of about 30,000 W700-class vehicles. These vehicles were not appropriate for most international applications, as they were generally too big for city streets in Europe and Asia. FedEx had started using the W700 in the mid-1990s, and the trucks had a useful life of 10 or more years. Therefore, over the next few years, many would be replaced. One of the issues facing FedEx, therefore, was how many of the new purchases should be hybrids.

Basic Vehicle Economics

The costs of purchasing and operating the FedEx delivery trucks were proprietary, but estimates of Class 4 delivery vehicle costs were used in an analysis of potential emissions reductions prepared for the Texas Council on Environmental Technology (TCET). The study assumed the price of a standard diesel truck to be $40,000, and the future price of a diesel-electric hybrid to be 30 percent higher once mature production volumes were achieved. The primary cause of the increased purchase price compared to a conventional vehicle was the hybrid powertrain (including the transmission, batteries, and motor), which were supplied by Eaton for the FedEx delivery trucks. The TCET study assumed that the standard diesel truck traveled 7 miles per gallon. Maintenance costs were estimated to be $0.16 per vehicle mile for the standard diesel, and about 10 percent less for the hybrid.[36] As a general rule, when FedEx replaced trucks of this

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[34] Data consolidated from: VIUS Survey, op. cit., pp. 13, 14, 25; Automobile Profile, Bureau of Transportation Statistics, http://www.bts.gov/publications/national_transportation_statistics/2002/html/table_automobile_profile.html (September 23, 2005); Annual Energy Outlook 2005, Supplemental Table 33, U.S. Department of Energy; Argonne National Laboratories, "How Much Fuel Do Trucks Use?" http://www.transportation.anl.gov/research/technology_analysis/truck_fuel_use.html (September 23, 2005). This analysis is based on the 1997 U.S. Census Bureau Vehicle Inventory and Use Survey. Fuel converted from BTU to gallons at 114,000 BTU/gal for gasoline, and 129,000 BTU/gal for diesel. Truck consumption assumed to be 32% gasoline, 68% diesel, based on truck census in VIUS Survey, op. cit., p. 28.

[35] Jeff Alson, Benjamin Allies, David Ganss, "Interim Report: New Powertrain Technologies and Their Projected Costs: Executive Summary," U.S. Environmental Protection Agency, October 2005, p. 1. Online at: http://www.epa.gov.otaq/technology/420s05013.pdf (November 30, 2005).

[36] William G. Barker and David Hitchcock, "Assessment of Potential Emission Reductions of Prototype Diesel/Electric Hybrid Pickup/Delivery Vehicles in the Houston-Galveston Region," Houston Advanced Research Center, November 12, 2003, p. 21.

type after about 10 years of operation, the trucks had little economic value remaining, and were scrapped for their material value. (**Exhibit 4** shows diesel fuel prices from 1999 through 2005.)

Eaton's Beaty, commenting on the price differential between conventional and hybrid trucks, noted that the company's public statement to government agencies considering financial incentives for hybrid buyers was that:

> Across the board, most companies are paying a minimum of 50 percent or more premium for the hybrid system compared to the base price of the vehicle. That's probably as good as you can do in the marketplace today … [Thus] if you had a commercial truck that cost $100,000 today as a diesel, then the hybrid version would be at least $150,000… . At some critical volume, certainly not one that we will be at in the next year or 18 months, we would expect, and we are targeting, to get that premium down to around 25 percent.

Routes Suited to Hybrid Delivery Vehicles

Hybrids were not well suited to long-haul routes, as in rural locations with many miles between stops. In those applications, most of the driving would use the ICE, with little use of the electric motor, and little regenerative braking.

At the other end of the spectrum, some large-city routes were poor candidates for hybrids. On some routes, for instance, the driver would park for as long as 45 minutes while delivering and picking up packages in a large office building. Vehicles for these routes did not drive enough miles for the reduced fuel costs to offset the higher acquisition cost of the hybrid vehicle. Because they did not drive enough to generate substantial emissions, there was little opportunity for reducing them.

Between these two extremes lay the majority of delivery routes, where the driver made frequent, short stops to pick up and deliver packages. Thus, the first two hybrid vehicles in New York City were used on Staten Island and in Brooklyn, in a light-urban to suburban environment. These routes made substantial use of the electric motor, recharged by regenerative braking, and offered dramatic improvement in fuel efficiency and emissions. The performance testing that had been the basis of the hybrid design specifications was based on this type of delivery route. Delivery vehicles such as those that FedEx would replace with hybrids typically logged about 20,000 miles annually. (See **Exhibit 5** for a representative distribution of miles driven per year by delivery vehicles.)

Disposal of Used Batteries

One of the issues in the management of a hybrid-electric fleet was battery life, and the handling of used batteries. Batteries were a critical component of the hybrid system, accounting for substantial volume and weight that had to be accommodated in the chassis design. They were also expensive, and had a limited useful life. Battery technology was also rapidly progressing.

Eaton purchased the batteries used in the FedEx hybrid from Hitachi. FedEx's purchase agreement stipulated that Eaton take back the batteries at the end of their lifetimes. FedEx did not want to create a clean vehicle only to generate a large, dirty waste stream, and anticipated

that the used batteries would eventually be recycled by Hitachi. In fact, Eaton's discussions with Hitachi confirmed that the specific Li-ion battery chemistry being incorporated into the design had a very high degree of recyclable content. Thus, Eaton was ensured that virtually no environmental damage would arise at the end of the useful life of the batteries.

Ultimately, FedEx wanted to obtain batteries on a lease basis, where it would pay a negotiated amount per mile, or per hour of use. FedEx wanted its trucks to work, and preferred that someone else own the batteries and be responsible for ensuring that they worked properly. However, in mid-2005, it was not possible to lease batteries.

The initial batteries used in the FedEx hybrids were expected to last at least five years. A new design was expected to provide the same life, but be half as large. The batteries on one passenger hybrid came with a 9-year warranty that was not prorated—the manufacturer replaced it at no charge within the warranty period. But, due to the rapidly evolving technology, and the complex supply chain relationships (battery manufacturer, hybrid powertrain manufacturer, vehicle manufacturer), battery leases were not yet available.

Government Interventions

Government could promote increased fuel economy and reduced emissions in three ways: through research and development, regulation, or financial incentives. Intervention by one level of government might also drive different forms of intervention by other levels of government. For instance, federal regulations requiring reduced emissions (a "stick") might stimulate state and local governments to offer financial incentives (a "carrot") to encourage changes in areas that were out of compliance with the federal regulations.

Governmental intervention through research and development activity could be seen in the 21st Century Truck Partnership, in which Eaton was an active participant. This effort utilized government research centers, in combination with industry leaders, to define and develop technology that would provide substantial improvements in fuel economy and emissions for trucks.

Once a promising technology was identified, the primary challenge for manufacturers was obtaining sufficient demand to justify investments in specialized production resources and design for manufacturing that would lower the production cost per unit. Production cost would decrease with production volume simply through learning-by-doing. Unfortunately, vehicle purchasers would be disinclined to pay the high price for the first, expensive units produced, especially given the risk of quality problems inherent in any new product introduction. For instance, producing hybrids in low volume was expensive, yet without buyers for these early units, production could not grow to efficient production levels, and price premiums for hybrids could not dramatically decrease. Potential manufacturers and purchasers of hybrid vehicles faced a "chicken and egg"-type of coordination problem. Without high demand, manufacturers could not make the investments needed to reduce the production cost and improve quality. Without a reduction in the price premium and guarantee of quality, fleet operators could not justify buying a large number of hybrid vehicles.

Widespread deployment of hybrid vehicles would alleviate both local and global problems. Eliminating NOx and particulate pollution would have health benefits for local or regional

populations. Improving fuel efficiency would address global climate change (through reduced carbon dioxide emissions) and also benefit the national economy (through reduced energy demand and prices) and national security (through reduced reliance on foreign countries to meet the nation's energy needs). Therefore, regulators at the federal, state, and local governments all had some interest in encouraging the adoption of hybrid vehicles.

When federal air quality regulations were promulgated, state and local governments that were out of compliance needed ways to reduce pollution. Conversion of delivery fleets to cleaner technologies offered important opportunities to meet these requirements. Government regulations for truck emissions, however, did not look at the entire vehicle. Unlike regulations for cars, where emissions were measured at the tailpipe, the EPA looked only at the truck engine. The engine was run on a dynamometer through a prescribed duty cycle, and certified if it met minimum standards. This process did not take into account add-on devices such as particulate traps, which FedEx used on its trucks. Environmental Defense was trying to persuade the EPA to adopt performance requirements that represented the total vehicle.

States and municipalities were early adopters of incentives for technologies that reduced pollution and improved fuel economy. This was particularly the case in localities with pollution problems, such as Texas, New York, and California—some of which were locations of the initial FedEx hybrid truck placements.[37] The incentives typically took the form of grants that partially offset the price premium of the hybrid vehicle as compared with a conventional vehicle. In some cases, the amount of the grant depended on the amount of pollution that would be reduced over the expected operating life of the vehicle.

Crafting incentive programs often involved environmental groups, manufacturers, and fleet operators, working together with legislators and other political leaders. The environmental groups wanted to make sure that incentive programs were constructed in a way that rewarded purchase of vehicles that reduced pollution and improved fuel efficiency, as contrasted to using hybrid technology to increase engine size and power while maintaining emissions. Manufacturers and fleet operators wanted to ensure that the incentives would address the problem of low volume/high price for early production units, and help them reach economical production volumes.

In 2005, Congress passed an energy bill that provided the first federal incentives for purchase of commercial hybrid vehicles. The bill provided tax credits for a portion of the incremental cost of the hybrid vehicle compared to an equivalent vehicle with conventional power. For vehicles weighing between 14,000 and 26,000 pounds, the maximum incremental cost allowed is $15,000. The percentage of the incremental cost that is provided as a tax credit is determined by the percentage increase in fuel economy. For the FedEx case, with a fuel economy improvement of over 50 percent, the law provided a tax credit of 40 percent of the incremental cost, or $6,000 per vehicle.[38] These credits were to expire at the end of 2009.[39]

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[37] Florida, where two of the initial FedEx systems were placed, did not have a formal program, but the Florida Department of Electricity and Power made a grant to cover some of the incremental cost.

[38] Energy Policy Act of 2005, Title XV, Subtitle D—Alternative Motor Vehicles and Fuels Incentives, Section 30B(c)(3)—Credit Amount for Heavier Vehicles.

[39] Energy Policy Act of 2005. Subtitle D—Alternative Motor Vehicles and Fuels Incentives.

SUMMARY

By 2005, the FedEx hybrid delivery truck project had achieved many milestones. Pre-production trucks were operating on routine delivery routes, demonstrating their ability to meet their delivery performance objectives while dramatically reducing fuel consumption and emissions. Manufacturers were scaling up for volume production. Additional delivery companies were expressing interest in hybrid vehicles, offering the promise of increased volume and decreased unit prices. As Sturcken observed, "This project does not stop with FedEx. It goes on to try to create change throughout the entire trucking industry." In fact, early in the project, she had hired someone to help replicate the FedEx program in other fleets.

FedEx had received a great deal of publicity as a result of the project. In April 2005, FedEx, Environmental Defense, and Eaton received a Clean Air Excellence Award from the U.S. Environmental Protection Agency for developing the hybrid delivery truck.[40]

From Ruta's perspective, this was a good first step, but the real improvements in emissions reduction would not come until large numbers of existing trucks were replaced by hybrid trucks. FedEx was leading the way, but success required other large fleets to adopt the technology.

[40] "2004 Clean Air Excellence Awards Recipients," US EPA, http://www.epa.gov/air/caaac/2004awar.html (September 7, 2005).

Exhibit 1
21st Century Truck Partnership Members

The 21st Century Truck Partnership consisted of the following companies and governmental organizations:

COMPANIES

- Allison Transmission
- BAE Systems
- Caterpillar
- Cummins Engine
- DaimlerChrysler
- Detroit Diesel Corporation
- Eaton
- Freightliner
- Honeywell International
- International Truck and Engine
- Mack Trucks
- NovaBUS
- Oshkosh Trucks
- PACCAR
- Volvo Trucks North America

FEDERAL GOVERNMENT

- U.S. Department of Energy
- U.S. Department of Defense
- U.S. Department of Transportation
- U.S. Environmental Protection Agency

NATIONAL LABORATORIES

- Argonne National Laboratory
- Brookhaven National Laboratory
- Idaho National Laboratory
- Lawrence Berkeley National Laboratory
- Lawrence Livermore National Laboratory
- Los Alamos National Laboratory
- NASA Ames Research Center
- National Institute of Standards and Technology
- National Renewable Energy Laboratory
- Oak Ridge National Laboratory
- Pacific Northwest National Laboratory
- Sandia National Laboratories

Source: Department of Energy, http://www.eere.energy.gov/vehiclesandfuels/about/partnerships/21centurytruck/21ct_partners.shtml (September 2, 2005).

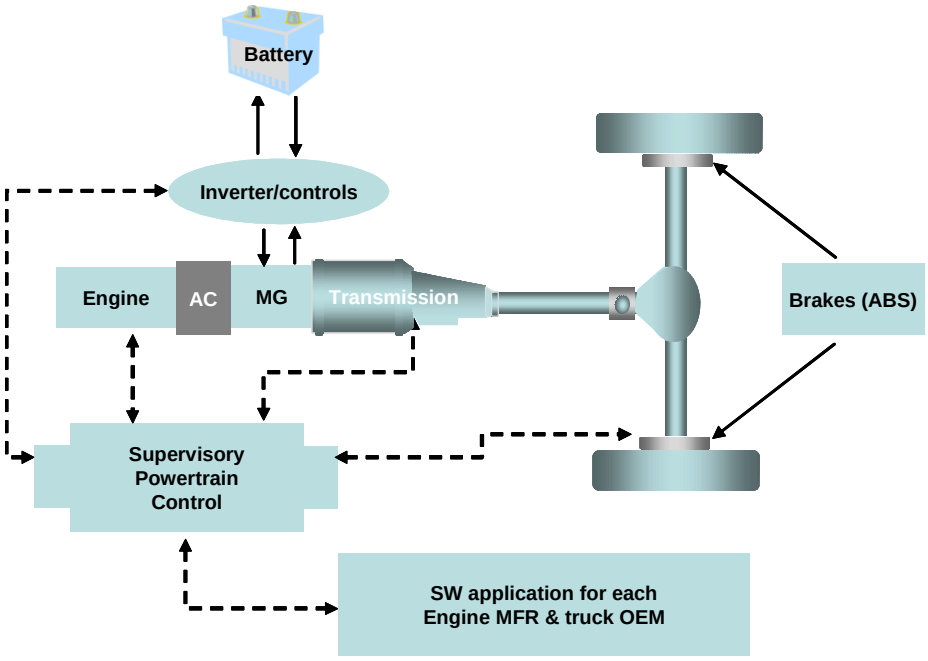
Exhibit 2
Comparison of W700 and Hybrid FedEx Delivery Truck

Characteristics	**Conventional Truck**	**Hybrid Truck**
Model	W700 Step Van	W700 Step Van
Body	Utilimaster	Utilimaster
Chassis	Freightliner MT45	Freightliner MT45
Cargo Area	700 cubic feet	700 cubic feet
Engine	5.9L Cummins I6 Diesel	4.3L Mercedes OM904 I4 Diesel
Transmission	Allison AT542FE	Eaton FO-8406A-ASX
Rear Axle Ratio	4.10	3.31
Tires Front	Front: Goodyear G647 225/70R19.5	Front: Goodyear G647 225/70R19.5
Tires Rear	Rear: Goodyear G159 225/70R19.5	Rear: Goodyear G159 225/70R19.5
Wheels	19.5 inch, steel	19.5 inch, steel
Brakes	Hydraulic	Hydraulic
Weight GVWR (lbs.)	16,000	16,000
Payload (lbs.)	5,720	5,390
Test Weight (lbs.)	13,280 (includes 3,000 lbs. of payload)	13,610 (includes 3,000 lbs. of payload)

The typical purchase price for a conventional medium delivery truck in the W700 class was $40,000.

Source: http://www.environmentaldefense.org/documents/4061_PrototypeTruck.pdf (July 15, 2005). Purchase price estimate from Barker, loc. cit.

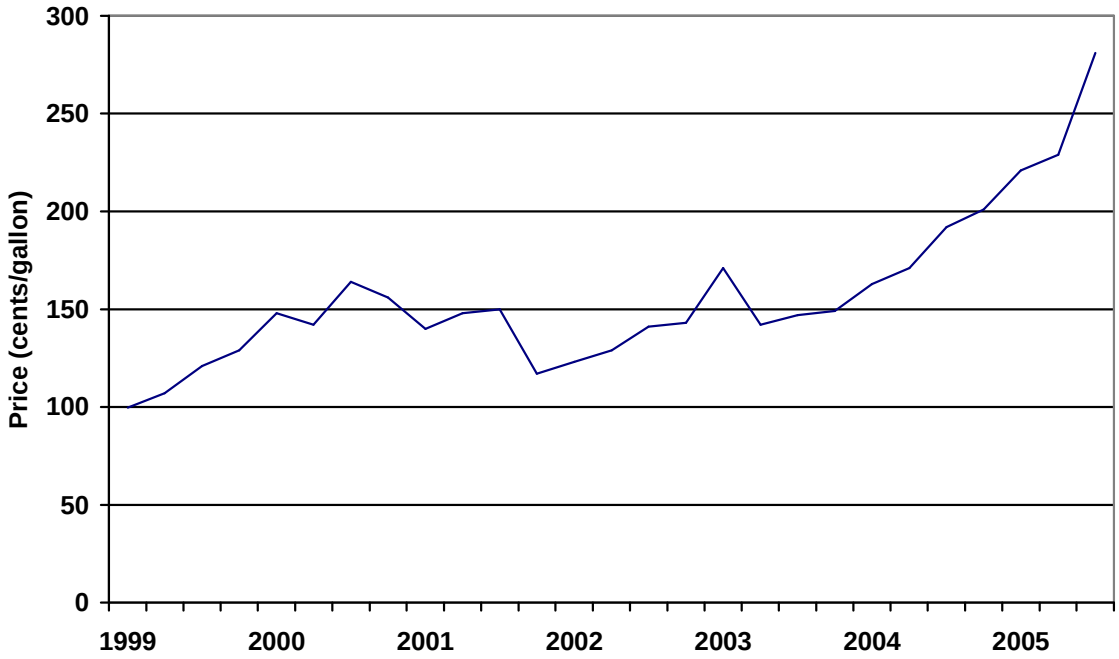
Exhibit 3
Eaton Hybrid-Electric Powertrain



The Eaton hybrid-electric powertrain replaces the conventional transmission and clutch. It consists of an automated transmission, automatic clutch (AC), and electric traction motor. The supervisory powertrain controller controls the operation of the hybrid system, monitors status, and manages communication with other onboard systems.

Source: Eaton Corporation: http://www.environmentaldefense.org/documents/4061_PrototypeTruck.pdf (September 30, 2005). Used with permission.

Exhibit 4
Diesel Fuel Prices, 1999-2005

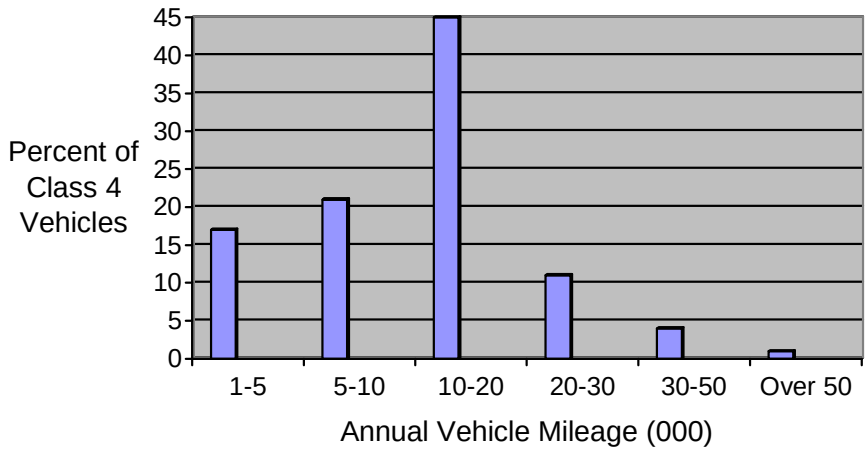


Data is U.S. Number 2 diesel retail sales by all sellers.

Source: Based on data from U.S. Department of Energy, http://tonto.eia.doe,gov/oog/ftparea/wogirs/xls/psw18vwall.xls (November 30, 2005).

Exhibit 5
Annual Miles Driven by Delivery Vehicles

The number of miles driven each year by FedEx delivery vehicles varied according to location and route. The following chart illustrates the range of vehicle mileage for Class 4 vehicles, using data from the U.S. Census 2002 Vehicle Inventory and Use Survey. This data provides an average mileage per vehicle that is consistent with the estimates used in the study prepared for the Texas Council on Environmental Technology.



Source: Data derived from U.S. Census Bureau, microdata file for "2002 Economic Census: Vehicle Inventory and Use Survey," issued on CD December 2004.