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*The Role of Public – Private  
Clean Diesel R&D  
Partnerships in the Regulatory  
Process*

*Christine Bik-Kay Ng*

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*Massachusetts Institute of Technology  
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THE ROLE OF PUBLIC-PRIVATE CLEAN DIESEL R&D PARTNERSHIPS  
IN THE REGULATORY PROCESS

by

Christine Bik-Kay Ng

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and the Department of Civil and Environmental Engineering  
in Partial Fulfillment of the Requirements for the Degrees of  
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Signature of Author.....  
Technology and Policy Program, Engineering Systems Division  
Civil and Environmental Engineering  
May 9, 2003

Certified by.....  
**Joanne Kauffman**  
Principal Research Scientist, Laboratory for Energy and the Environment  
Thesis Supervisor

Certified by.....  
**D. Eleanor Westney**  
Society of Sloan Fellows Professor of International Management  
Thesis Supervisor

Certified by.....  
**David Marks**  
James Mason Crafts Professor of Civil and Environmental Engineering  
Director, Laboratory for Energy and the Environment  
Thesis Reader

Accepted by.....  
**Oral Buyukozturk**  
Professor of Civil and Environmental Engineering  
Chairman, Departmental Committee on Graduate Studies

Accepted by.....  
**Daniel Hastings**  
Professor of Aeronautics and Astronautics and Engineering Systems  
Director, Technology and Policy Program  
Chairman, Committee for Graduate Students



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## ABSTRACT

This research considers the influence that public-private clean diesel R&D partnerships have on emission regulations in the U.S. While there is substantial literature on the contribution of public-private R&D partnerships to facilitating organizational learning, innovation, and national competitiveness, there has been little research on its influence on environmental policy and rulemaking. Understanding whether partnerships are influential in the regulatory process, and the conditions under which they are influential, will increase awareness of the potential regulatory impacts of future partnerships. This research focuses on the effects of such partnerships on U.S. Environmental Protection Agency (EPA) rulemaking with respect to diesel fuel quality in heavy-duty vehicles.

Diesel exhaust contains air pollutants such as particulate matter and nitrogen oxides, which have adverse human health and environmental impacts. For this reason, the heavy-duty diesel industry in the U.S. has been subject to increasingly stringent federal emission regulations. The EPA sets technology-forcing standards in order to drive industry progress in emissions reduction. Since the EPA bases its rulemaking largely on its appraisal of technological development in industry, technologists in companies and research organizations play an important role in providing the EPA with timely technical information.

A comparative analysis of three public-private partnerships, all of them including several industry and government partners, formed the basis for a comparative case study. The partnerships investigated the effects of diesel fuel quality, particularly sulfur levels, on emissions reduction. Publicly available documents, interviews, and questionnaires provided insights on the three partnerships and public-private partnerships in general.

The comparative analysis reveals that public-private partnerships do play a role in influencing policy, but that role is limited by the circumstances of each partnership and regulators' preference to rely more on other sources of knowledge for technical input. A clear understanding of upcoming regulations, broad stakeholder involvement, and the generation of publicly accessible results are all critical to a partnership's potential regulatory influence. Partnership results can directly provide input to a regulatory decision, but its effects on technological progress, knowledge networks, and further research collaboration are also relevant to the regulatory process.

Thesis Supervisor: Joanne Kauffman

Title: Principal Research Scientist, Laboratory for Energy and the Environment

Thesis Supervisor: D. Eleanor Westney

Title: Society of Sloan Fellows Professor of International Management



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# CHAPTER 1: RESEARCH FOCUS

## *Introduction*

When the U.S. Environmental Protection Agency (EPA) regulates vehicular emissions as part of its mandate to improve air quality, it typically sets technology-forcing standards, pushing the automotive industry to improve existing technologies or develop new technologies to meet those standards. Situations where emissions reduction comes at increased costs to the industry often propagate an adversarial relationship between EPA regulators and members of the industry who shoulder the largest cost burden. While EPA standards tend to raise the costs for an entire sector or industry, some firms are better equipped to adapt to change. Firms which anticipate stricter standards and plan accordingly are at an advantage relative to their competitors. Others vigorously resist new regulations, eventually challenging standards in court after they have been implemented. Regulations may pit one industry against another, who may disagree on the justification for the new regulations. Emissions reduction relies on a variety of interdependent technologies that are produced by different industries. A regulation may create a market for one industry's products while at the same time increasing the cost for the industry that must purchase those products.

Since transportation is such a vital part of the U.S. economy and the EPA's objective is to improve air quality, it is in the EPA's interest to verify that the automotive sector is capable of meeting tighter standards. Meanwhile, the industry benefits when it receives clear signals of future EPA standards because firms can better manage their technology R&D to enhance performance, cost-competitiveness, and regulatory compliance. Mechanisms are needed to improve the coordination between the EPA and industry such that their interests are considered and the environment is protected.

Since the EPA bases its rulemaking largely on its appraisal of technological progress in industry, technologists in firms, research organizations, and universities play an important role in providing the EPA with timely technical information. Knowledge about emissions-reducing R&D activities and regulations flows through a network of people, many of them technologists,

who help shape both the public and private sector policy towards emission regulations. While emission regulations often drive environmental R&D, can R&D influence the regulatory process?

I hypothesize that public-private environmental R&D collaboration operates as a formal means to facilitate knowledge flows among technologists and policymakers, flows which then feed into EPA rulemaking. The EPA relies on technologists' assessment of current and upcoming technologies, and their feedback on the technical feasibility of new regulations. Regulations built on a solid technical basis should reflect technological progress and continue to drive additional innovation. Since regulators may receive conflicting assessments on the technical feasibility of proposed regulations, partnerships may help to clarify some points of dispute and fill knowledge gaps. R&D partnerships may also promote the interaction of companies and regulators on a technical level in addition to the regulatory level.

Using a comparative case study approach, this research explores how knowledge-sharing and decision-making mechanisms, in the context of public-private partnerships, can provide valuable technical inputs into the policy process. Under what conditions do partnerships have a role in the regulatory process? To what extent do the formal knowledge networks created by the partnerships improve environmental rulemaking?

Boundary spanners, individuals who bridge across organizations or functions, have a potential role in mitigating some of the conflicts that emerge in environmental rulemaking. In addition to participating in public-private partnerships, they also hold positions on advisory panels and committees and build connections through conferences, trade associations, and informal external contacts. How do they assess the value of partnerships, and their impact on the regulatory process? How do their perspectives on partnerships vary based on their functional or organizational roles?

While public-private R&D has often been cited for its benefits to organizational learning, innovation, and national competitiveness, there has been little research on its influence on environmental policy-making. Popular business literature has embraced knowledge networks as a vehicle for innovation and learning, but its potential to advance environmental goals through R&D has not been adequately addressed.

This research seeks to improve the understanding of how the flows of knowledge and the formal knowledge networks created by clean diesel partnerships influence the regulatory process. The intention is to learn from past and existing partnerships and to increase the awareness of potential regulatory impacts. The predominant motivation of public-private R&D partnerships will still be technology development, but recognition that the partnerships may have policy relevance and influence will benefit future partnership planning.

Existing academic and business literature has helped to shape the direction of this research and drawn attention to areas for further study. In defining the research focus, the rest of the chapter surveys both the academic literature and popular business press in their treatment of corporate environmental strategies, collaborative R&D, and knowledge networks, with attention to the relevance to clean diesel R&D. The next section begins by discussing the changing corporate perspective on environmental issues, from the birth of the environmental movement in the 1970s to the recent emphasis on sustainability in the 21<sup>st</sup> century. As environmental regulations place pressure on industry to innovate, firms have increasingly turned to external sources of knowledge, often in the form of collaborative R&D, to meet the challenges of environmental innovation. Government concerns about underinvestment in R&D and national competitiveness have prompted public-private partnerships, often characterized by cross-organizational and cross-functional collaboration. One of the key motivations for collaborative R&D is knowledge transfer, which is discussed in the context of knowledge networks. Boundary spanners play a vital role in these knowledge networks because of their capacity to bridge across organizations and functions. The chapter ends by identifying gaps in the existing body of literature, which overlooks the potential to influence regulatory policy as a driver of R&D.

### ***Evolution of Corporate Attitudes about Environmental Performance***

In the 1960s, rapidly increasing public awareness about environmental damage led to the creation of the U.S. Environmental Protection Agency in 1970, and a series of major environmental legislation: Clean Air Act (1970), Federal Water Pollution Control Act (1972), Endangered Species Act (1973), Toxic Substances Control Act (1976), Safe Drinking Water Act

(1976), Clean Water Act (1977), Resource Conservation and Recovery Act (1978). In terms of industrial and manufacturing processes, the 1970s focused on end-of-pipe treatment, while the 1980s focused on waste minimization. The environmental regulations led to a substantial amount of environmental innovation to develop pollution reduction and end-of-pipe technologies (Lanjouw and Mody 1995). However, the EPA's media-based, "command-and-control" regulatory structures were characterized by adversarial relations between regulators and industry. Industry came to view environmental compliance as a "necessary evil" and a "cost of doing business" (Hoffman 2000).

In the early 1990s, many companies shifted the focus of their environmental activities from pollution control to pollution prevention (Lent and Wells 1994). There was also growing interest in corporate strategies that went beyond regulatory compliance, rather than those that reacted to regulatory requirements. This movement has been given a variety of names, such as "product stewardship," "environmental quality management," "green management" (Preston 2001, Hoffman 2000, Madu 1996, Vaitilingam 1993). While they all have slightly different meanings, they are all centered on environmental strategies that move beyond compliance. In the 1990s, companies began to view environmental protection as commingled with economic competitiveness rather than as a "good" within itself (Hoffman 2000). Environmental protection could be integrated with strategy and technology development to produce opportunities for business growth (Hart 1997). Some of the most common strategies to improve corporate environmental performance beyond compliance are summarized below:

Cost reduction: Reducing costs may go hand-in-hand with improving environmental performance. For example, reducing waste generation saves money that would otherwise go to transporting waste and paying disposal fees. Conserving electricity lowers the energy bill while decreasing pollutants emitted in the electricity generation process. Tools such as life cycle analysis and "design for environment" help product designers examine the environmental effects of a product throughout its life cycle. The identification of ways in which resource consumption and waste production can be reduced also results in cost savings.

Product differentiation: Companies choose products or processes that have greater environmental benefits or fewer environmental costs than their competitors'. The companies differentiate their products in the market, which may enable them to charge higher prices and/or capture larger market share. It does require the company to identify a market for the environmentally friendly product, communicate the product's environmental benefits credibly, and distinguish itself from imitators enough to earn a profit (Reinhardt 1999).

Competitive regulatory strategy: A proactive approach towards environmental innovation gives companies more time and flexibility to introduce a new technology and capture competitive advantage. By advancing technology, a company can offer more input to potential legislation, which may result in stricter standards and a higher return on their original investment (Vaitilingam 1993). The expectation is that companies will be able to strategically position environmentally responsible products to capture and gain competitive advantage more aggressively (Preston 2001). In some cases, stricter environmental regulations may increase costs for the company, but it can benefit if the higher standards cost its competitors disproportionately more. This requires a company to convince government regulators of environmental regulations that will benefit their product (Reinhardt 1999). For example, large multinational firms may have an interest in promoting stricter and harmonized standards, because of their higher financial and technical capacity relative to smaller firms. Those smaller firms face higher costs and greater difficulty in meeting the standards (Foster 2001). Maintaining environmental standards stricter than those required by law may also improve a company's reputation and work as a marketing tool to attract customers (Madu 1996). Green marketing by companies will contribute to environmental awareness, and further spur customer demand for their products and services (Preston 2001).

Risk management: Effectively managing business risk from environmental problems serves as a source of competitive advantage. Companies may face accidents, lawsuits, and boycotts, but they can reduce their risks from these incidents occurring by being responsive and flexible to new information and building in systems to react quickly to unexpected events (Reinhardt 1999). Well-publicized accidents and penalties may

damage a company's reputation and financial performance. Taking on a preventive approach to pollution can reduce environmental fines, cleanup costs, and environmental liabilities (Madu 1996). For example, product substitution may avoid the production of environmentally harmful substances in the first place, and stem concerns about accidental releases or improper disposal.

Redefining business models: Product take-back and service contracts are examples of ways in which companies can change how they do business. With product take-back, some manufacturing firms have garnered profit and public support from taking “end-of-life” products from customers, reusing the parts, and selling remanufactured equipment. Customers do not have to worry about disposing of the equipment themselves (Reinhardt 1999). For example, in Germany, “take-back laws” require automakers to assume responsibility for vehicles at the end of their useful lives. This gives an incentive for German automakers to manufacture vehicles that are easier to disassemble and recycle. Long-term service contracts can motivate companies to design their products for greater durability and energy efficiency if they are responsible for covering operation and maintenance costs.

These environmental strategies are part of a way of looking at corporate environmental management that is similar to the “Total Quality Movement” (TQM), which started in Japan in the 1980s. TQM was concerned about continuously improving the quality of products and services. Many of its principles parallel the “corporate environmental quality management” movement – going beyond compliance, cost-cutting, zero defects/zero emissions, continuous and incremental improvement, widespread employee participation (Vaitilingam 1993, Porter and van der Linde 1995, Madu 1996, Cole 1999). Both movements emphasize the importance of a strong guiding vision from management as well as the commitment from employees at all levels (Madu 1996). Preventing defects (TQM) or preventing pollution (environmental quality management) produces a higher-quality product that helps a company earn a better reputation among its customers. Environmental quality management may have become an offshoot of the 1980s TQM movement because managers could take advantage of the language and tools already developed by TQM (Lent and Wells 1994).

There is an inherent barrier to the spread of environmental quality management. Suppose companies view environmental quality as a competitive weapon, not necessarily as a proactive competitive regulatory strategy, but as the ability to meet environmental regulations at a cost lower than their competitors. Those with mature environmental technology may be unwilling to share information with their competitors (Madu 1996). Since environmental quality is a “public good,” this reluctance to transfer knowledge results in a suboptimal level of environmental performance across any given industry. Vertical strategic alliances among manufacturers, suppliers, vendors, and even customers offer a means to share information and reduce the high cost of R&D in developing less polluting technologies (Madu 1996). While there would be greater resistance to knowledge sharing and horizontal strategic alliances among competitors, benchmarking is one way for companies to learn from the best performers in the industry (Madu 1996).

Environmental responsibilities are not confined to the environmental management divisions in companies. More than half of the companies surveyed in a research study by Lent and Wells (1994) had some environmental responsibility located in the manufacturing and product development/R&D divisions. This shows the importance of the R&D function as a source of environmental innovation. R&D managers must be well-versed in the issues of environmental regulation and environmental management. In the long term, it is expected that environmental responsibilities will be better integrated throughout a company’s culture (Hoffman 2000). In addition to spreading environmental responsibilities across different business units, companies also extend their environmental management outside their firm, to their suppliers and customers. Supplier management was the first example of environmental management moving beyond the boundary of the firm (Lent and Wells 1994). As environmental considerations move across company boundaries, there is the challenge of facilitating communication and coordination among diverse groups who may specialize in R&D, manufacturing, sales, or accounting. This reinforces the need for strong direction and commitment to environmental goals from upper management.

The most recent trend has been a movement from the corporate environmental management of the 1990s to the more holistic approach of corporate sustainability. According to many ecologists, the earth’s resources and its capacity to “absorb” human waste and emissions

have been stretched to their limits, and overuse of resources threatens to diminish the quality of life for future generations. Sustainable development is most commonly defined as “development which meets the needs of the present without comprising the ability of future generations to meet their own needs (Bruntland 1987). It is not enough to employ pollution prevention practices and aim for zero emissions, which mainly rely on internal process improvements. Sustainability requires companies to look outwards at the impacts of their business practices on society as a whole. For example, a company may need to consider not only the amount of raw materials used in a process, but the sourcing of the materials and the impact of materials extraction on the local economy (Hart 1997).

Corporate social responsibility (CSR) rose in prominence in the business jargon around the same time as corporate sustainability. The World Business Council for Sustainable Development defines CSR as “the commitment of business to contribute to sustainable economic development, working with employees, their families, the local community and society at large to improve their quality of life” (WBCSD 2001). Although the business literature discusses corporate sustainability alongside corporate social responsibility, there is recognition that economic growth will be a more persuasive argument for businesses to pursue sustainable strategies than unselfish concern about environmental or societal improvement (Holliday 2001, Hart 1997, WBCSD 2001).

Like the corporate environmental management strategies that emerged in the 1990s, sustainable solutions will require technological innovation. In the motor vehicle industry, technological progress has led to substantial improvement in emissions reduction and fuel economy. Although this progress has been largely driven by regulation rather than industry initiative, there is a growing trend of companies trying to take a more proactive, sustainable approach towards innovation (Hart 1997, WCSBD 2001b) For example, Honda and Toyota have forged ahead of the rest of passenger auto industry with their use of lighter materials and hybrid electric propulsion systems, which reduce fuel consumption and tailpipe emissions.

## ***Government Regulation and Technological Innovation***

As mentioned earlier, environmental regulation can have the effect of spurring environmental innovation. Many researchers have referred to environmental regulations as “focusing devices” for motivating innovations once environmental concerns are brought to the forefront by high pollution levels, environmental disasters, and mounting public pressure (Lanjouw and Mody 1996, Pearce 1990, Rosenberg 1976,). According to Ashford (2000), “regulatory stringency is the most important factor influencing technological innovation.” A regulation is stringent when compliance requires significant pollution reductions, costs, or technological change (Ashford 2000). In some cases, compliance to a stringent regulation requires all three. While meeting regulations can pose significant costs on industry, “properly designed environmental standards can trigger innovations that lower the total cost of a product or improve its value” (Porter and van der Linde 1995). Porter and van der Linde argue that regulators tend to view regulation-setting with a static mind-set, rather than accounting for the dynamic competitive environment, where firms innovate to meet regulations. However, Porter and van der Linde’s arguments seem to apply mainly to practices tied specifically to reducing resource consumption, which do lower material costs and waste. In the case of diesel vehicle emissions, their argument may be less applicable, since environmental regulations focus on “end-of-pipe” pollution control. Government regulators do account for technological innovation from industry and typically set technology-forcing emission standards, which often require a substantial R&D effort. The extent to which regulations are enforced affects an industry’s impetus to innovate (Ashford 2000). If enforcement is credible, the industry has a greater incentive to innovate, whereas the possibility of delaying or loosening standards may convince an industry to stall its R&D efforts.

Porter and van der Linde (1995) suggest a set of principles for “innovation-friendly regulation.” Of particular relevance to the question of R&D’s impact on regulations is their suggestion to “require industry participation in setting standards from the beginning.” They believe that a more cooperative approach, such as the one that exists in Europe, should be implemented in the U.S., as opposed to the more adversarial approach that currently exists. A predetermined set of information requests and interactions with industry representatives would provide useful information to regulators (Porter and van der Linde 1995). Although this strategy

seems appealing and more efficient, it runs the risk of regulators becoming too close to the industry that it is regulating and suiting regulations to industry's demands. (Stigler 1971). Also, it would be difficult to overcome regulators' skepticism of industry claims, especially if industry-government relations have already been strained from past mistrust. Porter and van der Linde acknowledge that industry often overstates the expected compliance costs of environmental regulations. If companies have historically painted a pessimistic picture of the dire effects of regulation and yet have still managed to meet standards cost-efficiently, regulators have more reason to question their estimates in the future.

Companies whose countries have relatively stringent regulations may feel at a disadvantage to competitors whose countries have less stringent requirements. Stringent regulations may in fact have indirect benefits to domestic companies. If environmental regulations are stricter in the U.S. relative to other countries, American firms who are forced to innovate earlier may have the competitive advantage in foreign markets when other countries begin to strengthen their regulations. Their first-mover advantage will allow them to capture a larger market share when foreign firms are still catching up to meet increasingly stringent regulations in their home countries (Porter and van der Linde 1995).

Although market-based strategies such as SO<sub>2</sub> emissions trading are attracting greater interest in the U.S., most environmental regulations still rely on "command and control" legislation that uses specific standards or procedures to limit pollution. Governments may also use tax incentives, R&D subsidies, labeling, and information dissemination to encourage the development of environmentally beneficial technologies. Research on environmental innovation shows that innovation, as measured by patents, typically increases as R&D expenditures increase (Lanjouw and Mody 1996). The one major exception is vehicular air pollution. In the U.S., spending rose continually since the early 1970s, while the share of vehicular air pollution patents in total patents fell from 1973 to 1985. Lanjouw and Mody (1996) speculate that regulations may have constrained innovation or that new forms of vehicle technologies have not been reflected in the patent data. From the 1970s to 1980s, two-thirds of U.S. vehicular air pollution patents were granted to foreigners, mostly in Japan and Germany. These results definitely raise questions about the return of U.S. investment in vehicular air pollution technology, and the viability of U.S. firms in this area. Lanjouw and Mody's research also demonstrates that U.S.

vehicle emission regulations, which have been historically stricter than other countries, drive environmental innovation in foreign countries planning to sell to the U.S. market. As technologies improve and pollution levels decrease, public awareness and support for further pollution reduction increase, fueling cycles of further regulation and innovation.

### ***External Collaboration and Social Networks***

Firms have been increasingly reaching outside of their organizations to find fresh perspectives for a variety of functions, from research and development to marketing. In the area of research and development (R&D), the 1980s witnessed a surge in growth of inter-firm partnerships, growing from 30 established annually in the late 1960s and early 1970s to over 500 established annually by the late 1980s (Hagedoorn 2002). External collaboration often takes the form of inter-firm alliances, but it can also take the form of partnerships with academic institutions, research laboratories, or the government.

There is an extensive body of literature on the role of external collaboration in innovation. R&D is most often referred to as the primary activity for which external collaboration contributes to innovation. R&D partnerships are defined here as “cooperative arrangements engaging companies, universities, and government agencies and laboratories in various combinations to pool resources in pursuit of a shared R&D objective” (Council on Competitiveness 1996).

The following are some of the most commonly cited reasons for firms to engage in external collaboration: To (1) obtain access to external knowledge and resources, (2) obtain access to new markets and technologies, (3) facilitate organizational learning, (4) accelerate rates of innovation, (5) contribute to firm growth, (6) improve corporate reputation, (7) maintain firm survival, (8) pool complementary skills, (9) share costs and risks, (10) reduce or eliminate competition between allied companies, and (11) elevate the position of an entire industry or sector. (Powell et al. 1996, Hagedoorn 1993, Mitchell and Singh 1996, Hamel 1991, Stuart et al.

1999; Kogut 1989, Kleinknecht and Reijnen 1992, Mowery and Teece 1993, Eisenhardt and Schoonhoven 1996, NSF 2002, Hagedoorn et al. 2000).

Partnering with outside organizations builds social networks among individuals that enhance innovation. Liebeskind et al. (1996) examine social networks formed by collaborative research efforts between scientists at two new biotechnology firms and scientists at other organizations. They find that boundary-spanning social networks, where the boundary is at the interface of different organizations, increase the transfer and integration of knowledge, as well as the firms' flexibility. Hicks et al. (2001) find that firms in the information technology sector are doing more research of their own, but they also note that universities are becoming even more important in innovation, as their publications are increasingly cited by patents assigned to companies in the same state. Even though universities have historically been less likely than firms to patent the results of their innovation, overall patenting by universities has grown in the last two decades, surpassing government patenting by the late 1980s. This is a signal that universities are becoming more entrepreneurial, and that firms have the opportunity to tap into a large knowledge base by interacting with local universities.

Ahuja (2000) questions the extent to which network structures benefit a firm's innovation output, suggesting that there is a balance between "densely embedded networks" and more disconnected networks with "structural holes." He points out that a dense structure is important for collaboration among competitors for establishing norms and building trust. However, rapid access to diverse information is better served by structural holes, which reduces the number of redundant ties. Ties to diverse individuals or organizations would be more valuable in providing unique information. In their analysis of inter-organizational networks in biotechnology, Powell et al. (1996) call R&D alliances "the admission ticket, the foundation for more diverse types of collaborations, and the pivot around which firms become more centrally connected." They argue that the locus of innovation is found within inter-organizational networks, as opposed to intra-organizational networks, for fields of rapid technological development. In addition to improving their absorptive capacity and organizational learning, firms are also becoming better at collaboration itself. Firms' network position, i.e. central connectedness to other firms, has reciprocal influences on R&D ties, experience and diversity. Firms enter a feedback loop, where the most central firms continue to strengthen their position in the network through more R&D

collaboration. Research on manufacturing firms has shown a positive correlation among the cooperative R&D conducted by a firm, the firm's market share, and the productivity of in-house R&D (Link and Bauer 1989). Similarly, Stuart (1998) finds that firms with the greatest prestige situated in crowded networks are the ones with the highest alliance-forming rates. This would create a barrier for entrant firms without ties to enter into a crowded network. Meanwhile, established firms already central to the network reinforce their position with alliances. The potential for R&D partnerships to block competition by creating or reinforcing monopolies is an important caveat to their otherwise substantial benefits (Hagedoorn et al. 2000).

Economists frown upon horizontal R&D partnerships, arguing that a perfectly competitive market stimulates socially optimal levels of R&D (Ouchi and Bolton 1988). Ironically, research has shown that R&D expenditure rises with industry concentration (Scherer 1980). Firms have a greater incentive to perform R&D if they are assured of capturing a large market share. The large R&D investments of the monopolistic Microsoft and pre-divestiture AT&T Bell Labs are prime examples of this phenomenon. There has also been disagreement about whether redundant R&D by competing firms is wasteful or helpful (Ouchi and Bolton 1988). The economists' criticism of R&D partnerships may be tempered by the resource and cost-sharing possible through partnering. Partnerships often facilitate expensive, high-risk R&D ventures that would not be undertaken by any single company (NSF 2000). For R&D with environmentally beneficial outcomes, some may argue that sacrificing some competition may be worth the social benefits of improved health and environment.

Motivations for academia and government to participate in external collaboration differ from the private sector's reasons. Universities benefit from collaboration with industry, government, and non-profit institutions by having the opportunity to channel academic research toward practical applications (Jankowski 1998, NSF 2002). There is also a financial incentive for universities and publicly funded research labs or institutes to do "targeted research" when the government sets aside research grants for collaborative research. Since one of the goals of academic research is training personnel to enter the workforce, collaborative research activities give students a better understanding of industry and government needs, and offer them valuable professional ties even prior to graduation. Since the 1970s, U.S. universities have undergone a transition in how they have defined their role in society. In addition to the university's

traditional missions of research and teaching, academics have been faced with the possibility of a third role: economic development (Etzkowitz and Leydesdorff 2000). Meanwhile, the government funds and participates in R&D partnerships with its own set of priorities: To contribute to the public welfare, to spur economic growth, and to promote the competitiveness of national firms (NSF 2002). The government may identify research areas which are underinvested because of high risk or high cost. Technological progress in these areas may have substantial society-wide benefits such that the government intervenes with incentives for joint research. Partnering with industry may help government R&D personnel widen their knowledge base and provide a mechanism for technology transfer.

### ***Trends in R&D Partnerships***

The two types of formal R&D partnerships are contractual partnerships and joint ventures. Companies are increasingly drawn to contractual partnerships as opposed to joint ventures, which entail the set-up of a semi-independent unit. Contractual partnerships require less commitment as no new entity is created; resources and costs are simply shared among the participating companies. Companies are less dependent on each other and the time period for an R&D partnership is shorter (Hagedoorn 1993). Contractual partnerships may be perceived as being less risky and more flexible, because if it does perform well, companies can break off the agreement without burdensome “sunk costs” of ending a joint venture prematurely.

Inter-firm R&D partnerships have grown from a couple dozen per year in the early 1970s to a record 700 R&D partnerships in 1995. The growth of inter-firm R&D appears to be driven by the reasons that motivate R&D collaboration, rather than increased public funding of R&D partnerships (Hagedoorn 2002). However, the database used by Hagedoorn to study R&D partnering is limited to partnerships exclusively sponsored by private companies. The database not account for partnering initiated by government funding, which excludes public-private R&D partnerships.

High-tech industries such as information technology and pharmaceuticals have been dominant in R&D partnering, making up over 80% of newly established R&D partnerships in 1998. Meanwhile, medium-tech industries' share has dropped to 15% and low-tech industries have dropped to less than 5% (Hagedoorn 2002). Of particular interest to clean diesel research are the automotive and oil and gas sectors. According to the OECD sector categories, the automotive sector is included in the medium-tech category while oil and gas is included in the low-tech category. These correlations reflect the idea that sectors characterized by rapid technological change, like IT and pharmaceuticals, have higher rates of R&D partnering than slower-changing sectors like oil and gas.

The share of R&D partnerships that are international has stagnated around 50 to 60% in the past 25 years. In the automotive sector, international partnering increased until the 1980s, and then dropped off sharply in 1990s, while overall contractual partnering in that sector increased slightly from the 1980s to the 1990s, indicating the growing importance of domestic partnerships (Hagedoorn 2002). Hagedoorn suggests that changes in federal antitrust policy may have been more supportive of collaborations among U.S.-based competitors.

Amidst concerns about economic losses from foreign competition, the U.S. government passed the 1984 National Cooperative Research Act (NCRA) and the 1993 National Cooperative Research and Production Act. Prior to NCRA, the risk of antitrust litigation discouraged companies from entering into R&D partnerships that did not have a university at its center. Academic institutions were less likely to be accused of antitrust behavior. After 1984, cooperative research was subject to less antitrust scrutiny and the dynamics of R&D partnerships changed; many were formed without formal university involvement (Dinnen 1988). The 1986 Federal Technology Transfer Act required federal labs to actively seek opportunities to transfer technology to industry, universities, and state and local governments. It also gave preference to U.S.-based companies. In addition to promoting technology transfer through technical assistance and patent licenses, laboratories were permitted to enter into Cooperative Research and Development Agreements (CRADAs) with industry, universities, non-profits, and state or local governments. The 1980 Bayh-Dole Act actually restricted dissemination of the results of many federally funded R&D projects. It sought to remedy the paradox of underutilization of the publicly available information that came out of national labs and universities. Since the

information was free for all, companies could not capture exclusive rights to develop that information or technology. Granting patents and licenses for federally funded research encouraged greater commercialization of the research results (Mowery 1998). These pieces of legislation increased collaboration among these various organizations, and spurred R&D activity between the public and private sector.

### ***Public-private R&D Partnerships***

Since the 1980s, lackluster returns from internal R&D and changes in federal antitrust policy contributed to the growing trend of firms' externalizing a portion of their R&D activities and working collaboratively with the public sector (Mowery 1998). The growth in the number of CRADAs serves as a measure of the increased collaboration between the public and private sectors. From 1987 to 1996, CRADAs grew significantly, with an average of 68% per year (NSF 2002).

Public sector institutions include national labs, universities, government agencies, and nonprofit research organizations. Although many universities are private, much of their research is funded by the federal government, so they are considered public sector institutions (NSF 2002). The federal government may supplement existing R&D partnerships to increase their viability. Supporting collaborative R&D may help meet a variety of public policy objectives, especially defense and public health. For example, as of 2001, 44.6% of federal R&D funding went to the Department of Defense and 23.6% went to the Department of Human and Health Services. Meanwhile, R&D funding to the Environmental Protection Agency was a meager 0.7% of total federal R&D expenditures. Department of Defense and Department of Energy labs have been the most active participants in CRADAs (NSF 2002).

Efforts to restrict foreign firms from participation in publicly funded U.S. R&D programs have limited effectiveness. The premise is that restricting foreign participation will increase the share of the R&D returns for domestic firms. However, the international nature of many firms and strategic alliances between domestic and foreign firms makes "cross-border" dissemination

of the results inevitable. Exclusion may foster a retaliatory and exclusionist attitude from foreign research programs, which is ultimately detrimental to global innovation (Mowery 1998).

Most collaborative research programs are organized to promote “pre-competitive” research. Generally, firms would be reluctant to collaborate on near-market research since they would not want to disclose proprietary information about their technologies (Ouchi and Bolton 1988). However, an empirical study of UK firms in 3 sectors indicated that joint R&D projects do pursue near-market research in development. Those joint R&D projects tend to be privately funded rather than publicly funded. Public-private R&D partnerships tend to focus on basic and applied research, as opposed to development or commercial production (Chen 1997). Government agencies are reluctant to fund research that industry should be readily doing on its own.

Underinvestment in R&D occurs because organizations do not fully realize or appropriate the benefits created by the R&D investments. Economists and policymakers alike have recognized this is as a common market failure (Link and Scott 2001). In many cases, particularly in environmental R&D, firms cannot capture the full social benefits of the R&D. Government may choose to intervene and subsidize R&D such that the private benefits are adequate to induce investment. Studies of the rate of return on R&D have shown that the aggregate rate of return on research is positive, and the social rate of return, on average, exceeds the private rate of return (Georghiou and Roessner 2000).

Another key reason for government to fund and initiate R&D is the difficulty of coordinating combinations of technologies that may be necessary for technology development. Organizing multiple actors that do not sit in the same industry may be unwieldy and costly, and no firm would want to take on that burden on its own. A public institution with a strong technology base could act as an “honest broker” and organize a collaborative effort that would reduce the costs faced by the market (Link and Scott 2001). Public-private partnerships may leverage funds to tackle common technology challenges or build consensus among stakeholders (RAND 1999). In a RAND case study of four firms involved in environmental R&D, firm representatives “placed heavy emphasis on the use of science to inform public policy and environmental decision-making.” Not only does this require government investment in R&D,

but it requires institutions that can communicate knowledge and incorporate knowledge into regulations (RAND 1999). Although the firm representatives interviewed in the RAND study did not discuss their views on regulatory change, interest in informing policymaking implies that R&D could provide the “science” to inform decision-making.

### ***Knowledge Transfer as a Motivation for Collaboration***

One of the most frequently cited reasons for external collaboration is access to external knowledge and resources. In defining knowledge, the knowledge management literature distinguishes between explicit and tacit knowledge. Explicit knowledge is transferred through writing, recording, or some other tangible medium. Tacit knowledge is “highly personal and hard to formalize . . . subjective insights, intuitions and hunches fall into this category of knowledge” (Nonaka and Takeuchi 1995). Tacit knowledge is not easily passed through reports and presentations, media which are commonly used to transfer explicit knowledge. It often requires “communication through observations, conversation, on-the-job learning. Its very intangibility makes its management a challenge” (Skyrme 1997). According to Nooteboom (1999), the transfer of tacit knowledge only happens with close proximity. Collaborative relationships have been frequently cited as a way for firms to overcome the difficulties with transferring tacit knowledge (Badaracco 1991, Hennart 1998, Watkins 1991). Organizations working together can learn by performing tasks together. Personal contacts both inside and outside an organization, even with competitors, may provide tacit knowledge (Senker and Faulkner 1996).

The International Institute for Sustainable Development, an organization interested in sustainable development knowledge networks, describes six basic collaborative models (Creech and Willard 2001). They are summarized below, along with examples relevant to this research.

**Table 1: Six Collaborative Models**

Type	Description	Advantages	Disadvantages	Example
Internal knowledge management networks	Knowledge-sharing mechanisms within a single organization	Can be managed and suited for use within the organization	Largely internal	Internal memos
Strategic alliances	Purposeful, often contractual arrangements among distinct but related organizations motivated by pursuit of competitive advantage	Only pursued if each partner perceives contribution to its market position	Limited in size	Alliance between an engine manufacturer and automaker to jointly develop a new vehicle model
Communities of practice	Voluntary, informal networks for conversation or information exchange, based on expertise or interest area	Build capacity by sharing expertise in exchange for gaining expertise from others	Participation fluctuates based on interest and does not necessarily lead to actual collaboration	Industry professionals who meet occasionally at industry meetings and workshops
Networks of experts	Networks that bring together individuals for their expertise in a particular area.	Common expertise	Limited to invited “experts”	Government advisory panels
Information networks	Provide access to information supplied by network members	Permits remote access and does not require personal contact	Passive - Users must come to the network to benefit	Websites (e.g. Dieselnet.com); Trade associations
Formal knowledge networks	Networks with an formally established structure and objectives	Productivity and impact on decision-makers	Weak in communicating research with broader audiences	R&D partnerships

R&D partnerships are a way of establishing formal knowledge networks by creating a formal structure for collaboration. According to the International Institute for Sustainable Development, formal knowledge networks “tend to be more focused and narrowly-based than information networks; more cross-sectoral and cross-regional than internal knowledge management networks; more outward looking than communities of practice; and they involve more partners than some strategic alliances” (Creech and Willard 2001). Although R&D partnerships have the advantage of stability and purposeful goals, their more focused and task-oriented approach can limit the extent of learning and innovation compared to the more fluid communities of practice or information networks (Storck and Hill 2000).

## **Formal and Informal Networks**

Formal organization and informal organization often exist independently of one another. Examining an organizational chart does not necessarily explain patterns of communication. Allen (1977) observes that formal organization may be the more important of the two determinants of communication, but informal organization makes a nearly equal and independent contribution. While informal organization cannot be forced, management can foster its development. Interdepartmental projects are one way for an organization to bring people together (Allen 1977). In the same vein, inter-organizational projects, such as collaborative R&D, also draw people together who would not otherwise meet or work together.

Collaboration among organizations is usually initiated through formal partnering via contractual agreements or joint ventures, which establishes formal knowledge networks. Over time, personal relationships supplement the formal roles and “informal psychological contracts increasingly substitute for formal legal contracts” (Ring and Van de Ven 1994). It is conceivable that some of the formal network ties between individuals evolve into informal personal relationships, which are sustained well after the formal collaboration has ended and formal obligations are fulfilled (Hutt et al. 2000, Allen 1977). Some indicators of post-partnership success are the assimilation of the partnership results into internal R&D, subsequent participation in similar collaborative R&D, and the movement of R&D personnel into business units and

product development (Quintas and Guy 1995). The first two indicators demonstrate the effectiveness of ties built within and external to an organization, while the third indicator shows that knowledge is moving across organizational boundaries.

According to a 1989 study of a sample of U.S. manufacturing firms, nearly 90% of research partnerships were informal in nature (Link and Bauer 1989). Unfortunately, the informality of these relationships has made them difficult for researchers to track. However, they indicate the tremendous potential for formal networks to contribute to or build on informal partnering.

Fostering informal networks also builds “social capital,” which is a sense of goodwill and trust established among individuals based on informal social relationships. It may be considered the “glue” that holds informal knowledge networks together. Adler and Kwon (2002) explain the benefits of social capital in terms of external and internal networks. Investment in external networks reaps benefits in the form of superior access to information, power, and solidarity. Internal networks within an organization or group strengthen collective identity and capacity for collective action. Collective action may come in the form of more collaborative activities. In order to foster social capital, organizations can provide initial collaborative opportunities for their members both within and outside their organizations. As the formal networks of R&D partnerships evolve into informal networks, they may indirectly contribute to social capital.

### **Intra-firm and Inter-firm Networks**

Inter-firm networks have an advantage over intra-firm networks in that they are more “loosely coupled” than intra-firm networks. This means that inter-firm networks have greater flexibility and adaptation. However, since network ties within an organization are stronger than those between organizations, intra-firm networks do possess more stability and continuity. Boons and Berends (2001) believe that loosely coupled units are more sensitive to environmental variation, especially in the face of conflicting interests. Therefore, loose inter-firm networks can allow for “local adaptation.” Problems associated with conflicting interests do not spread across the entire organization. This may minimize the risk for organizations that choose to enter an

R&D partnership within a specific area. Organizations with differing interests can still reach agreement about a specific R&D project without necessarily jeopardizing the interests of the entire organization. This may be especially valuable in cases where the R&D project seeks to resolve conflicting technological assessments by different organizations.

R&D collaborations bring together “heterophilous actors,” individuals who differ in beliefs, culture, values, education, social status, or other attributes. In the R&D environment, dissimilar attributes would be professional education or training, organizational culture, and job function. Homophilous actors may also refer to similar organizations, or competitors. Firms may be more eager to learn from each other if they are homogeneous and competitors (Provan and Human 1999). Although homophilous actors with similar attributes exchange information more frequently than heterophilous actors, exchange between heterophilous actors can be more unique, and therefore more valuable for innovation (Boons and Berends 2001). Homophilous interaction and group homogeneity may be easier and more comfortable, but it can hinder innovation and lead to groupthink (Rogers and Schoenmaker 1972, Janis 1982). Subgroups within an organization may gravitate toward one another based on common interests and have little interaction with other subgroups (Cross et al. 2002). A heterogeneous group can be more successful in solving complex problems, and more conducive to learning (Boons and Berends 2001, Dodgson 1996). Since inter-firm networks are more heterogeneous and diverse than intra-firm networks, they are more likely to result in greater innovation and learning. Inter-firm networks among heterogeneous firms at different parts of the supply chain may also be more innovative than inter-firm networks among competitors.

Collaboration is a way to promote heterogeneity in organizations and industries that are becoming more homogeneous. Organizations tend to become more institutionalized as they mature. Their outlooks converge and resist adaptation to environmental changes (DiMaggio and Powell 1983). Shearman and Burrell’s (1987) model of industry development moves progressively through the phases of community, informal network, formal network, and club. The well-established diesel industry in the U.S. could easily be labeled a formal network, with its strong trade associations and organizational identities. To some, it may even be perceived as possessing a “social structure that resembles a club with exclusive membership” (Shearman and Burrell 1987, Boons and Berends 2001). Collaboration with organizations outside the diesel

industry may help the industry overcome its tendency toward homogeneity, thereby increasing flexibility and innovation.

## **Challenges to Cross-organizational and Cross-functional Communication**

Despite the praise given to heterogeneity or diversity in organizations, it is not without its challenges. Public-private partnerships require communication across different functional roles, such as scientists, engineers, managers, and policymakers, as well as communication across different organizations, such as private companies, national labs, and universities. Although functional diversity offers a wider range of input and unique problem-solving approaches, there may also be higher costs, less group cohesiveness, and higher stress (Keller 2001). Functional diversity results in increased external communication because its members have diverse backgrounds and areas of expertise and contacts with important external knowledge networks. Ironically, this very strength – strong external communication – has the effect of hurting group cohesiveness because members may have stronger identification with external contacts than group members (Keller 2001).

Even among actors with similar functional roles, differences in organizational affiliation can put a strain on partnerships. For example, industrial technologists tend to put more emphasis on profitability, international competitiveness, and turnaround time than government technologists. Meanwhile, the government technologists tend to be more long-range and idealistic (NSF 2000). According to Rogers et al. (1998), these different perspectives have been a major barrier to further public-private partnerships. However, Lesko and Irish (1995) feel that these organizational differences can be overcome once both sides realize their mutual benefits as global competition increases and resources shrink. Universities and private firms also approach research quite differently. For example, industry generally operates on a shorter time horizon than academia. This can be disruptive if industry pulls out of a joint project on short notice or hires graduate students in the middle of their degree programs. Universities are accustomed to publishing the results of their research, but private firms may pressure university partners to delay publication if they seek to patent the results (NAS 1999).

## Trust

Many of those involved in partnerships have drawn attention to the necessity of trust in enabling collaborative relationships. In a 1998 workshop on collaborative research held by the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine, participants identified trust as a very important, but often neglected, precondition for successful collaborations (NAS 1999). A case study of an inter-firm alliance identified communication frequency and openness as important drivers of trust (Hutt et al. 2000). Regularly scheduled information-sharing, such as weekly conference calls, may supplement the interpersonal flow of communication. In a study of partnership relationships between automobile companies and suppliers in the European automobile industry, Friedberg and Neuville (1999) find that the functioning of networks does not depend only on the actual industrial functions and process, but also on the trust and cooperation that characterizes day-to-day interaction.

Embedding collaborations in a competitive environment, where firms fear partners will leak proprietary information, can definitely heighten tension and reduce trust (Hutt et al. 2000). A formal policy about the various levels of confidentiality required for different types of information may alleviate this problem. Partners could enter contractual agreements that limit the use of knowledge and require confidentiality. An alternative would be to give a third party the “informational pawns” of the partners, such that this third party would be a “trustee of the alliance” (de Laat 1999). This third party trustee would in turn have to be perceived as trustworthy and accountable by all the partners. De Laat (1999) suggests government can act as the third-party trustee, but partners can also rely on industry associations, universities, and other independent parties. According to a research study on the attributes of effective R&D consortia, the most effective consortia were managed by individuals from outside the consortium. The elements of independence and neutrality were important to building trust in management (Souder and Nassar 1990).

The inclusion of participants from different sectors “enhances the credibility of the results – results that might be less effective and believable if they come from only business, or only civil society, or only government” (WBCSD 2001). Companies’ pursuit of sustainable business

practices has the potential to forge new bonds among business, government, and nonprofit organizations that may displace or at least mitigate previous antagonistic relationships (Preston 2001).

## **Boundary Spanners**

The business literature stresses the importance of individuals who facilitate knowledge network development. They are known as boundary spanners, network champions, strategic bridges, catalysts, among other terms (Mylonadis 1993, Westley and Vredenburg 1991, Roome 1997, Clarke 1999). They play an important role in situations that require sharing different types of expertise, especially in R&D. Their existence is rare because the boundary spanner role requires a breadth of intellectual expertise, a wealth of social contacts, and the personality traits to be accepted by vastly different groups (Cross and Prusak 2002). Boundary spanners who have evolved into their role over time may be more effective than those formally assigned to that role because the latter may lack the strong communication networks necessary (Allen 1977).

Allen (1977) refers to the key people to whom others frequently turn for technical information as “technological gatekeepers.” His surveys conducted in R&D laboratories reveal several important traits of gatekeepers. Compared to their colleagues, they have more contacts with those outside their organization and read more referred journals. Gatekeepers also produce more papers for presentation at technical conferences and are highly valued by their managers and peers. Others turn to them for their technical competence, which Allen considers to be their most important quality. They participate frequently at professional meetings and conferences, and are often selected for special task forces or panels for their own organizations, professional societies, or government agencies (Allen 1977). These meetings and task forces allow for gatekeepers from different organizations to gather and exchange information, further reinforcing the value and effectiveness of their role.

For networks formed on the basis of environmental interests, boundary spanners enable the exchange of environmental knowledge between organizations (Clarke and Roome 1999). In their case study of the Canadian company Systec, Clarke and Roome (1999) find that Systec

simultaneously fostered formal collaborations and a less formal network of interactions between the company and its stakeholders. These networks provided mechanisms for mutual learning and action, showing that networks are not just a means of knowledge exchange but a basis for knowledge creation (Clarke and Roome 1999). This implies that networks between a company and regulators could allow for each party to learn from each other, and adjust their perspectives based on this learning.

Environmental managers hold a crucial role in facilitating network development, but organizational support is needed as well (Clarke and Roome 1999). The success of partnering hinges on senior management's willingness to commit resources, personnel, and guidance to collaborative activities (Hutt et al 2000). Efforts to integrate the concepts of environmental sustainability into business practices are very dependent on executive-level commitment (Madu 1996, Preston 2001). Environmental managers and other boundary spanners must be able to bridge across different communities or islands of knowledge and language (Clarke 1997). To advance its goals of sustainability, Hewlett-Packard formed a leadership council consisting of Product Stewardship managers and representatives from different functional groups in marketing, regulatory issues, government relations, supply chain management, and workplace operations. It hoped that the group's weekly conference calls and in-person workshop would increase communication flows and establish a network of sustainability-minded people within the company (Preston 2001).

De Laat (1999) goes as far to assert that the use of "liaison personnel," his term for boundary spanners, is the most potent knowledge transfer mechanism, more effective than shareholder board meetings, technical advisory meetings, seminars, newsletters, and publications. Hansen and Oetinger's (2001) appraisal of BP's conducive environment for "T-shaped managers" reflects the growing trend of companies to respond to the need for knowledge sharing by direct personal contact rather than reliance on their state-of-the-art knowledge management systems. T-shaped managers share knowledge freely across the organization's business units while remaining committed to individual business unit performance. Technologists may also take on dual roles as both knowledge community practitioners and task-oriented team members. As a member of a community of practice, they can keep up with their

technical or professional specialty, meet colleagues in the same field, and share knowledge. At the same time, they are accountable for their specific tasks and job functions (Wenger 2002).

Despite the importance of individuals as boundary spanners in collaborative activities, inadequate attention has been given to researching their role. Most economic evaluations of knowledge exchange and scientific research centers on projects and programs as units of analysis. They usually ignore the role of the individual scientists and engineers who create and transfer the knowledge (Hutt et al 2000, Georghiou and Roessner 2000). Cross and Prusak (2002) express concern that informal networks are often hidden and therefore do not receive enough management attention or resources. The current state of the research for environmental issues is also unsatisfactory. Clarke and Roome (1999) note that boundary spanners' capability "to promote learning, action and change through networks appears a critical, yet under-researched aspect of environmental management and sustainable development practice."

Some practitioners have tried to develop tools to analyze the effectiveness of knowledge networks, especially informal networks, which are not readily understood through formal roles or organizational charts. The most common tool is social network analysis. Practitioners survey individuals in a defined network and ask the members of the group to characterize their relationship with each other. It is often used by managers who are trying to promote collaboration and knowledge sharing in their networks. Social network analysis can help identify boundary spanners, knowledge bottlenecks, and under-utilized or over-burdened individuals (Cross et al. 2002). Most examples of social network analysis in popular business literature have been limited to informal networks within single organizations, albeit global ones (Cross and Prusak 2002, Cross et al. 2002).

### ***Gaps in the Existing Research***

The vast literature on research partnerships can be divided into three broad categories – transaction costs, strategic management, and industrial organization theory (Hagedoorn et al 2000). However, interest in influencing regulatory policy has not been considered as a

motivation behind R&D partnerships. It may find a place in strategic management theory when a firm seeks to create a more favorable competitive position or defend the viability of the industry as a whole, but it has not yet been included in this body of research. Most research on public-private R&D partnerships takes the technology policy perspective, out of interest for how government intervention influences the innovation process and encourages national competitiveness. While the literature addresses R&D partnerships as a way to increase technological information exchange among firms, universities, and public research institutions, it is rooted in the desire to promote innovation (Hagedoorn et al. 2000). It leaves out the potential feedback loop of government-funded R&D influencing government regulation.

There has been some acknowledgement of the existence of R&D partnerships that influence policy. Dinnen (1988) discusses a distinct category of R&D consortia that “test for adherence to standards or regulations or promote standards for regulations.” For example, the DEET Joint Research Venture has 20 members which sponsor research on DEET, a pesticide ingredient, and submit their research results, such as toxicity data, to EPA. EPA then uses this data in regulatory considerations. The Motor Vehicle Manufacturers Association, which includes U.S. automakers and the American Petroleum Institute as members, develops methods for measuring emissions and testing fuels. The key challenge identified for standard-setting consortia is accepting that “what is right or good for the industry is also right or good for their individual corporation in the long run” (Dinnen 1988). However, Dinnen does not explore the mechanism through which R&D results are used by the industry or government standard-setting organization. The ability of such R&D consortia to influence policy is still an open question.

Environmental interests broaden the definition of networks and strategic alliances. Whereas most of the business literature on knowledge networks focuses on networking among firms and between firms and their customers, knowledge networks based on environmental interests also involve the media, environmental advocacy groups, scientific and technical communities, government agencies, educational institutions, and think tanks (Coddington 1993, Preston 2001). Most of the research on collaborative R&D networks centers on the technologists, and seldom reaches out to explore the ties to government actors or policymakers.

My research seeks to close some of these gaps by considering the potential to influence policy as a driver for R&D partnerships and taking a broader view of knowledge networks that stem from these partnerships.

## **CHAPTER 2: RESEARCH CONTEXT**

It is important to understand the technological, institutional, and regulatory factors that influence clean diesel R&D. This chapter gives an overview of the U.S. diesel vehicle industry and efforts to control emissions. It explains the role of the U.S. Environmental Protection Agency in regulating vehicle emissions and the role of the U.S. Department of Energy in supporting clean diesel technology development.

### ***Clean Air Act***

Since the Clean Air Act Amendments were passed by Congress in 1970, following the original 1963 Clean Air Act, sources of air pollution have been regulated to improve the nation's air quality. The Clean Air Act was amended in 1990, and subsequent laws and regulations have been added since then. Section 101-2 of the Clean Air Act explicitly attributes the increase of air pollution to “urbanization, industrial development, and the increasing use of automobiles.” Strategies to control air pollution have prominently featured the motor vehicle industry.

The U.S. Environmental Protection Agency (EPA) sets National Ambient Air Quality Standards (NAAQS) for six principal or “criteria” pollutants detrimental to human health – carbon monoxide, lead, nitrogen dioxide, ozone, particulate matter, and sulfur dioxide. EPA has the regulatory authority to create national standards and strategies to control emissions of these criteria pollutants from both mobile and stationary sources. These pollutants can cause respiratory problems, heart and lung disease, and even premature death. Poor air quality also has adverse effects on animals, vegetation, and buildings.

### ***Diesel Engines and Emissions***

The vast majority of heavy-duty vehicles are powered by diesel engines, because they provide improved fuel efficiency over spark-ignited, gasoline engines. Diesel engines typically average a 30% higher fuel economy over their gasoline counterparts. Diesel engines' fuel

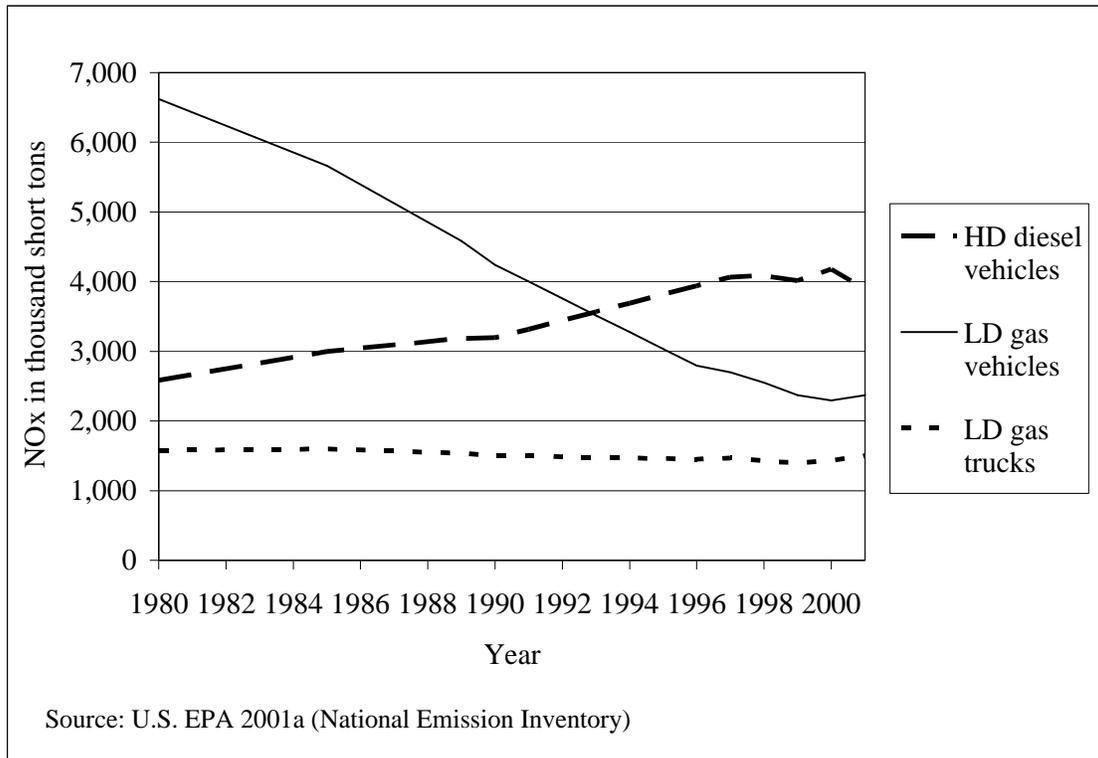
economy and durability have enabled them to dominate freight transportation, where operations and maintenance costs matter more than for passenger vehicles. In 1997, approximately 60% of on-highway trucks in the U.S. ran on diesel engines. The larger the truck, the more likely it is powered by diesel. For example, 91% of “heavy-heavy” trucks, the largest class of trucks, operate on diesel fuel (U.S. Census Bureau 1997).

Better fuel economy translates to reduced CO<sub>2</sub> emissions, which is good news amidst growing concerns about climate change. Diesel exhaust also releases less carbon monoxide and hydrocarbons than gasoline exhaust. On the other hand, diesel engines produce exhaust containing more particulate matter (PM) and nitrogen oxides (NO<sub>x</sub>) than gasoline engines equipped with catalytic converters. Particulate matter has been known to be a chronic respiratory hazard, causing asthma, reduced lung function, and premature death. NO<sub>x</sub> is one of the main ingredients in the creation of tropospheric ozone, which causes serious health problems. NO<sub>x</sub> is a precursor to smog, acid rain, nutrient pollution in waterways, and crop damage. Diesel exhaust also contains a variety of other air toxics, many of which are not yet measurable or regulated. The EPA’s latest health assessment in 2002 claims that diesel exhaust is “likely to be carcinogenic to humans by inhalation,” and the California Air Resources Board (CARB) has already categorized particulate emissions from diesel exhaust as a known carcinogen (U.S. EPA 2002a, CARB 1998).

Since the Clean Air Act’s passage, diesel vehicles have not been regulated as stringently as gasoline vehicles. In 1970, passenger vehicles were the biggest contributor to mobile source pollution. For example, mobile sources accounted for 35% of the nation’s NO<sub>x</sub> emissions in 1970, and light-duty gasoline passenger vehicles accounted for almost 60% of those emissions (U.S. EPA 2001a). Consequently, in the past 30 years, regulations have focused on gasoline-powered passenger vehicles, resulting in a significant reduction in vehicular emissions in spite of the increased vehicle miles traveled. Meanwhile, diesel vehicles’ share of NO<sub>x</sub> has grown in both absolute and percentage terms. Despite dramatic decreases in PM emissions since 1990,

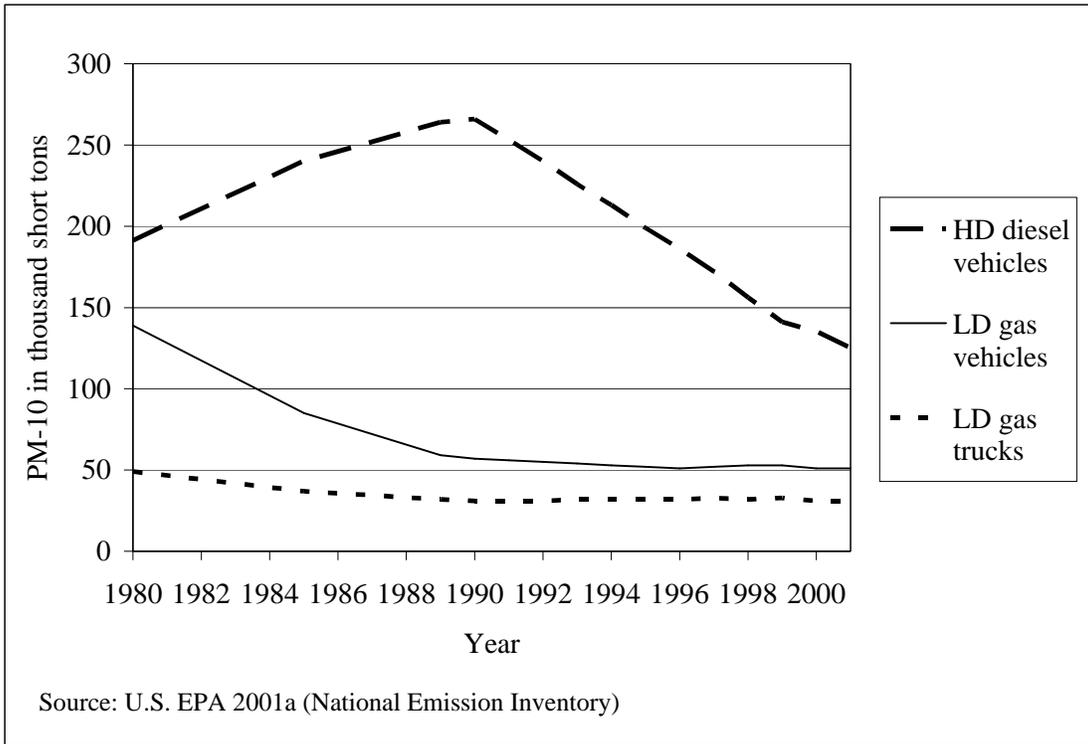
diesel vehicles are still the largest on-road contributors to PM-10 and PM-2.5 emissions<sup>1</sup> (U.S. EPA 2001a).

**Figure 1: NOx Emissions from On-road Vehicles**

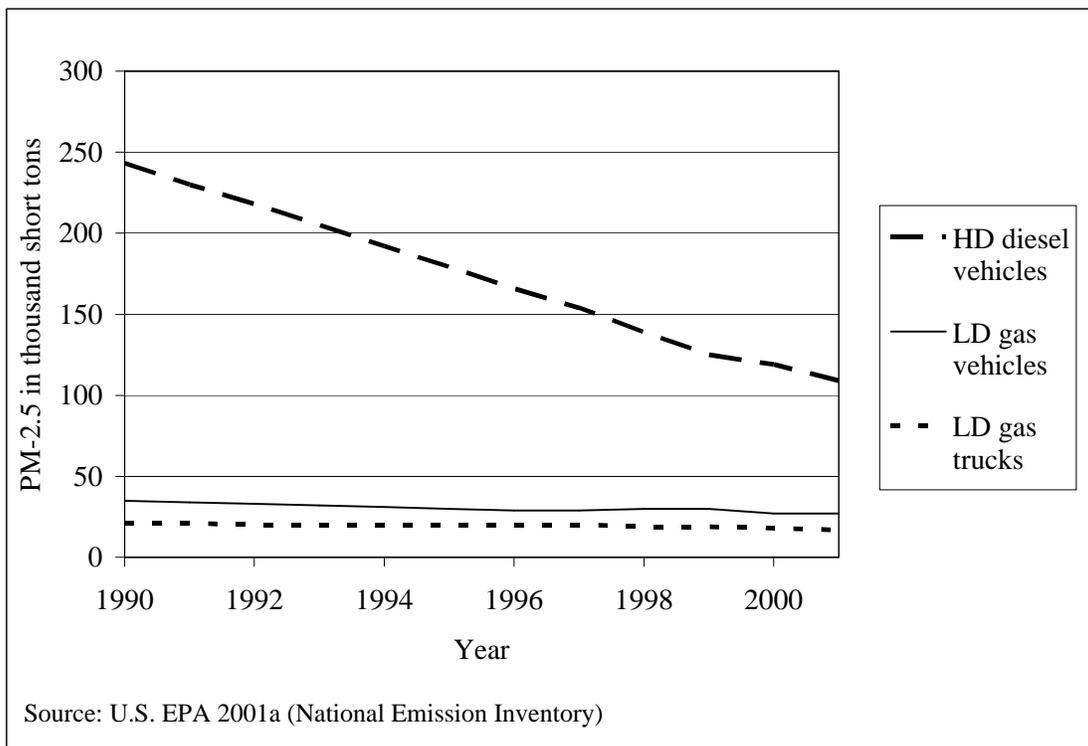


<sup>1</sup> PM-10 refers to particles with a diameter less than 10 microns. PM-2.5 refers to particles with a diameter less than 2.5 microns.

**Figure 2: PM-10 Emissions from On-road Vehicles**

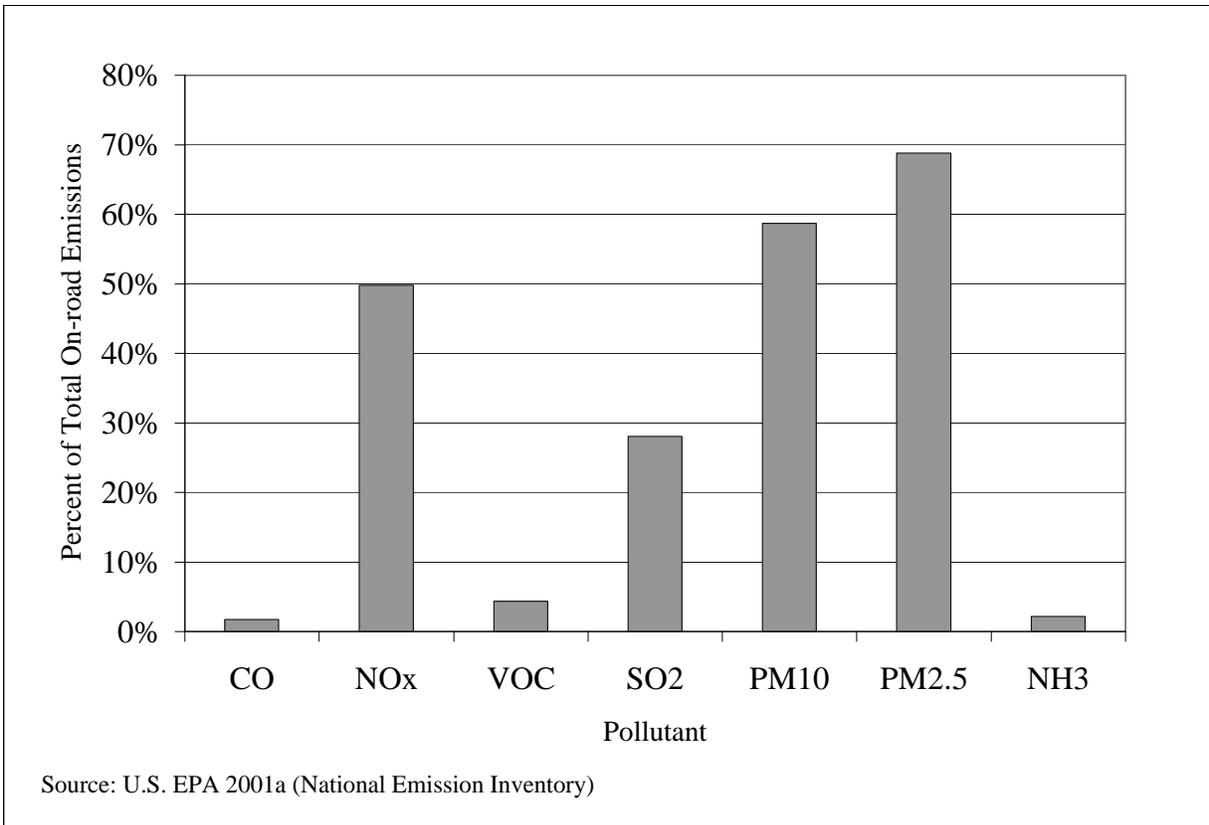


**Figure 3: PM-2.5 Emissions from On-road Vehicles**



The share of on-road NOx emissions from diesel vehicles rose from 22% in 1980 to 50% in 2000. In that same time period, diesel vehicles have consistently contributed to about 60% of highway emissions of PM-10, and since 1990, about 70% of highway emissions of PM-2.5 (U.S. EPA 2001a).

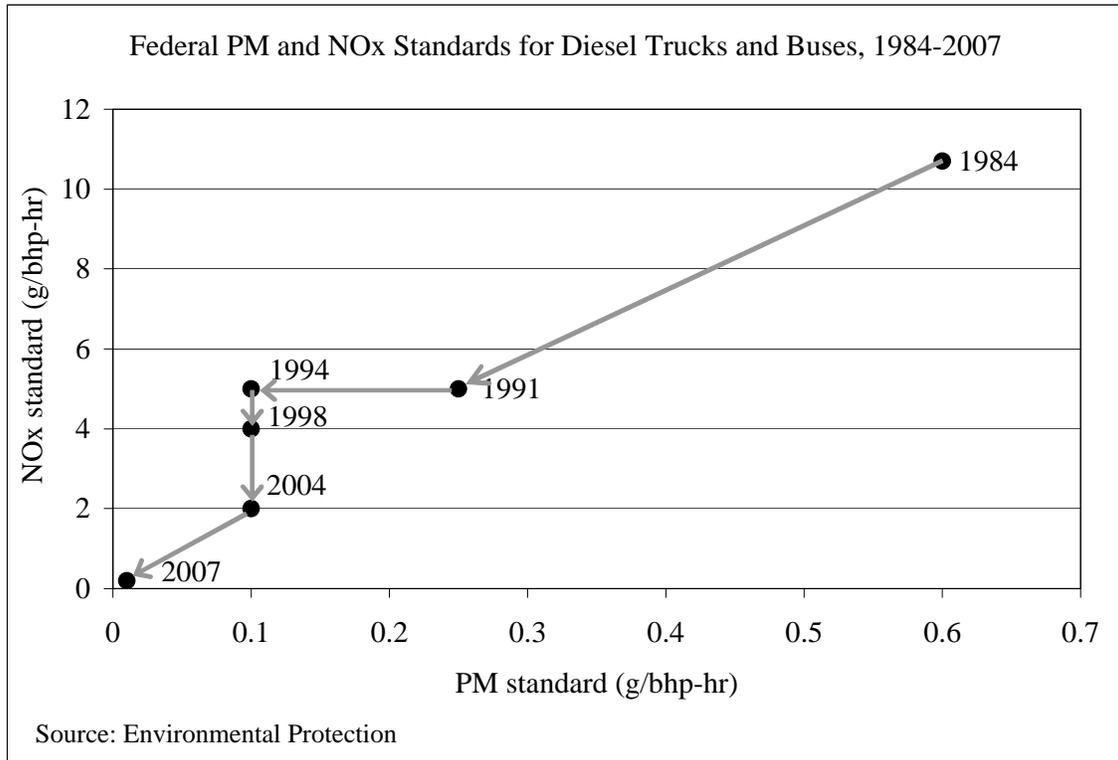
**Figure 4: Heavy-Duty Diesel Vehicle Emissions Relative to Total On-road Emissions, 2000**



### ***Emission Standards for Diesel Trucks and Buses***

EPA set the first standards on new trucks and buses in 1984, with limits of 10.7 g/bhp-hr for NOx and 0.6 g/bhp-hr for PM-10. However, unlike the emission standards on passenger vehicles, these emission standards apply to the vehicle engine, not to the vehicle itself. Also, emissions are measured in grams per brake horsepower-hour rather than grams per mile. The next figure shows the progression of federal regulations of NOx and PM, starting in 1984.

**Figure 5: Federal PM and NOx Standards**



EPA’s standards are “technology-forcing.” In other words, EPA typically sets the standards ahead of current technology, but leaves it up to the industry to select the technologies with which to meet the future standards. EPA assesses the status of current technology through technology reviews, which can include private meetings with industry representatives, review of the latest R&D publications, and in-house laboratory testing. In an effort to give manufacturers enough time to comply with regulations and to reduce the regulatory burden, Section 202 of the Clean Air Act requires stability and lead time for all heavy-duty vehicle emission standards. Standards must remain the same for at least 3 years, and industry must receive at least 4 years of lead time before the promulgated standards go into effect.

EPA has a panel of outside experts that provides advice on air quality policy issues. The Clean Air Act Advisory Committee (CAAAC) was created by the Federal Advisory Committee Act in 1990. It is comprised of approximately 60 senior managers and experts representing state and local government, environmental and public interest groups, academic institutions, unions, trade associations, utilities, and industry. CAAAC has subcommittees that convene to discuss

more specific scientific and technical issues. The two subcommittees concerned with vehicles are the Mobile Sources Technical Review Subcommittee and the Clean Diesel Independent Review Panel. The Mobile Sources Technical Review Subcommittee offers advice and recommendations on EPA programs dealing with mobile source emissions and fuels. The Clean Diesel Independent Review Panel was specifically chartered to gauge industries' progress in developing technologies to reduce highway emissions and meet ultra-low sulfur fuel requirements according to highway diesel standards promulgated in 2001. Both of these subcommittees play a role in helping EPA determine the technical feasibility of its air quality policies.

There are several steps that EPA follows for new emission regulations. EPA first issues a Notice of Proposed Rulemaking in the Federal Register. The notice explains the proposed rule and the motivation behind it. It is accompanied by a Regulatory Impact Analysis (RIA) which provides analysis and supporting data for the new regulations. For example, the RIA for the 2004 on-highway heavy-duty diesel regulations covered the health impacts, technological feasibility, economic impact, environmental impact, and cost-effectiveness of the proposed standards. There may also be a Technical Support Document that provides the air quality modeling analyses used to support the proposed rule.

In the Notice of Proposed Rulemaking, EPA schedules a comment period that allows interested parties to submit comments about the rule. If a party requests a public hearing or if EPA anticipates the demand for one, EPA sets a date for a hearing. Interested parties are invited to testify at the hearing and offer their comments on the proposed rule. For the 1999 public hearing for the MY2004 regulations, EPA made the following announcement: "The most useful comments are those supported by appropriate and detailed rationales, data, and analyses. The Agency also encourages commenters that disagree with elements of the proposal to suggest and analyze alternate approaches to meeting the air quality goals of this proposal" (U.S. EPA 1999b). Once the deadline for comments passes, EPA reviews the comments and public hearing testimony. EPA responds to them in the final rule, which may be amended or withdrawn depending on EPA's review of the comments.

Once the final rule is promulgated, industry is granted at least four years of lead time before the rule goes into effect. In order to sell a new engine model on the market, an engine manufacturer must obtain a “certificate of conformity” from EPA. This certificate demonstrates that the engine has passed EPA’s emissions certification testing. New engine models must pass the Federal Test Procedure, a 20-minute test procedure designed by EPA in the late 1970s. The test has been criticized for not simulating realistic driving conditions, particularly long-haul highway driving. It had been originally designed to address urban air quality problems, and therefore simulated urban driving conditions (i.e. stop-and-go city driving). In 2000, EPA added supplementary steady-state and not-to-exceed (NTE) test procedures to the Federal Test Procedure for model year 2007 heavy-duty diesel engines. These supplementary test procedures are meant to cover the steady highway driving conditions not captured in the Federal Test Procedure. Addressing the weaknesses of the Federal Test Procedure became a top priority after engine manufacturers were caught circumventing regulations in 1998 (U.S. EPA 2002e).

### ***“Defeat Devices” and the Consent Decree***

In 1998, seven heavy-duty diesel engine manufacturers, comprising 95% of the U.S. diesel engine market – Caterpillar, Cummins, Detroit Diesel, Mack, Navistar, Renault, and Volvo Truck – were charged with violating the Clean Air Act by illegally installing devices that defeat emission controls. Their engines met EPA emission standards during certification testing, but when the “defeat device” software disabled the controls during highway driving, the NO<sub>x</sub> released was up to 3 times the EPA limit. The problem surfaced during a routine enforcement audit of an engine in 1997. Test results indicated the existence of questionable calibration strategies. EPA conducted an industry-wide compliance investigation and software review, and learned that the use of defeat devices was widespread (U.S. House of Representatives 2000). In October 1998, the manufacturers eventually settled with EPA for over \$1 billion, the largest settlement in Clean Air Act history. The manufacturers sold 1.3 million engines between 1988 and 1998 with these defeat devices, resulting in the release of 6.9 million tons of excess NO<sub>x</sub> in that decade (U.S. EPA 1998). Emission control technology operates at the

expense of fuel economy and performance, and the trucking industry's priorities resulted in the "defeat devices" becoming common industry practice, albeit an illegal one.

While the manufacturers' behavior was illegal and detrimental to public health, the Federal Test Procedure (FTP) heavy-duty transient cycle has been criticized for being flawed and outdated. As early as 1978, EPA was aware of the existence and increasing use of sophisticated electronic engine controls that could potentially be used to circumvent the test procedures, and even issued an advisory called "Prohibition on Emission Control Defeat Devices." A U.S. House of Representatives Commerce Committee report claims that as early as 1991, various sources informed EPA of the existence of electronic engine control software which was being used to circumvent emission control systems (U.S. House of Representatives 2000). EPA insists that it did not know of the defeat devices until 1997. Industry representatives contend that EPA learned in 1994 how flaws in the FTP resulted in actual NO<sub>x</sub> emissions much higher than those reflected in the test. Reportedly, an EPA observer was present at a 1994 meeting held in Geneva to discuss European certification procedures, where the International Automotive Constructors Organization presented data on the weaknesses of FTP to everyone present (U.S. House of Representatives 2000).

An important outcome of the consent decree was that the engine manufacturers agreed to meet January 2004 emission standards by October 1, 2002. This required the manufacturers to accelerate product development, which also decreased the amount of time for field testing the new engines. Uncertainty in the trucking industry about the performance and durability of the new technologies used to meet the 2002 deadline led to a massive pre-buy of the older models in early 2002. Truck fleet owners either purchased trucks prior to the introduction of the new October 2002 trucks or purchased only a few or none of the new trucks, and held onto their older vehicles longer. This compromised the emission benefits associated with the accelerated deadline. Following allegations of misconduct, EPA conducted an investigation of the manufacturers' sales and marketing practices to determine if they encouraged customers to pre-buy the engines before the October 2002 deadline (Angelo 2002).

Meanwhile, as the October 2002 deadline approached, some of the engine manufacturers filed lawsuits against EPA, contending that unexpected cost increases would make compliance to

the consent decree more expensive than previously estimated and less beneficial to the public. The U.S. District Court denied them any modifications of the consent decree, and manufacturers that did not meet the October 2002 deadline had to pay non-compliance penalties for each engine sold not meeting the MY2004 emission standards (U.S. DCDC 1999).

The consent decree and the subsequent controversies highlight the tension between EPA and the heavy-duty diesel engine industry, particularly where the interpretation of emission regulations and compliance is concerned. The regulatory violations, lawsuits, and conflicting assessments of technological progress demonstrate the need for improved communication between regulators and industry. Industry-government R&D partnerships, where the regulated and the regulators are participants in a joint project, may be one way to improve the lines of communication.

### ***The Department of Energy's Interest in the Diesel Industry***

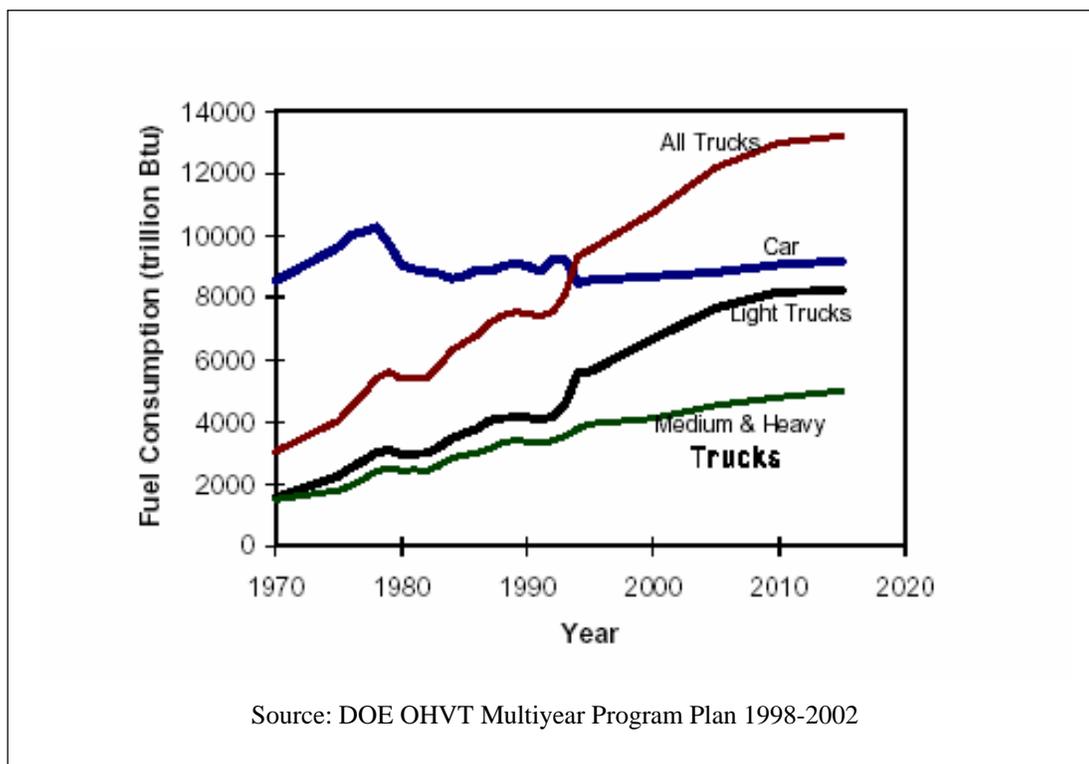
EPA is not the only federal government agency with a keen interest in the diesel industry. The U.S. Department of Energy (DOE) is concerned with the increasing amount of petroleum consumed by the nation's transportation industry. Although interest in reducing petroleum consumption in the U.S. has prompted research into alternative fuels and technologies, 97.1% of transportation energy needs are still met by petroleum-based fuels. The transportation industry makes up over two-thirds of the total U.S. petroleum demand (BTS 2002).

According to DOE, fuel consumption by both light-duty and heavy-duty trucks is increasing at a faster rate than passenger vehicles. Economic growth and the subsequent increase in freight transportation have prompted the growth in heavy-duty truck use and diesel consumption. Meanwhile, the popularity of pick-ups and SUVs is responsible for the growth in light-duty truck use and gasoline consumption.<sup>2</sup>

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<sup>2</sup> There are three classes of trucks. Class 1 & 2 include pickups, vans, and sport utility vehicles (SUVs). In the U.S., these are almost entirely gasoline-powered. Class 3-6 refer to medium-duty trucks such as delivery vans, and Class 7 & 8 account for the large, on-highway trucks. The term "heavy-duty" usually applies to the Class 3-8 vehicles, which tend to be primarily diesel-powered.

**Figure 6: Fuel Consumption by Transportation Mode**



According to its mission statement, DOE’s overarching goal is to enhance national security. DOE sees energy conservation and efficiency as a way to reduce U.S. dependence on foreign oil and to make the most efficient use of finite petroleum resources. DOE also funds science and technology R&D in developing renewable and alternative energy sources, as well as enhancing the production and use of fossil fuel sources.

As early as 1992, there was a formal requirement for DOE to help diesel manufacturers meet future NO<sub>x</sub> and PM emission standards. The Energy Policy Act of 1992 specifically called for DOE to begin an “Advanced Diesel Emissions Program.” The following is excerpted from the Energy Policy Act, Section 2027. Particular notice should be paid to parts (a) and (b), which articulate the focus of the proposed R&D.

1992 Energy Policy Act, Title XX

SEC. 2027. ADVANCED DIESEL EMISSIONS PROGRAM.

(a) PROGRAM DIRECTION.-The Secretary shall initiate a 5-year program, in accordance with sections 3001 and 3002 of this Act, on diesel engine combustion and engine systems, related advanced materials, and fuels and lubricants to reduce emissions oxides of nitrogen and particulates. Activities conducted under this program shall supplement activities of a similar nature at the Department of Energy. Such program shall include field demonstrations of sufficient scale and number in operating environments to prove technical and economic viability to meet the goal stated in subsection (b).

(b) PROGRAM GOAL.-The goal of the program established under subsection (a) shall be to accelerate the ability of United States diesel manufacturers to meet current and future oxides of nitrogen and particulate emissions requirements.

(c) PROGRAM PLAN.-Within 180 days after the date of enactment of this Act, the Secretary, in consultation with appropriate representatives of industry, institutions of higher education, Federal agencies, including national laboratories, and professional and technical societies, shall prepare and submit to the Congress a 5-year program plan to guide the activities under this section. Such plan shall be included as part of the plan required by section 2021(b).

(d) SOLICITATION OF PROPOSALS.-Within 1 year after the date of enactment of this Act, the Secretary shall solicit proposals for conducting activities consistent with the 5-year program plan.

The 1992 Energy Policy Act followed on the heels of the 1991 Persian Gulf War, when the government was anxious to reduce reliance on foreign oil. DOE recognized that meeting future emissions requirements would impose a large cost on industry, which would ultimately pass those costs onto the consumers. Government assistance in emissions reduction R&D was intended to alleviate the burden on industry and strengthen domestic competitiveness.<sup>3</sup>

DOE's Office of Energy Efficiency and Renewable Energy (EERE) has the responsibility of "strengthening America's energy security, environmental quality, and economic vitality in public-private partnerships." Before EERE reorganized in July 2002, it was divided into five "sector" offices – industry, transportation, buildings, power, and federal energy. Under EERE's Office of Transportation Technologies was the Office of Heavy Vehicle Technologies (OHVT), devoted to addressing the energy challenges facing heavy transport vehicles. OHVT's mission was to "work with industry partners and their suppliers to research and develop technologies that

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<sup>3</sup> Energy Policy Act of 1992. Title XX, Section 2027.

make heavy vehicles more energy efficient and able to use alternative fuels, while reducing vehicle emissions” (U.S. DOE 2002c).

DOE’s OHVT was not established until 1996 because DOE had previously focused its transportation energy concerns on passenger vehicle manufacturers, suppliers, and users, much as EPA had focused its emission regulations on passenger vehicles. Up until the creation of OHVT, the manufacturers, suppliers, and users of heavy transport vehicles had been “largely unrecognized” (U.S. DOE 2000e).

The essentialness of freight movement makes heavy vehicles crucial to the national economy. Highway freight transportation consumes around 12% of the U.S. total petroleum demand (U.S. DOE-EIA 2001a). The heaviest vehicles average 5 or 6 miles per gallon. Trucks account for \$25.7 billion of net oil imports annually, and medium and heavy trucks account for 80% of that total. OHVT wanted to improve the fuel efficiency of the nation’s trucks and eventually enable them to run on alternative fuels.<sup>4</sup> In the meantime, OHVT saw the fuel economy advantage of diesel engines over gasoline engines for light-duty trucks and SUVs. OHVT wanted to push for even higher energy conversion efficiency in diesel engines through R&D. Applying heavy-duty diesel technology to light-duty vehicles suitable for the U.S. market would reduce overall petroleum consumption and dependence on foreign oil. At the same time, OHVT knew that reductions in vehicle emissions would be necessary to meet increasingly stringent U.S. emission standards (U.S. DOE 1998).

Increasing national competitiveness was also a top priority for OHVT. The late 1990s witnessed a flurry of mergers and acquisitions in the automotive and truck industry, including several acquisitions of American companies by European companies. In 1997, Volvo bought GM’s remaining shares in Volvo GM Heavy Truck, which had been created by the two companies in 1988. Also in 1997, Freightliner, which was sold to Daimler-Benz (now DaimlerChrysler) in 1981, purchased Ford’s heavy truck business. In 1990, Mack Trucks became a wholly-owned subsidiary of Renault VI, Renault’s commercial vehicle division; Renault VI/Mack was ultimately acquired by Volvo Truck in 2000. As of 1996, U.S. domestic

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<sup>4</sup> By “alternative,” DOE does not necessarily mean non-petroleum-based. “Alternative” also refers to biodiesel, synthetic diesel, propane, natural gas, alcohol, and ethanol.

companies held the majority of the market share in the heavy-duty truck engine market and the light truck market, but the recent acquisitions have eroded that market share. Even at that time, domestic companies had less than 50% of the heavy-duty truck vehicle market. OHVT worried that pressure to reduce CO<sub>2</sub> emissions around the world would lead to a dieselization of light trucks. U.S. firms would not be able to compete with European and Japanese firms which have respectively developed advanced diesel engines and hybrid gasoline engines for passenger vehicles. With those circumstances as a backdrop in the mid-1990s, OHVT initiated programs for U.S. heavy-duty engine manufacturers and passenger automakers to team up to develop light-duty diesel vehicles.

At the same time that OHVT saw the opportunity to promote diesel as a means to improve energy efficiency and address global warming concerns, EPA was performing its own technology reviews of the automotive and truck industry, and planning tighter emission standards from both gasoline and diesel vehicles. OHVT knew that technology development to meet stricter emission standards would have to be a major component of any DOE research activities on diesel technologies.

Understanding the background on clean diesel R&D helped to develop a research approach that could capture the impacts of partnerships on regulatory policy. The next chapter describes the research methodology behind the comparative case study of three clean diesel R&D partnerships.

## CHAPTER 3: METHODOLOGY

Exploring how public-private clean diesel R&D partnerships could influence the regulatory process requires an understanding of clean diesel technologies and relevant regulations. To obtain background information on diesel technology and regulations, I reviewed public documents on federal regulations on diesel emissions and diesel fuels and technical publications featuring industry progress in clean diesel technologies.

These background materials referred to several government-industry collaborations on R&D, and suggested two different approaches that could be pursued. The first approach would be to generate an exhaustive list of public-private R&D partnerships, and to determine, based on public information and surveys, how much influence each one had on regulations. The second approach would be to perform an in-depth, comparative analysis of a few select partnerships, still using public information and interviews, but in a much more targeted way. Since I am interested in understanding the mechanisms by which partnerships affect regulations as well as the characteristics of partnerships that enable policy input, I chose the second approach. This approach would permit a more meaningful evaluation of the individual partnerships than a broad survey of many partnerships.

The lack of scholarship on the potential policy influence of public-private R&D partnerships meant that the conditions for policy influence were not well understood. This implied that I would need to use an inductive approach to answering my research questions. Instead of testing known theories or concepts with a statistically significant number of partnerships, I had to identify common patterns from a detailed examination of a more limited number of partnerships. This approach had the advantage of being more open to unexpected potential “policy-influencing” conditions and mechanisms. My selection of the comparative case study methodology was rooted in these considerations. Using more than one case study gave me the opportunity to evaluate the role of the partnerships’ similarities and differences in their outcomes.

## *Overview*

I selected public-private R&D partnerships for my case study based on a set of selection criteria described below. I used publicly available progress reports and results from the partnerships to place the partnerships in their appropriate regulatory context. Next, I searched for references to the partnerships or the partnership results in federal regulatory documents, technical publications, conferences, and workshops in the time period during or after each partnership's work. Identifying these references allowed me to establish the contribution of individual partnerships to different regulatory stages, from policy formation to legal challenges to the final regulation. From my background research on the diesel industry and on the partnerships themselves, I identified individuals whose experiences would offer valuable insight into partnerships and the regulatory process. I contacted and interviewed these individuals, who were from industry, government, academia, and research laboratories in the U.S. Common themes emerged from the interviews, and brief questionnaires were sent to the interviewees to gauge the interviewees' reaction to some of these themes. Finally, the partnerships were compared across a set of specific criteria. The comparison revealed characteristics that enable partnerships to provide input to the regulatory process.

## *Selection of Partnerships*

I wanted to focus on three public-private partnerships which I could use as case study examples of how partnerships function and how they contribute to regulatory decision-making. Using online search engines and personal contacts in the diesel industry as sources of information, I built a working list of public-private partnerships engaged in reducing diesel emissions.<sup>5</sup> Some of the information found online or suggested by industry and academic contacts also led me to specific research institutions, universities, and labs.

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<sup>5</sup> The following were the primary online sources used to identify public-private partnerships in clean diesel technology: Manufacturers of Emission Controls Association, Dieselnet, Diesel Technology Forum, Engine Manufacturers Association, U.S. Department of Energy, U.S. Environmental Protection Agency, California Air Resources Board, company press releases, and Lexis-Nexis Academic-Business News.

In selecting partnerships that would be appropriate for my case study, I used the following set of selection criteria:

1. Diesel emissions reduction is the main or one of the main project goals.
2. Research and/or development is the focus of the project, as opposed to operations.
3. Projects deal specifically or predominately with on-road diesel vehicles.
4. Participation from more than one industry.
5. Participation from more than one government agency.
6. Pre-competitive research where results would be publicly available.
7. Accessibility of information on the progress of the project.
8. Familiarity or prominence of the project in industry and government.
9. Most of the participating organizations are in the U.S., or the research has a U.S.-based focus.

Since my research is interested in regulations on diesel emissions, projects with emissions reduction as a key driver would have greater potential of affecting the regulatory process. Emission regulations are intricately tied to what the latest technology can do, so R&D seems to be the best indicator of the state-of-the-art technology. Although partnerships in operations and maintenance do occur in the diesel vehicle industry, they only indicate what the existing technology can do. To date, there has been little regulation of off-road vehicles, and therefore little R&D on off-road emissions reduction.<sup>6</sup> The third criterion eliminates projects that are too broadly focused on various types of energy technologies, e.g. projects comparing diesel to gasoline, natural gas, or hybrid technologies.

The benefits of heterogeneous interaction cited by the theoretical literature motivated the fourth and fifth criteria. Requiring the involvement of more than one industry and more than one government agency allowed me to test the partnerships' ability to enable knowledge sharing across companies producing complementary, not just competitive, technologies, and across government agencies with different institutional mandates. For example, a partnership may span

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<sup>6</sup> On April 15, 2003, EPA released a proposal to dramatically reduce emissions from off-road diesel engines starting in 2008. If the off-road emission and fuel standards are promulgated, it is likely that R&D in off-road diesel emissions reduction will increase substantially.

the engine and fuel industries, and involve both the DOE and EPA. Although not an explicit criterion, I also preferred partnerships that include academic or research institutions because of the opportunity for knowledge-sharing to and from universities and research labs.

Publicly available and easily accessible results are necessary from a practical point of view. Obtaining proprietary information from companies would be extremely difficult. Publicly available data have the advantage of being easily accessible to policymakers as well, and therefore more likely to play a role in the regulatory process. By its very nature, research performed by multiple industry partners tends to be pre-competitive because participants are unlikely to engage in research if their work has already reached the proprietary stage. This ruled out the possibility of including CRADAs (Cooperative Research and Development Agreements), which are partnerships between a company and a public entity. Since CRADAs help develop commercial products, both parties sign confidential agreements to protect proprietary information. It is important that a selected partnership feature prominently in industry and government because if public-private partnerships do influence the regulatory process, it will presumably be the most well-known ones. Since the scope of this research is limited to the U.S. regulatory system, considering mainly U.S.-based partnerships is appropriate.

### ***Review of Public Documentation***

Using the selection criteria described above, three partnerships emerged suitable for further investigation. They were the following: the Diesel Emission Control – Sulfur Effects Program (DECSE), the Advanced Petroleum-Based Fuels – Diesel Effects Control Program (APBF-DEC), and the EC-Diesel Technology Validation Program. All three partnerships investigated the effects of diesel fuel quality on emissions reduction, and included DOE as a sponsoring government agency. Although these characteristics were not specified as selection criteria, these commonalities facilitated more consistent comparisons.

After selecting the partnerships, I reviewed the partnership-specific documentation such as project plans, progress reports, conference or seminar presentation slides, and technical publications. These materials were used to identify the project's relevance to diesel regulations.

I then reviewed EPA's documentation for its diesel technology reviews and regulations to determine whether these partnerships had been mentioned, discussed, or presented at the policy-making level. I assumed that any impact of a partnership on regulations would occur during or after the partnership. Therefore, for the time period during and after each partnership, I reviewed EPA notices of proposed rulemaking, regulatory impact analyses, submissions and responses from the comment period, final rules, and legal challenges. I also considered regulatory action pursued by the California Air Resources Board because of California's tendency to impose stricter or earlier emission standards than EPA.

### *Interviews*

I used the membership lists and organizational charts from these documents to identify individuals key to the partnerships and/or the regulatory process. In most cases these would be project team leaders, R&D supervisors, regulatory advisory panelists, and agency division or department heads. I sent a letter to approximately 30 individuals in government agencies, national laboratories, private firms, industry associations, and research institutions introducing them to my interest in interviewing them in person or by phone. The letter described the purpose and scope of my research and discussed how their confidentiality would be protected. Most letters were mailed in December 2002. A second round of letters was mailed in January 2003, based referrals received from the first round of letters.

After allowing two weeks for the potential interviewees' receipt of the introductory letter, I telephoned or emailed the individuals to arrange a convenient time and date for a 30 to 45 minute interview. In the cases where the interviewees preferred a face-to-face meeting and distance was not prohibitive, I arranged to meet them at their work location. Some individuals declined the interview or referred me to another person in their organization. Twenty-two individuals were interviewed during January and February 2003.

At the beginning of the interview, before I proceeded with any questions, I informed the interviewees of the following:

1. Participation is voluntary
2. The interviewee may decline to answer any questions.
3. The interviewee may decline further participation at any time without prejudice.
4. Any notes of the interview will be for my personal use and not publicly distributed.
5. Comments will not be attributed to the interviewee unless consent is granted.
6. When comments remain anonymous, the information collected will be reported in such a way that the identity of the individual is protected.
7. Proper measures will be taken to safeguard the collected information.

In both the in-person and phone interviews, I took hand-written notes only and did not audiotape any conversations.

There were multiple objectives for the interviews. One was to get an inside view of the partnerships that I selected for my case studies, and to assess whether these individuals felt that the partnerships had any impact on the regulatory process. Most of the individuals were directly involved in one or more of the partnerships, so I could ask targeted questions about those specific partnerships. Secondly, I wanted to better understand the role of the partnerships in creating, changing, or reinforcing knowledge networks. Thirdly, I wanted to know how the EPA regulatory process – particularly technical reviews and regulatory timelines – affected how R&D was performed in partnerships and in individual companies. Finally, since many of the interviewees, by the nature of their job assignments, bridged across organizations and functional roles (e.g. many had both technical and policy roles), I sought to determine how they acquired and balanced these responsibilities. While the exact questions that I asked varied depending on the person being interviewed, the basic core questions remained the same. A sample version of the questions can be found in the Appendix.

Following each interview, I sent an email draft of my summary notes from the interview to the interviewee for his/her review. Each interviewee was given the opportunity to revise the summary notes to better reflect what was said or meant, or to designate any comments as anonymous or off-the-record to protect confidentiality.

Comments which have been included in this work have been paraphrased based on notes taken in the interviews, and those paraphrased comments have been reviewed by the interviewees prior to inclusion in this work. In cases where interviewees consented to disclosing their identity, their comments have been attributed by their titles and organizational affiliations. Otherwise, their comments remain unattributed.

### ***Questionnaires***

Several common themes emerged from the interviews; interviewees' comments led me to draw some preliminary conclusions. To test the robustness of these findings, I administered a short questionnaire to all the interviewees, once all the interviews had been completed. The questionnaire consisted of 5 brief questions. Four questions are answerable on a scale of 1 to 5, and one is a comparison between two items (see Appendix). All of these questions had been asked or discussed in some of the interviews, but in a more qualitative and less methodical way. This questionnaire allowed me to quantify some of the more qualitative results and to establish patterns based on organizational affiliations of the interviewees (e.g. industry, DOE/national labs, academia, and regulatory agencies).

I contacted the interviewees by email to inform them of this follow-up questionnaire and my intention to contact them shortly. I also explained that their responses would be anonymous. Over a two-week period, I phoned the interviewees to administer the questionnaire or, at their request, I sent them the questionnaire to answer by email.

### ***Criteria for Comparison***

Based on my background research and interviews, I established seven criteria for comparison that could potentially play a role in various aspects of policy influence. They provided a consistent way to compare the R&D partnerships.

**Table 2: Criteria for Comparison**

	Criteria	Explanation	Basis for evaluation
1	Fulfillment of goals	The interim and final results should meet the objectives stated at the beginning of the project. Ongoing projects should be progressing as expected. Partnerships that have met their goals would be perceived as successful and could serve as viable appropriate policy inputs.	Partnership documents such as program plans, progress reports, interim reports, and final reports
2	Development of data and/or technology useful to future technology development	The ability to trigger future technology development by industry has important policy ramifications because policymakers use industry's technological progress as a major factor in setting technology-forcing standards.	Interviews; industry action/R&D after partnerships; questionnaires
3	Public availability of results and communication of those results outside the partnership	Results may be disseminated to policymakers and the rest of the diesel industry through conferences, presentations, technical publications, and websites during and after the project's progress.	Presentations and papers at industry conferences and meetings; interviews; websites
4	Influence on regulations	Citations in rulemaking documents at various stages of the regulatory progress would demonstrate the role of the partnership results.	Regulatory documents; interviews
5	Credibility to regulators and the rest of industry	The extent to which the results are seen as credible and unbiased would affect policymakers' receptiveness to using the results for policymaking.	Interviews; questionnaires
6	Generation of further research or partnerships	The existence of follow-on projects by partnership participants as a group or as individual organizations could result in policy influence in the future.	Partnership documents; interviews
7	Contribution to formal and informal knowledge networks	Knowledge transfer occurs through networks. The formal networks are based on organizational structure and reporting mechanisms, while the informal networks rely more on personal relationships and trust. Building communication links would facilitate dialogue between policymakers and technologists.	Partnership documents; interviews

The review of public documentation, interviews, questionnaires, and criteria-based analysis would collectively contribute to the comparative case study and reveal the common conditions and mechanisms that allow partnerships to have influence on the regulatory process. The next chapter describes the Department of Energy's approach towards industry-government R&D and profiles the three partnerships that are the subject of the comparative case study.

## **CHAPTER 4: PARTNERSHIPS IN CLEAN DIESEL TECHNOLOGY**

Because of its interest in energy efficiency, energy security, and national competitiveness, the Department of Energy very actively pursues joint R&D programs with the diesel industry. The Office of Heavy Vehicle Technologies, until its reorganization in 2002, was the DOE office primarily responsible for those R&D programs. Much of the R&D has focused on clean diesel technologies because of the increasing stringency of federal diesel emission standards. The following chapter lays out the overarching motivations behind the Office of Heavy Vehicle Technologies' public-private clean diesel R&D. It then profiles the three public-private partnerships that are the subject of the comparative case study, with a particular emphasis on the regulatory context and policy influence of the partnerships.

### ***DOE's Motivation for Public-Private R&D Partnerships***

In 1997, and again in 2000, DOE's Office of Heavy Vehicle Technologies (OHVT) released a Roadmap that laid out its goals and priorities. OHVT had three major rationales for supporting heavy-duty vehicle research through investment in public-private R&D partnerships:

**(1) To enable coordination among industry actors that would otherwise not collaborate.**

Government funding would ideally make the best technologies available to all the companies, and help industry identify the best technologies to pursue collectively. If companies worked alone, they would be far less motivated to develop a technology with spillover benefits to the entire industry. Collaborative R&D was intended to raise the competitiveness of the entire domestic heavy vehicle industry as a whole, relative to their European and Japanese competitors. In addition overcoming the resistance of competitors to collaborate, public-private partnerships could also coordinate the activities of complementary industries, such as the engine manufacturers, fuel suppliers, and emission control equipment manufacturers.

- (2) **To help industry meet emissions requirements in the most timely and cost-effective way possible so as to reduce the costs passed onto the customer.** EPA’s technology-forcing emission standards require breakthrough technologies. By taking advantage of the expertise and facilities in the DOE national laboratories and in universities, companies would be better poised to meet standards expediently. In addition to adding to the costs of engines, aftertreatment devices attached to reduce exhaust emissions have a 5-10% fuel economy penalty. DOE wanted to reconcile its goal of reducing fuel consumption with EPA’s goal of reducing exhaust emissions.
- (3) **To better inform standard-setting and policy-making by EPA and to improve coordination with other agencies.** DOE wanted to generate scientific data to bolster science-based decision-making by EPA. Partnerships would also enable DOE to work with other government agencies with similar goals of facilitating more efficient and cleaner transportation, such as the Department of Transportation and the Department of Defense. Building better communication and coordination across agencies may help to avoid compliance failure and misalignment of goals. The use of “defeat devices” by the engine manufacturers and the resulting consent decree accelerated the deadline for meeting MY2004 emission standards. This had the effect of disrupting the development of technologies that would have increased engine efficiency (U.S. DOE 1997, U.S. DOE 2000e).

## **Factors Influencing Research Programs**

OHVT’s roadmap plans demonstrate that it understood how the EPA regulatory process affected heavy vehicle R&D. OHVT sought to adjust the timing and scope of their R&D to better align with industry’s need to meet emission regulations. In recent years, DOE had focused on short-term R&D because of budgetary constraints and stakeholder interests. Uncertainty about funding renewal limited the length of research programs. Companies were under pressure by EPA’s incrementally tightening emission standards every few years. Consequently, meeting relatively short-term goals took priority over R&D goals more distant on the time horizon. However, OHVT recognized that setting longer-term goals was necessary for effective R&D.

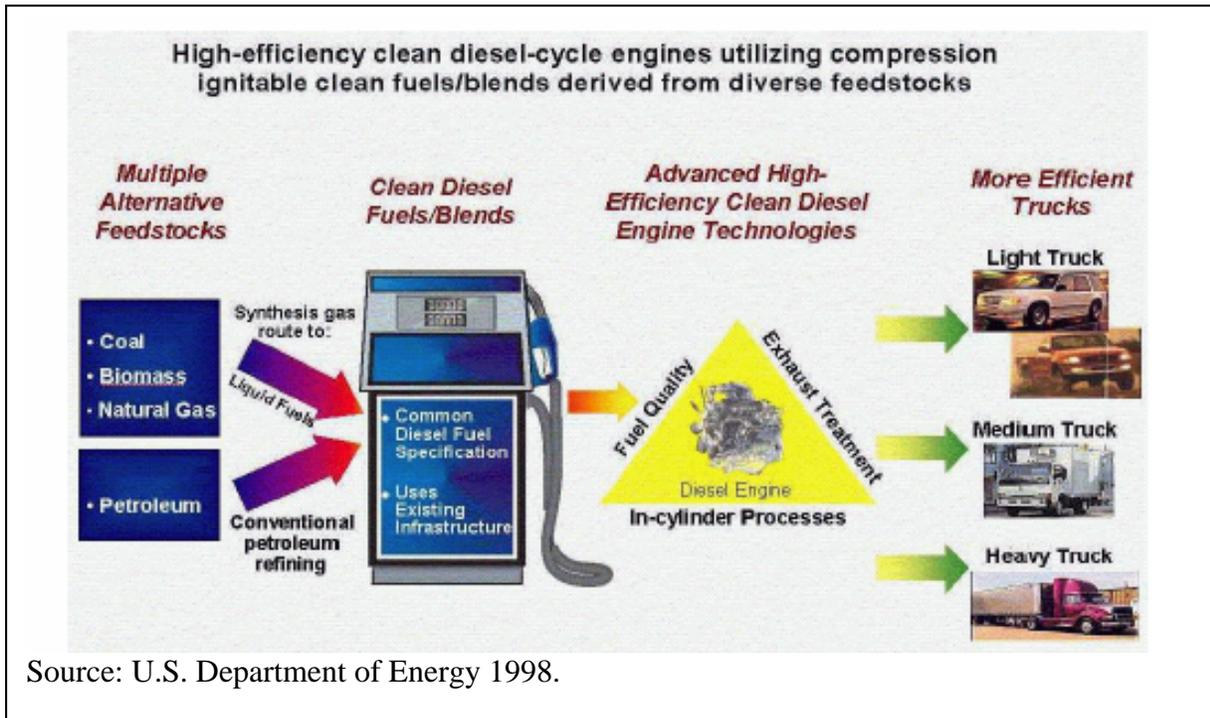
After individual programs make basic technical data available, it takes at least three years before technology is ready for commercial production. The average time from the start of a research program to commercial production is eight years, whereas EPA emission standards can change as quickly as every four years (CETS 2000). This requires a more proactive approach to anticipating emission regulations and undertaking research to advance technology.

OHVT's desire to shift its focus from short-term to long-term research activities would affect how it selected projects. They wanted to build in flexibility to change directions as a program progressed to adhere to goals. Programs should not support specific engine or component development industry, but provide basic information for industry to make its decisions about technology. Although "heavy vehicle technologies" does necessarily mean diesel vehicles, the pervasiveness of diesel and the existing infrastructure for diesel fuel made diesel the primary focus. During OHVT's existence from 1996 to 2002, there was mention of including development of alternative technologies, but this seemed like a secondary priority relative to diesel.

The trade-off between fuel efficiency and emissions reduction is a prominent consideration in the diesel vehicle industry. Emission standards for PM and NO<sub>x</sub> pose a challenge to developing more efficient diesel vehicles because of aftertreatment devices' fuel economy penalty and sensitivity to fuel properties. This led OHVT to take on an integrated systems approach to diesel engines by considering the in-cylinder process, fuel quality, and exhaust treatment as one system. Even beyond engine efficiency, OHVT wanted to explore other factors such as aerodynamics, truck material design, and roadway conditions that contribute to fuel economy.

The following diagram summarizes the OHVT strategy, reflecting their underlying assumptions and priorities about the future of fuels and vehicle technologies.

Figure 7: OHVT's Clean Diesel Strategy



## Shying Away From Ambitious Goals

OHVT's goals for 2004 may be a moving target: The 2000 version of the OHVT Roadmap is significantly less ambitious than the 1997 version. The major differences in the roadmap goals are underlined in the next section. One possible explanation for the less aggressive 2000 Roadmap is industry's focus on meeting the earlier October 2002 deadline for highway diesel emission standards. This would have had the effect of shifting industry focus away from the very aggressive stretch goals of improving fuel efficiency to simply meeting EPA regulations on time. There is also the fear that even laying out non-binding stretch goals somehow prematurely commits the industry to meeting them. The 1997 Roadmap has a stronger emphasis on considering alternative fuels, while the 2000 version does not mention alternative fuels at all, implying that diesel is the assumed fuel of choice (U.S. DOE 1997, U.S. DOE 2000e).

## Goals spelled out by OHVT for 2004

### **October 1997 Roadmap**

Develop by 2004 the enabling technology for a class 7-8 truck with a fuel efficiency of 10 mpg (at 65 mph) which will meet prevailing emission standards, using either diesel or a liquid alternative fuel.

By 2005, develop advanced powertrain technology for medium/heavy-duty trucks that achieve three times today's fuel economy (up to 30 mpg), and as a research goal, reduce criteria pollutant emissions to 30% below proposed regulated levels.

Develop by 2002 the diesel engine enabling technologies to support large-scale industry dieselization of light trucks, achieving a 35% fuel efficiency improvement over equivalent gasoline-fueled trucks, and bettering applicable emission standards.

Develop by 2006 diesel engines with fuel flexibility and a thermal efficiency of 55 percent with liquid alternative fuels, and a thermal efficiency of 55 percent with dedicated gaseous fuels.

### **February 2000 Roadmap**

Develop by 2004 the enabling technologies for a Class 7 & 8 truck with a fuel efficiency of 10 mpg (at 65 mph) that will meet prevailing emission standards.

For Class 3–6 trucks operating on an urban driving cycle, develop by 2004 commercially viable vehicles that achieve at least double the fuel economy of comparable current vehicles (1999), and as a research goal, reduce criteria pollutants to 30% below EPA standards.

Develop by 2004 the diesel engine enabling technologies to support large-scale industry dieselization of Class 1 & 2 trucks, achieving a 35% fuel efficiency improvement over comparable gasoline-fueled trucks, while meeting applicable emission standards.

(Sources: U.S. DOE 1997, U.S. DOE 2000e)

## *Partnership Profiles*

All three public-private partnerships that were chosen for this research involved the DOE as a partner. Two featured DOE as the lead organization. There was also substantial overlap in some of the other organizations and personnel involved. All three partnerships centered on investigating the effect of lowering diesel fuel sulfur levels on the effectiveness of diesel exhaust aftertreatment.

This section profiles each partnership's regulatory context, organization, design, results, and impact on the regulatory process. The next chapter compares the three partnerships across the set of criteria outlined in the methodology (Chapter 3). The intent is to identify the common characteristics that enable partnerships to offer input into regulations.

The three public-private clean diesel R&D partnerships profiled are the following:

- I. Diesel Emission Control – Sulfur Effects Program (1998-2001)
- II. Advanced Petroleum-Based Fuels – Diesel Emission Control Program (2000-2010)
- III. EC-Diesel Technology Validation Program (1999-2002)

## ***I. Diesel Emission Control – Sulfur Effects Program (1998-2001)***

### **Introduction**

The Diesel Emission Control – Sulfur Effects (DECSE) Program was initiated in September 1998 by the Department of Energy’s Office of Heavy Vehicle Technologies (OHVT), in partnership with two industry associations – the Engine Manufacturers Association (EMA) and the Manufacturers of Emission Controls Association (MECA). It had a well-defined mandate – to evaluate the effects of varying levels of fuel sulfur content on emissions reduction and on up to 250 hours of engine aging for on-highway diesel trucks. The program “aims to determine the impact of diesel fuel sulfur levels on emission control systems whose use could lower emissions of nitrogen oxides (NO<sub>x</sub>) and particulate matter (PM) from on-highway trucks from the 2002-2004 model years” (U.S. DOE 1999a). DECSE’s timeliness helped to fill a knowledge gap about the levels of sulfur and the emissions performance of emission control technologies. By generating a body of publicly available and credible data, DECSE provided a technical basis for EPA’s 2006 diesel sulfur rule.

### **Regulatory Context**

At the time the project began, the EPA had already informally announced its intentions to enact more stringent emission regulations in late 1999 or early 2000, including a NO<sub>x</sub> reduction of 75-90% and a PM reduction of 80-90%. EPA was also proposing a reduction of diesel fuel sulfur content of approximately 90%. Engine manufacturers had been pushing for lower fuel sulfur levels because their engines could not meet the emission standards without ultra-low sulfur fuel. High sulfur content in currently available diesel fuels threatens to render emission control devices ineffective, which would make meeting more stringent federal engine emission standards far more difficult, if not impossible.

As early as 1997, DOE had discussed sulfur poisoning problems in engine aftertreatment devices with EPA. Senior officials at the DOE and EPA agreed that if DOE's tests could make a case for ultra-low sulfur diesel, EPA would consider using it as a basis for a low-sulfur rule.<sup>7</sup>

On May 13, 1999, EPA issued an Advance Notice of Proposed Rulemaking on the control of diesel fuel quality. The document indicates that EPA was well aware of the need for lower sulfur fuel, but needed to determine at what level to set the standard:

“Manufacturers have suggested that sulfur should be capped at 30 ppm, although the need for even lower levels has also been discussed. Even for those technologies that require low-sulfur fuel to function, there may be a range of operations in which the technologies may be able to tolerate higher sulfur levels but emissions performance may be further enhanced by additional reductions in fuel sulfur. We are interested in information that will help us understand both the range of sulfur levels over which operation of the relevant control technologies is possible, and the relationship between emissions performance and fuel sulfur levels within this range” (U.S. EPA 1999a). (Emphasis added)

The emphasized statement indicates DECSE was designed to provide the type of information that EPA wanted for its decision-making. Program participants expected that DECSE would add to the common knowledge base on engines, diesel fuels, and emission control technologies, the three areas comprising DOE's “systems approach” to clean diesel technologies. DECSE results would help industry participants with technology development, DOE and its national labs with planning future research activities, and EPA with technical information for regulatory decisions regarding diesel fuel sulfur content. According to DOE, DECSE “address[es] a critical lack of sound technical, publicly available information” (U.S. DOE 2001d). In its Advance Notice of Proposed Rulemaking, EPA expressed its interest in reviewing the DECSE results as it prepared its Notice of Proposed Rulemaking on diesel fuel composition.

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<sup>7</sup> Based on an interview with a DOE representative.

## Program Organization

The program partners included DOE, two national labs – the National Renewable Energy Laboratory and Oak Ridge National Laboratory, the Engine Manufacturers Association, and the Manufacturers of Emission Controls Association. The Environmental Protection Agency was not a formal partner in the program but EPA representatives were involved in the project.

In Phase 1 of DECSE, which began in 1998 and ended in 2001, the government provided \$1.8 million in direct funding, and industry made \$1.6 million in in-kind contributions. These in-kind contributions were primarily in the form of equipment and support staff. For example, Caterpillar, Navistar, Cummins, and DaimlerChrysler provided engines for testing.

The timeline for DECSE at the time the program was designed is shown below (U.S. DOE 1999a):

**Table 3: DECSE Program Timeline**

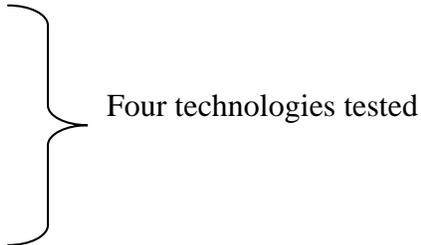
Task	Scheduled Start	Scheduled Finish
Program design	9/98	1/99
Test engines selected, delivered	12/98	4/99
Emission control systems selected, delivered	9/98	4/99
Test fuels, lubricants, delivered	1/99	5/99
Contract with testing laboratories	12/98	2/99
Conduct tests on four technologies		
(1) Particle trap/filter	4/99	12/99
(2) Lean NOx catalyst	5/99	4/00
(3) Diesel oxidation catalyst	5/99	4/00
(4) NOx adsorber catalyst	5/99	12/99-2/01
Interim test reports available	10/99	11/99
Final test reports available	TBD	TBD

The DECSE project was governed by a Steering Committee composed of:

- Two representatives of heavy-duty engine manufacturers
  - Michael J. Quinn, Caterpillar, Inc.
  - Glenn Keller, Engine Manufacturers Association
- One from emission control systems manufacturers
  - Dale McKinnon, Manufacturers of Emission Controls Association
- Two from DOE
  - Stephen Goguen, DOE Office of Heavy Vehicle Technologies
  - John Garbak, DOE Advanced Automotive Technologies
- One each from the two national labs
  - George Sverdrup, National Renewable Energy Laboratory
  - Ronald L. Graves, Oak Ridge National Laboratory

The DECSE Steering Committee established policies for the project, oversaw project management and technical activities, authorized dissemination of information and results, and held general responsibility. DECSE was led by George Sverdrup of the National Renewable Energy Laboratory.

Six technical committees were responsible for the technical aspects of testing, with one committee assigned to each of the four technologies:

1. Lean NO<sub>x</sub> catalyst
  2. Oxidation catalyst
  3. NO<sub>x</sub> adsorber
  4. Particle filter/trap
  5. Fuels and lubricants
  6. Data analysis/reporting.
- 
- Four technologies tested

The technical committees oversaw the testing process, reviewed data, and determined when the data could be disseminated among participating DECSE organizations.

Monthly Steering Committee meetings, to which all project participants were invited, allowed for members to discuss plans, work in progress, issues and decisions. Although EPA was not a voting member of the Steering Committee, it routinely sent a representative to sit in on the meetings. Project participants relied primarily on consensus and discussion to make decisions, but ultimately, decisions were made by the Steering Committee.

Members of technical committees could request data from labs, but committee members decided what information should be released to outside organizations. Concerns about releasing proprietary information required initial confidentiality. This encouraged participants, many of them competitors, to share information more readily.

Obviously, those companies involved in the DECSE project would benefit from this formal knowledge sharing, but companies outside of this project circle would have been at a disadvantage. Participating companies had influence over what information would be released to those outside this network, so outside companies would not receive the full benefits of the partnership. However, those who were not involved could still benefit from the publicly available data generated by the project in the reports.

## **Program Design**

The four emission control technologies were selected for testing because they were commercially available or “state-of-the-art” almost ready to market. For the first three technologies listed in the following table, engine systems were available with the specified control technology. However, in the case of the NO<sub>x</sub> adsorber catalyst, there were no existing engine systems available to DECSE, and a prototype had to be used. It was assumed that the emission control technologies tested could be implemented for the 2003-2004 model years. Three independent labs were given contracts to test the engines. Engine manufacturers supplied the test engines and emission control manufacturers provided the filters and catalyst devices.

**Table 4: DECSE Projects**

Technology	Test Site	Engine
Diesel particulate filters (DPFs)	Engineering Test Services, Charleston, South Carolina	Caterpillar 3126
Lean-NO <sub>x</sub> catalysts (LNO <sub>x</sub> )	West Virginia University	Cummins ISM370, Navistar T444E
Diesel oxidation catalysts (DOCs)	West Virginia University	Cummins ISM370, Navistar T44E
NO <sub>x</sub> adsorber catalysts	FEV Engine Technology, Auburn Hills, Michigan	DaimlerChrysler/DDC 1.9L HSDI prototype

Except for the HSDI prototype, the engines were of 1998 or 1999 calibration, electronic controls, turbocharged, with or without exhaust gas recirculation. The DaimlerChrysler/DDC prototype engine used a common-rail injection system and included exhaust gas recirculation.

Researchers started with a base fuel similar in content to commercially available diesel, which, on average, has 350 ppm sulfur. The fuel supplier, Chevron Phillips, blended various amounts of this base fuel with 3 ppm fuel, fuel formulations with 3, 30, 150, and 350 ppm sulfur. In some tests, a 16 ppm sulfur fuel was created as an intermediate value by mixing 50% of the 3 ppm fuel and 50% of the 30 ppm fuel. The 3 ppm fuel was intended to represent a sulfur-free fuel. The 30 ppm fuel reflected EPA's likely standard, based on its May 1999 advance notice. The 150 ppm fuel was based on the level proposed by the American Petroleum Institute as one that could be made available by the petroleum industry in the short-term. Finally, the 350 ppm fuel represented the currently available fuel.

During the program design phase, the fuels and lubricant technical committee had considered using a sulfur-free lubricant instead of a typical commercial lubricant with sulfur concentrations in the 3,000-5,000 ppm level. Sulfur in both the fuel and the engine lubricant contribute to sulfur in the exhaust gases. Sulfur in the lubricant may also poison NO<sub>x</sub> adsorbers and sulfur ash may plug particulate filters. According to calculations performed by the engine manufacturers, a 3,500 ppm sulfur-containing lubricant's contribution to engine-out SO<sub>2</sub> was equivalent to the contribution from a 3 ppm sulfur fuel. Commercially available low-sulfur or sulfur-free lubricants were not readily available, and the committee decided against formulating

a special sulfur-free lubricant for the project. Instead, the committee chose to conduct the experiments with the Shell Rotella T 15W40 lubricating oil, a commercial lubricant with 3,500 ppm sulfur (U.S. DOE 1999b).

## **Program Results**

The final project results demonstrated that two of the four tested emission control technologies have the most promise for reducing NO<sub>x</sub> and PM emissions to levels below the 2007 federal standards. These technologies – diesel particulate filters and NO<sub>x</sub> adsorbers – are both very sensitive to fuel sulfur, and only function properly with ultra-low sulfur fuel, below 30 ppm. Even with ultra-low sulfur levels, there are still challenges in facing degradation cycles and long-term durability.

DECSE showed that diesel oxidation catalysts had insufficient PM control effectiveness to meet the 2007 EPA standards. Lean-NO<sub>x</sub> catalysts had limited NO<sub>x</sub> control effectiveness, which would also be inadequate for the 2007 standards. However, in their recommendations, the DECSE Steering Committee did not write off these two technologies altogether. Diesel oxidation catalysts may still be required as a component in NO<sub>x</sub> adsorber catalyst or SCR catalyst systems. Lean-NO<sub>x</sub> catalysts could be sufficient to meet the 2004 heavy-duty diesel emission standards.

For diesel particulate filters, increasing the sulfur levels from 3 ppm to 350 ppm resulted in an essentially linear increase of baseline engine-out PM emissions. Using 3 ppm sulfur fuel reduced engine-out emissions by 95% for both particulate filters tested. Lowering fuel sulfur to 30 ppm was not enough to meet the 0.01 g/bhp-hr PM standard for 2007. Compared to engines without the filters, a 350 ppm sulfur level, the average U.S. diesel fuel sulfur level, had the effect of *increasing* PM in engines equipped with the filters. Thermal aging effects were also worse for high sulfur fuel.

After improving calibration with 3 ppm fuel sulfur in Phase II of DECSE, the NO<sub>x</sub> adsorber catalyst was able to reach NO<sub>x</sub> conversion efficiencies above 90%, meaning that over 90% of the NO<sub>x</sub> stored by the adsorber was converted to harmless N<sub>2</sub>. As expected, the emission control equipment did reduce fuel economy, but the largest penalty was 4% for the

NOx adsorber catalyst. Since the NOx adsorber catalyst was the last technology tested, the project team did not test it with 150 and 350 ppm fuel because the initial results with the other three technologies already showed the need for lower sulfur levels. Instead, they added a test for 16 ppm sulfur fuel along with the 3 ppm and 30 ppm fuel tests (U.S. DOE 1999b).

The DECSE team wanted to further investigate technologies that looked promising in meeting MY2007 regulations, and chose two technologies to pursue in future research: (1) Selective catalytic reduction combined with the diesel particulate filter, and (2) the NOx adsorber catalyst combined with the diesel particulate filter. The main reason for discontinued interest in the diesel oxidation catalyst and the lean-NOx catalyst was their inability to meet EPA's 2007 PM and NOx standards, respectively. EPA saw them as promising technologies for existing vehicle retrofits, but not for new engines (U.S. EPA 2000a). The results from the DECSE study supported this conclusion.

The next phase following DECSE came to be called the Advanced Petroleum-Based Fuels – Diesel Emission Control (APBF-DEC) Program. While the DECSE program focused primarily on sulfur content in diesel fuel, this successor program broadened in scope to examine the interaction among fuels, lubricants, diesel engines, and emission control systems to meet emission standards and fuel economy goals.

## **Impact on the Regulatory Process**

### **Rulemaking - Support for the Diesel Fuel Sulfur Rule**

At the time that EPA issued its Advance Notice of Proposed Rulemaking in 1999, EPA had not received any data on diesel fuel sulfur content's effect on the durability of emission control. "Some manufacturers have claimed that this is especially relevant for engines employing an extensive degree of cooled EGR, although this is yet to be proven. As discussed above, we have not yet received any durability data to support these claims using realistic in-use operating conditions and corrosive resistant materials" (U.S. EPA 1999a). However, the Agency did know that lower sulfur content improved the durability of the engine itself. The Advance Notice does mention that EPA was awaiting data from the Engine Manufacturers Association,

which was conducting “a joint test program with the U.S. Department of Energy to evaluate four levels of diesel sulfur with five different aftertreatment technologies and four different diesel engines” (U.S. EPA 1999a). Although DECSE actually tested four, not five technologies, the other details show that this is a direct reference to DECSE. In May 1999, the test materials and equipment for DECSE had just been delivered, and the testing was just getting started.

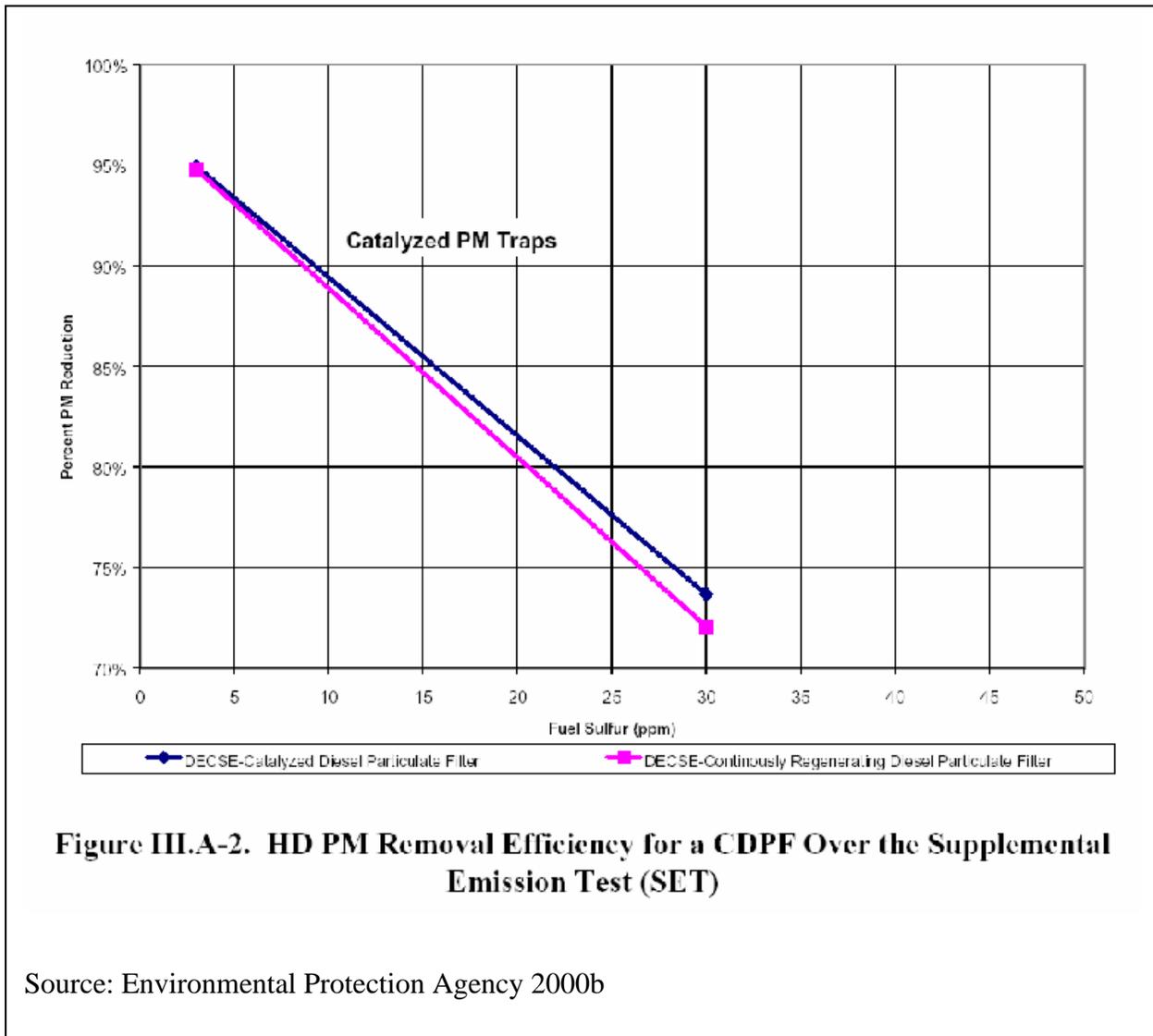
The Regulatory Impact Analysis (RIA) for the Heavy-Duty Emission Standards and Diesel Fuel Rule was finalized in December 2000. By this time, the DECSE Interim Reports covering the results of the NO<sub>x</sub> adsorber catalyst and the diesel particulate filter technologies had been released. Incidentally, these are the two primary technologies which the U.S. heavy-duty diesel industry has chosen to pursue to meet the 2007 regulations. The results for the diesel oxidation catalyst and lean NO<sub>x</sub> catalyst were not published until June 2001.

DECSE results are cited several times in the RIA to support the technical feasibility of the emission standards. The authors of the RIA explicitly point out the importance of DECSE in the report: “Five reports documenting the DECSE program are available from the DOE OTT website and were used extensively throughout our analysis.”

For example, Chapter 3 of the RIA refers to DECSE Interim Report No. 4 on diesel particulate filters. It considers the DECSE data showing the total PM emissions from a heavy-duty diesel engine for different fuel sulfur levels. Based on an interpolation of the straight-line fit through the data for 3 ppm and 30 ppm sulfur, the PM emissions produced from using 15 ppm sulfur would be 0.009 g/bhp-hr, which is 10% lower than the 0.01 g/bhp-hr standard set in EPA’s proposed rule. Meanwhile, a 30 ppm sulfur level would be unable to meet EPA’s PM emission standard.

The following figure and table are excerpted directly from EPA’s RIA for the diesel emission and fuel sulfur standards. They show how EPA interpolated from the DECSE data on catalyzed diesel particulate filters, the most promising PM control technology identified by DECSE. They provide evidence of DECSE’s role in justifying the 15 ppm fuel sulfur standard.

**Figure 8: Effects of Fuel Sulfur on CDPF PM Reduction**



**Table 5: PM Emissions for a CPDF at Various Fuel Sulfur Levels**

<b>Table III.A-1. PM Emissions from a Heavy-Duty Diesel Engine at the Indicated Fuel Sulfur Levels</b>		
	<i>Supplemental Steady State</i>	
<i>Fuel Sulfur Level</i>	<i>Tailpipe PM [g/bhp-hr]</i>	<i>Relative to the Standard (%)</i>
3	0.003	-70
7*	0.006	-40
15*	0.009	-10
30	0.017	70
150	0.071	610

\* The PM emissions at these sulfur levels are based on a straight-line fit to the DECSE program data;<sup>20</sup> PM emissions at other sulfur levels are actual DECSE data.

Source: Environmental Protection Agency 2000b

DECSE results for the NOx adsorber catalyst were also summarized to illustrate the importance of low fuel sulfur levels on NOx emissions reduction. DECSE data complemented information about the effectiveness of NOx adsorber catalysts provided by companies and trade associations. Cummins, one of the DECSE participants, reported in a 1999 DOE workshop that it had used a NOx adsorber catalyst to reach NOx emissions of 0.055 g/bhp-hr (U.S. EPA 2000b, III-34). MECA provided four different catalyst systems for EPA to test at the National Vehicle and Fuel Emissions Laboratory. Results from those tests indicate that NOx adsorber catalysts are capable of reaching the new emission standards (U.S. EPA 2000b, III-35). DECSE was influential in justifying the selection of 15 ppm over 50 ppm, one of the other commonly discussed fuel sulfur levels. DECSE demonstrated that even a 30 ppm sulfur level could dramatically increase the NOx catalyst’s poisoning rate (U.S. EPA 2000b, III-61).

Up until DECSE, there was no publicly available information on NOx adsorber desulfurization, a procedure to restore efficiency by removing accumulated sulfate particles. It was important to remedy sulfur poisoning caused by misfueling with a high-sulfur diesel fuel.

According to the RIA, “the [previous] work does not directly answer whether NO<sub>x</sub> adsorber desulfation is practical for diesel engine exhaust conditions. The DECSE Phase II program answers that question.” DECSE Phase II for the NO<sub>x</sub> adsorbers demonstrated a desulfurization process that could restore a NO<sub>x</sub> adsorber’s efficiency after sulfur contamination (U.S. EPA 2000b, III-62). DECSE Phase II’s work on the NO<sub>x</sub> adsorber’s durability following aging and desulfurization cycles made EPA aware of the declining performance associated with repeated cycles. Recognition of this problem strengthened the argument for capping fuel sulfur levels at 15 ppm, because long-term performance deterioration is limited by minimizing the NO<sub>x</sub> adsorber’s exposure to sulfur.

DECSE’s findings on the relatively small contribution of lubricating oil sulfur to total sulfate PM emissions reassured EPA that reducing sulfur levels in lubricants would not have a substantial effect on overall exhaust emissions. The Final Rule does not require sulfur level reductions for lubricating oil. However, this does not mean that future regulations on lubricating oil are not possible. EPA is still awaiting further information, and APBF-DEC, the follow-on project to DECSE, attempts to fill this knowledge gap by conducting further research on lubricants.

### **Technology Review – Helping EPA assess technological progress**

In December 2000, after EPA finalized the 2007 Highway Diesel regulations, EPA’s Office of Transportation and Air Quality conducted a progress review of the technologies needed to meet the 2007 regulations. Based on the Highway Progress Review report, EPA relied on three main sources to assess the technological progress: (1) company visits, (2) EPA’s own testing at the National Vehicle and Fuel Emissions Laboratory, and (3) DOE’s research programs. In describing the role of DOE’s research programs, the report concentrates on DECSE, “The information from that program documented in five technical reports played an important role in informing the Agency during the HD 2007 rulemaking.” It notes the importance of the NO<sub>x</sub> adsorber and catalyzed diesel particulate filter testing occurring as part of APBF-DEC.

According to the report, DOE does regularly submit formal communication to EPA about its research programs that would interest EPA. For NO<sub>x</sub> adsorbers, the research conducted by

DOE and EPA reach similar conclusions: NO<sub>x</sub> adsorbers are promising, but must overcome some technical challenges.

DECSE results on the degradation of NO<sub>x</sub> adsorber performance after repeated desulfurization events became the center of a dilemma which was finally resolved through additional testing.<sup>8</sup> The high rate of aging observed in DECSE contrasted with the very good performance at Ford's Scientific Research Laboratory. In trying to make sense of this discrepancy, EPA obtained information from a major catalyst developer and manufacturer. New test data from this company was able to explain this discrepancy in terms of differences in cyclic lean/rich aging and desulfurization temperatures. This prompted the company to develop a new catalyst formulation to address this problem (U.S. EPA 2002c). DECSE results helped to draw attention to a problem that may have otherwise been overlooked or inadequately understood. DECSE provided publicly accessible data and methodologies that could be analyzed by others, and used as a benchmark for industry R&D staff to compare their own results.

### **Comment Period – DECSE results become fuel for debate**

During the comment period for the 2007 Rule, some commenters questioned the basis that EPA used for the proposed standards. ExxonMobil sent a letter to EPA, writing, “The DECSE program on which EPA relies did not test integrated systems with NO<sub>x</sub> and PM control functions. Without data on integrated systems there is no basis for the proposed standards” (U.S. EPA 2000a, Comment 3.1.1(B)). It was true that DECSE had tested each emission control technology individually, but EPA was still convinced that its technology-forcing standards would result in successful integration of PM and NO<sub>x</sub> controls by industry. EPA relied on information from its own laboratory testing and Toyota's technology development to assert that integration was feasible. However, there was still a need for a broader demonstration of feasibility (U.S. EPA 2002b, III-26-27). APBF-DEC, the follow-on to DECSE, addressed the need to test the performance of an integrated system capable of simultaneously meeting the PM and NO<sub>x</sub> standards. ExxonMobil supported 50 ppm sulfur levels, and it claimed that EPA “inappropriately relied on the DECSE report” (U.S. EPA 2000a, Comment 3.3.1(D)).

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<sup>8</sup> In order to ensure long-term NO<sub>x</sub> adsorber performance, sulfur must be removed from the catalyst through desulfation, where the catalyst is heated to a high temperature and exposed to fuel-rich exhaust conditions. However, when performed repeatedly, this process can lead to damage, or aging, of the NO<sub>x</sub> adsorber.

ExxonMobil charged that DECSE had not optimized diesel particulate filters to minimize sulfate formation. Meanwhile EPA claimed that ExxonMobil did not understand that actions to minimize sulfate formation lead to poor CDPF regeneration. Only ultra-low sulfur fuel could remedy this paradox.

When its NO<sub>x</sub> adsorber testing at NVFEL was criticized by the American Petroleum Institute, EPA defended the robustness of its laboratory testing, and again cited Toyota's progress and DECSE's results as further proof of NO<sub>x</sub> adsorber's feasibility (U.S. EPA 2000a, Comment 3.2.1(C)). API and Marathon Ashland Petroleum used DECSE data to challenge EPA's belief that NO<sub>x</sub> adsorbers can be made durable for the vehicles' useful life. DECSE showed that NO<sub>x</sub> adsorbers lose 50% of their effectiveness after 250 hours of service accumulation (U.S. EPA 2000a, Comment 3.2.1(J)). In response, EPA pointed to a later stage in DECSE's progress. In DECSE Phase II, researchers were already working on a desulfurization procedure to improve drivability. The report from DECSE Phase II had just been published in October 2000, just two months before EPA published its Response to Comments Document in December 2000.

To address the technical feasibility of the diesel rule, one commenter used DECSE to support the position that engine and vehicle standards can be met as long as ultra-low sulfur diesel fuel is available. Some commenters used the DECSE program as "supporting documentation" to support the need for ultra-low sulfur fuel for diesel particulate filters and NO<sub>x</sub> adsorbers (U.S. EPA 2000a, Comments 3.3.1(A), 3.3.2(A)). These commenters included several DECSE participants, such as DOE, EMA, MECA, and the individual companies themselves. Others suggested sulfur levels lower than the 15 ppm cap to meet the PM standard (U.S. EPA 2000a, Comment 3.3.1(A)). According to EPA, its interpolation of the DECSE data demonstrated that the 15 ppm standard is capable of meeting the PM standard.

Both EPA and industry used DECSE's results on fuel consumption to debate the significance of the fuel economy penalty. There was some agreement that the fuel economy impact of particulate filters would be small, perhaps limited to 1-2%, but different perspectives on the fuel economy impact of NO<sub>x</sub> adsorbers emerged. The oil industry as well as one engine manufacturer, Cummins, argued that the fuel economy penalty attributed to NO<sub>x</sub> adsorbers would be large (U.S. EPA 2000a, Comment 3.4(C)). They noted that DECSE exceeded its 4%

target penalty in some of its tests. EPA disagreed about the significance of the fuel economy penalty, since it expects manufacturers to improve fuel economy as NOx adsorber technology is developed.

### **Legal Action - Defending the Final Rule**

After EPA promulgated the Final Rule on January 18, 2001, petitioners from the engine, automotive, and petroleum industries sent briefs to the District of Columbia Circuit Court of Appeals, asking for review of the Final Rule. Each industry had a different criticism of the Final Rule.

Cummins Inc., an engine manufacturer and DECSE participant, characterized EPA's rulemaking as "arbitrary and capricious." Cummins argued that EPA had made unreasonable projections about engine manufacturers' ability to develop emission control systems in time for the new rule (U.S. Court of Appeals 2002). The Court relied heavily on EPA's Regulatory Impact Analysis to conclude that EPA did have a technical basis for expecting NOx adsorber technology would be developed by 2007. Both EPA and Cummins used results of the DECSE study to support their different positions. EPA used it to show the effectiveness of NOx adsorbers, while Cummins used its findings on desulfurization-induced deterioration to show the obstacles still facing development. Cummins' participation in DECSE did not translate to acceptance of associated regulatory implications, but the public results offered a technical basis for debate. EPA's reliance on a range of knowledge sources – its own in-house laboratory testing, emission control manufacturers' data, individual companies' research, DECSE, and Society of Automotive Engineers technical papers – convinced the Court that EPA had weighed a large amount of information collectively. EPA had to demonstrate that meeting upcoming standards was plausible given the technology trajectories, but it did not have to give detailed solutions to all the technical problems (U.S. Court of Appeals 2002).

Petroleum industry petitioners, which included industry associations like the National Petrochemical and Refiners Association (NPRA) and the American Petroleum Institute (API), argued that the Final Rule would lead to high diesel fuel costs and fuel shortages. They also argued that EPA's regulation was "arbitrary and capricious" because it was setting fuel standards based on emission control technology that was not yet fully developed. They claimed that the

NO<sub>x</sub> adsorber technology requiring the ultra-low sulfur fuel would not be in use by the time 15 ppm sulfur fuel is available in 2007. The Court viewed EPA's assessment of the availability of the technology in 2007 as reasonable, and referred again to the various sources that EPA used to make its assessment. Thus, in addition to playing a role in the rule formation, technology review, and comment period, the timeliness of the DECSE findings also allowed EPA to use the results to defend the Final Rule in court after it had already been promulgated.

The information generated by DECSE provided a valuable knowledge input to the regulatory process. Awareness of upcoming regulatory action on fuel sulfur standards at the partnership's inception helped the organizers design a timely program of regulatory relevance.

## ***II. Advanced Petroleum-Based Fuels – Diesel Emission Control (2000-2010)***

### **Introduction**

The Advanced Petroleum-Based Fuels – Diesel Emission Control Program (APBF-DEC) stemmed from the DECSE Program. APBF-DEC officially began in January 2000. It is essentially the second part of DECSE, but with a broader scope and scale. The seven-member DECSE Steering Committee expanded to a twenty-member committee with representation from the original DECSE participants – DOE and its national labs, engine manufacturers, and emission control manufacturers – and new participants – automakers, energy/oil companies, and chemical companies. EPA continued its involvement, this time with a formal role on the Steering Committee.

In the APBF-DEC reports and DOE press releases, it is clear that one main driver for funding research in diesel technology is to improve fuel economy and thereby reduce U.S. dependence on foreign oil. Improving diesel technology for light-duty pickups and SUVs would also increase American competitiveness relative to European and Japanese vehicle manufacturers. This program draws the heavy-duty engine manufacturers and passenger automakers together in the hopes that the automakers can benefit from the diesel expertise of the mature heavy-duty engine industry. Concerns about energy security and national competitiveness play a more prominent role in motivating APBF-DEC than DECSE, which was more narrowly focused on enabling aftertreatment technology for heavy-duty engines.

Although APBF-DEC was a successor to the highly influential DECSE program, APBF-DEC's broad, less focused scope and vague long-range plans diminish its potential policy influence and expose it to budget cuts. However, APBF-DEC has been helpful in assisting industry with improving the most promising technologies for meeting the 2007 diesel engine emission standards. The inclusion of more industries and companies compared to DECSE also provided more opportunities for knowledge sharing in diverse areas of expertise.

## **Regulatory Context**

The project mission looks beyond sulfur content in fuel to “identify optimal combinations of fuels, lubricants, diesel engines, and emission control systems to meet projected emission standards during the period 2000 to 2010 while maintaining continuous improvement in engine efficiency and durability” (U.S. DOE 2000f). This is much more ambitious than DECSE’s primary task of selecting sulfur content as the single fuel property for testing. The APBF-DEC project stresses that new technologies should still maintain customer satisfaction with vehicle performance and economical passenger and freight transportation. The project acts as a technology-enabler for the phase-in of heavy-duty emission standards for the model years MY2007-10 and the Tier 2 emission standards in MY2004-09. APBF-DEC is also expected to foresee and address future changes in regulations beyond 2010, including stricter standards for regulated pollutants and new standards for currently unregulated pollutants, such as toxics, ultra-fine particulates, and carbon dioxide.

However, Phase I (2001-03) still primarily focuses on sulfur and regulated pollutants; not until Phase II (2004-07) does the project examine other fuel properties and unregulated pollutants in-depth. Whereas DECSE focused on heavy-duty diesel trucks, APBF-DEC covers both light-duty and heavy-duty diesel vehicles. DECSE involved the oil and chemical industries only as suppliers or sources of information, but APBF-DEC formalizes their role by making them project participants (Sverdrup 2002).

## Program Organization

**Table 6: APBF-DEC Participating Companies/Organizations**

Government:

Department of Energy  
National Renewable Energy Laboratory  
Oak Ridge National Laboratory  
Environmental Protection Agency  
California Air Resources Board  
South Coast Air Quality Management  
District

Automobile:

Ford  
GM  
DaimlerChrysler  
Toyota

Engines:

Engine Manufacturers Association  
Caterpillar  
Detroit Diesel  
Cummins  
John Deere  
Mack Trucks  
International Truck & Engine

Technology:

Battelle

Emission Control:

Manufacturers of Emission Controls  
Association  
Johnson Matthey  
Delphi  
3M  
Engelhard  
Siemens  
Benteler  
Arvin Meritor  
Clean Diesel Technology  
Corning  
Donaldson  
OMG  
NGK  
Rhodia  
Tenneco Automotive

Energy/Additives:

American Petroleum Institute  
American Chemistry Council  
NPRA  
BP  
Ethyl  
ExxonMobil  
Marathon Ashland  
Pennzoil-Quaker State  
Lubrizol  
Equilon  
Chevron Texaco  
Chevron Oronite  
Ciba  
Ergon  
Valvoline  
Motiva  
Infineum

## Membership of the APBF-DEC Steering Committee

John Garbak, DOE\*

Glenn Keller, Engine Manufacturers Association\*

Michael Quinn, Caterpillar\*

Stephen Goguen, DOE\*

Ron Graves, Oak Ridge National Laboratory\*

Jim Williams, American Petroleum Institute

George Sverdrup, National Renewable Energy Laboratory\*

Walt Kreucher, Ford

Dale McKinnon, Manufacturers of Emission Controls Association\*

Kent Hoekman, Chevron Products

Bruce Bertelsen, Manufacturers of Emission Controls Association

Charles Schenk, EPA

Peter Devlin, DOE

Rick Klein, Chevron Oronite

Loren Beard, DaimlerChrysler

Lowell Miller, DOE – Fossil Energy

Larry Cunningham, Ethyl

\* Original member of the DECSE Steering Committee

Source: U.S. DOE 2000f

The DOE budget for this project is an order of magnitude larger than for DECSE. Over the first four years, the funding will total \$33 million, \$19.3 million in cash, with \$12 million from the federal government, and \$14 million in in-kind contributions. Meanwhile, Phase I of DECSE cost the government \$1.8 million, which was matched by industry's \$1.6 million in-kind contributions.

## Program Design

APBF-DEC is made up of five projects. The first project tests the selective catalytic reduction (SCR) and diesel particulate filter (DPF) technologies, fuels, and engines, identified as one of the two promising technology combinations in the final DECSE report. The second, third, and fourth projects revolve around the second promising technology combination – the NO<sub>x</sub> adsorber catalyst and DPF, but it considers the technologies, fuels, and engines in the context of a passenger car, light-duty truck/SUV, and heavy-duty truck. The fifth project will investigate the effects of lubricant formulations on the performance and durability of advanced diesel emission control systems. Since it was already determined in the DECSE project that fuels with sulfur content greater than 30 ppm significantly jeopardized the performance of the emission controls, the projects test fuels with 3, 8, 15, and 30 ppm sulfur. In the DECSE project, the Steering Committee chose to vary the sulfur levels in a base fuel rather than rely on refinery-based fuels. In the APBF-DEC project, “doped” fuels like those in the DECSE tests are used for most Phase I tests, but refinery-based fuel will be used for investigating unregulated emissions in Phase II. Fischer-Tropsch fuel is used for the SCR-DPF tests (APBF-DEC Quarterly Update No. 2). The 3 ppm sulfur base fuel was purchased from Chevron Phillips and “doped” to create 8-, 15-, and 30 ppm sulfur fuels. The actual base fuel that was delivered by Chevron Phillips had a sulfur content of 0.6 ppm. In Phase I, a refinery-processed fuel, called BP15, was used in addition to the doped fuels. Emissions would be measured from the test engines during up to 1500 hours of aging.

The following table summarizes the five projects, their scheduled start and finish dates, test site, and test vehicle. The test sites were awarded the contracts for testing based on a competitive solicitation and selection process.

**Table 7: APBF-DEC Projects**

Technology	Start	Finish	Test Site	Test Vehicle
Urea SCR+DPF	11/01	8/03	Southwest Research Institute	2 heavy-duty Caterpillar C12 engines, 12L SCR catalysts with DPFs
NOx adsorber catalyst + DPF: Passenger car	6/01	12/03	FEV Engine Technology,	Audi A4 Avant with a 1.9-liter TDI engine
NOx adsorber catalyst + DPF: SUV/pickup	6/01	12/03	Southwest Research Institute	2500 Series, Chevrolet Silverado with a 6.6-liter Duramax engine
NOx adsorber catalyst + DPF: Heavy-duty engine	6/01	12/03	Ricardo Inc.	15-liter Cummins ISX engine
Lubricants (medium-duty engine)	4/01	12/03	Automotive Testing Laboratories	International T444E engine or Navistar T444E 7.3L V8 engine

While there are aggressive and specific technical targets for engine-out PM and NOx emissions, fuel economy, and thermal efficiency, the targets for other health and environmental effects, like greenhouse gas emissions, ultrafine particles, unregulated toxics, and groundwater contamination potential are rather vague (U.S. DOE 2000a). The key emissions goal for the passenger car and SUV/pick-up vehicles is to meet EPA’s light-duty Tier 2 Bin 5 emission levels (0.01 g/mi PM and 0.07 g/mi NOx) – for the various low-sulfur fuels (3 ppm to 30 ppm). Meanwhile, for the heavy-duty vehicles, the goal is to meet the MY2007 engine standards of 0.20 g/bhp-hr for NOx and 0.01 g/bhp-hr for PM.

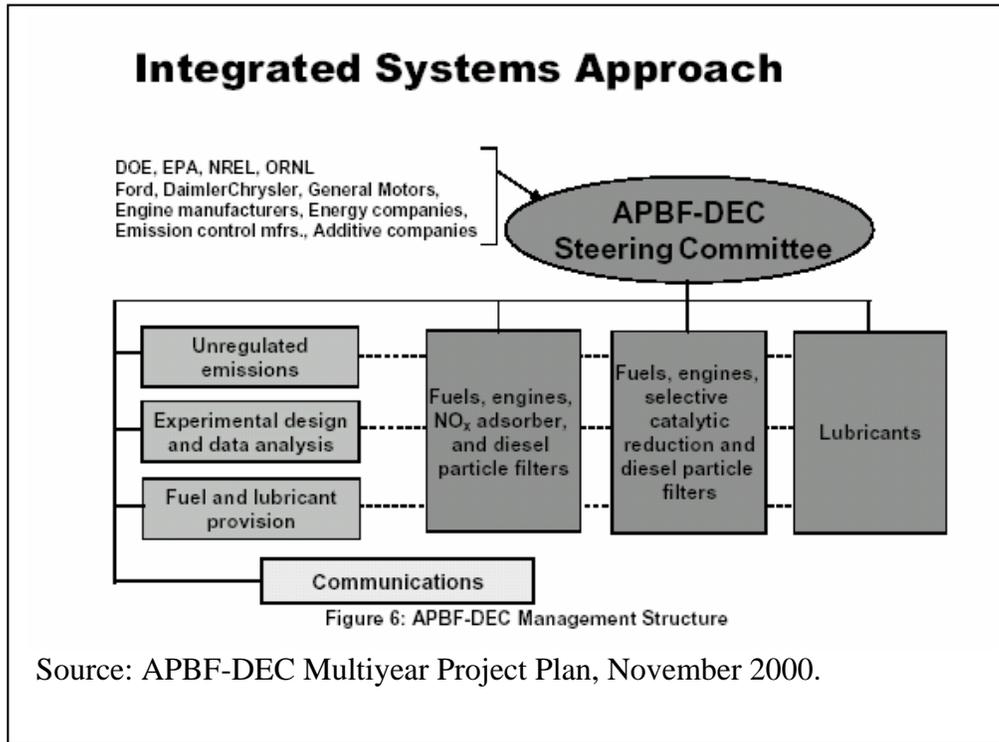
One of the technologies, selective catalytic reduction (SCR) requires the addition of urea, an ammonia reductant, to the exhaust stream. A major challenge for SCR is the urea infrastructure required, which may require more than the existing urea distribution pathways.<sup>9</sup> NREL has contracted with AD Little/Acurex to study the availability of infrastructure for urea, from production to distribution to use in vehicles (U.S. DOE 2000f).

The APBF-DEC 20-member Steering Committee oversees three systems workgroups and three supporting workgroups, as indicated in the figure below. The three systems workgroups on

<sup>9</sup> The most common grade of urea is currently used as fertilizer.

the right encompass the five projects and the supporting workgroups on the left represent the considerations that apply to all five projects.

**Figure 9: APBF-DEC Organizational Structure**



DOE has established a publicly available online Fuel Property Database that provides data on advanced compression ignition fuels. Project participants have access to a database of technical information that is only available by contacting the Steering Committee or working group representatives.

### **Preliminary Program Results**

Presentations given in the DOE-sponsored October 9-10, 2002, Motor Fuels joint meeting summarized preliminary results from the five APBF-DEC projects. When the SCR/DPF system was tested for steady-state emissions, the low-sulfur fuels, ranging from 3 ppm to 30 ppm, produced emissions below the 2007 NO<sub>x</sub> and PM regulatory standards. In the transient

emissions test, NOx emissions were just over the 2007 limit, while the PM emissions were within the 2007 limit. There are no emissions data available from the light-duty and medium-duty applications of the NOx adsorber/DPF system since the project teams are still working on system integration and test methods. For the heavy-duty NOx adsorber/DPF system, interim results show that a fresh NOx adsorber can reduce NOx emissions by 85%, and as much as 98% at peak efficiency. Under transient conditions, the emissions are below the 2007 heavy-duty NOx standard. The lubricants part of the program is in the midst of characterizing the species in lubricating oil that may affect the performance of emission control technologies (U.S. DOE 2003c).

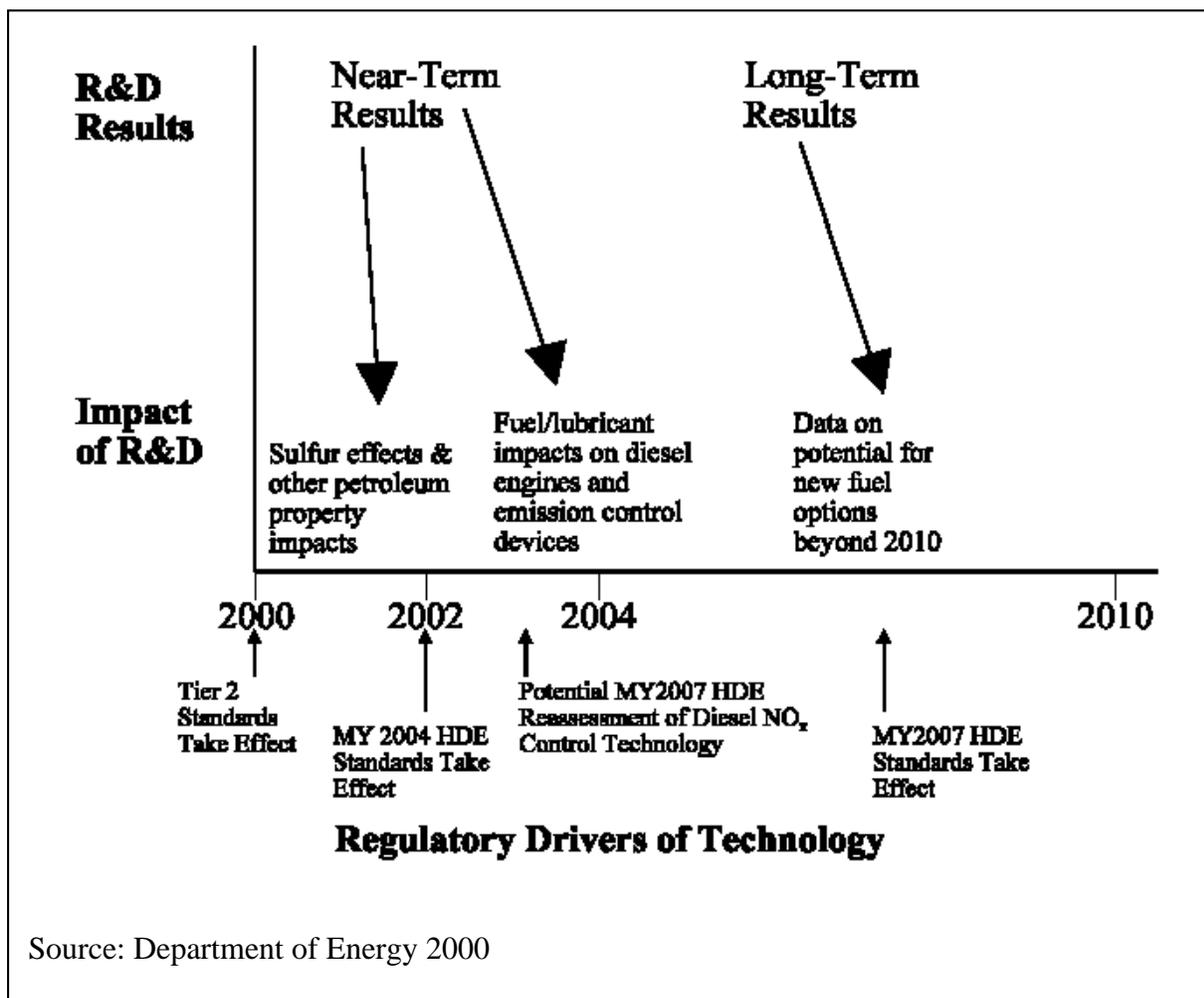
### **Impact on the Regulatory Process**

There was an explicit effort made to schedule the results of APBF-DEC to coincide with EPA's technical reviews and deadlines. The APBF-DEC Multiyear Program Plan, completed in November 2000, referred to three specific EPA regulatory actions for which the program would "provide timely information": (1) the MY2004 heavy-duty engine emission standards, implemented early in 2002 because of the consent decree, (2) the MY2007 heavy-duty engine emission standards, and (3) highway diesel fuel sulfur requirements to be implemented in 2006. The technical review for the first regulatory action already took place in 1999, before APBF-DEC began. Because the heavy-duty diesel engine consent decree accelerated the MY2004 deadline to October 2002, most engine manufacturers already had incorporated some type of aftertreatment in new engines. It was unlikely that APBF-DEC could provide any information in time to meet the MY2004 standards. It makes more sense that APBF-DEC would have impact on technology development as industry tried to meet the 2006/2007 regulations. DOE expected that the technical review for the second and third actions would occur in the 2003-04 time period. This assumption was the rationale for breaking up the 10-year program into two time periods, 2000 to 2003, and 2004 to 2010. The first time period would be focused on providing data suitable for the anticipated technical review in 2003-04. The Multiyear Program Plan released in 2000 focuses on the first time period, with funding and milestones established only from 2000 to 2003.

Even though DOE’s Office of Heavy Vehicle Technologies had emphasized the importance of promoting long-term projects, the division of APBF-DEC into two project periods has had the effect of creating two short-term projects. The urgency of upcoming regulations and technical reviews makes the program susceptible to near-term results’ taking precedence over long-term results. Funding was only secured for the first four years of the program, so it may have been difficult to commit to a “long-term” vision if the funding situation for 2004-10 was not yet secure.

The following timeline was included in the Multiyear Program Plan, and illustrates how R&D results would be directly mapped to providing information for regulatory action:

**Figure 10: Mapping APBF-DEC’s Timeline to EPA Regulatory Processes**



The California Air Resources Board (CARB), a state regulatory agency which often takes the lead in setting air quality standards, sometimes ahead of EPA, is relying on results from APBF-DEC research to consider future regulations on sulfur and/or ash in lubricating oil. It expects APBF-DEC will generate publicly available data to help CARB decide whether to regulate lubricants used in on-highway and off-highway vehicles in 2006 (CARB 2001).

APBF-DEC has the potential to provide information to EPA about the technological progress of the aftertreatment technologies that will be used in 2007. However, since the regulations for 2007-10 are already set, APBF-DEC will probably not have much influence on rulemaking. APBF-DEC does refer to the opportunity to consider future regulations beyond 2010, but there is nothing in its current plans that formally addresses post-2010 issues. It is implied that these post-2010 research topics will be formulated in the second period of the project, starting in 2004, but it may be difficult to convince industry partners to look beyond 2010 when they are under mounting pressure to meet the 2007 deadline.

APBF-DEC is aware of the regulatory context of its projects, but its results seem more relevant to technology assessment than rulemaking or standard-setting. While long-term, less focused R&D may be characteristic of government-funded research, these attributes may not be assets if a partnership is to provide input to policymaking.

### ***III. EC-Diesel Technology Validation Program (1998-2002)***

#### **Introduction**

ARCO (now a BP company) initiated a fleet technology validation program in California to evaluate the use of passive regenerative catalyzed diesel particulate filters using ultra-low sulfur diesel fuel. It used its own ultra-low sulfur diesel fuel – Emission Control Diesel (EC-Diesel) – which has approximately 7 ppm sulfur content. For several California truck fleets, some of the vehicles were retrofitted with catalyzed diesel particulate filters, and then fueled with ARCO’s EC-Diesel fuel or CARB fuel. “CARB fuel” is California’s commercially available diesel fuel with a sulfur content of 120 ppm, which is already significantly lower than the national average of 350 ppm.

At the outset, the program had three stated objectives:

1. Evaluate vehicle emissions differences for ECD and CARB diesel fuels.
2. Evaluate the performance, emissions, and durability of the vehicles retrofitted with catalyzed particulate filters and fueled with ECD over 12 or more months of service.
3. Collect fuel consumption, maintenance, reliability, and operating cost data for the participating vehicle fleets and compare to control vehicles fueled with California diesel fuel.

Testing emissions performance on actual truck and bus fleets provided results for real, in-use operating conditions as opposed to the laboratory conditions of DECSE and APBF-DEC. EC-Diesel tested only existing or near-market technologies, so the major value from the program was testing those technologies together. EC-Diesel grew out of awareness of California’s regulatory environment, and consequently, its policy influence was mostly limited to California’s regulatory processes.

#### **Regulatory Context**

At the time that the program began, EPA had announced the requirement for ultra low sulfur diesel fuel by 2006 to accompany stricter emission standards for MY2007 heavy-duty engines. Meanwhile, in 1998, the California Air Resources Board (CARB) had designated diesel

particulate matter as a toxic air contaminant. As a consequence of this designation, CARB produced a Diesel Risk Reduction Plan in October 2000 to address reducing diesel emissions from both new and existing diesel engines and vehicles. EPA's diesel retrofit program is voluntary; federal regulations presently regulate new engines only. CARB plans to require diesel particulate filter retrofits on existing engines and vehicles. ARCO saw the opportunity to demonstrate that clean diesel was possible, and presented its concept for a technology program to other companies and to government agencies.<sup>10</sup>

## **Project Organization**

### Project Participants:

#### Industry

Cummins, Detroit Diesel, International Truck & Engine, Ford, Engelhard,  
Johnson Matthey, Fleetguard/Nelson, NGK-Locke, Corning

#### Research/Technology

Battelle

#### Academia

West Virginia University, University of California at Riverside

#### Government

Department of Energy (Office of Transportation Technologies and OHVT),  
National Renewable Energy Laboratory, California Air Resources Board,  
California Energy Commission, South Coast Air Quality Management District

NREL coordinated emissions testing for the entire program with the West Virginia University chassis dynamometer emissions laboratory. Battelle supported NREL with data collection and evaluation. EPA helped to prepare and review the emissions test plan. Several project partners took on management roles for the different fleets tested. In most cases,

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<sup>10</sup> Based on an interview with the ECD Marketing Manager, BP, February 2003.

companies acted as fleet managers for vehicles with their engines. Engelhard and Johnson Matthey provided the particulate filters and performed the vehicle retrofits.

## Program Design

The program was expected to have two rounds of emissions testing. In the first round, approximately 45 vehicles would be tested shortly after some were retrofit with emission control technology. After one year of operations, starting in September 1999, the same set of vehicles would be tested again. The second round testing would include particle sizing, emissions speciation, and unregulated toxic emissions. There would be no cold-start testing; all testing would occur after 10 minutes of warm-up. Most testing was performed using West Virginia University’s transportable emissions laboratory.

The EC-Diesel fuel provided by ARCO for the program was not commercially available at the time of the program’s start. However, since 1999, ARCO had an ultra-low sulfur diesel fuel on the market in Southern California – ARCO ECD-1. It has a maximum sulfur content of 15 ppm and a high cetane number. ECD-1 costs 5 to 10 cents more per gallon than the regular CARB diesel fuel. EC-Diesel (ECD) has different fuel properties from ECD-1. Besides having sulfur content averaging 7 ppm, ECD has less than 10% aromatics by volume and a nominal cetane number of 60. It is thought that decreasing aromatics and increasing the cetane number in diesel fuel yields emissions reduction benefits (U.S. EPA 2001c). Although EC-Diesel was already developed by 1999, ARCO chose to sell ECD-1 first because it could be produced cost-effectively in sufficient volumes to meet anticipated demand (Dieselnet 1999).

For the eight vehicle fleets tested, the vehicles within the fleets were nominally identical except for their aftertreatment systems and fuel. The arrangements tested were as follows:

**Table 8: EC-Diesel Testing Arrangements**

Type of filter	CARB fuel	ECD fuel
No filter	X	X
Engelhard catalytic soot filter (DPX)		X
Johnson Matthey continuously regenerating technology (CRT) filter		X

No alterations were made on the existing engines themselves. Instead, passive filters simply replaced the existing muffler system. As shown in the table below, the types of trucks ranged from medium-sized shuttle vans to large buses and Class 8 trucks.

**Table 9: EC-Diesel Test Fleets**

Vehicle Fleet	Make	Fleet Manager	Test Laboratory
San Diego School District School Buses	1998 Amtran 3000RE/International buses with 275 hp 8.7 L International 530E engines	International	West Virginia University (WVU) transportable emissions laboratory
ARCO Tanker Trucks	1995-96 Kenworth Class 8 trucks with Cummins M11 330 hp 10.8L engines	ARCO	WVU transportable emissions laboratory
Ralphs Grocery Class 8 Trucks	1998 Sterling L-Line Class 8 trucks with 430 hp 12.7 L Detroit Diesel Series 60 engines	NREL	WVU transportable emissions laboratory
LA City Refuse Haulers and Dump Trucks	Peterbilt chassis refuse haulers with Cummins ISM 305 hp engines; Kenworth T-800 dump trucks with Cummins ISM 370 hp engines	Cummins	WVU transportable emissions laboratory
Santa Monica Big Blue Buses	Detroit Diesel Series 50 engines	Detroit Diesel	WVU transportable emissions laboratory
Shuttle Vehicles	4-wheel drive vehicles with Detroit Diesel Series 40 diesel engines	Detroit Diesel	WVU transportable emissions laboratory
Los Angeles County Mass Transit Association	1998 Detroit Diesel Series 50 engines	ARCO	LAC MTA laboratory
Hertz Equipment Rental	Medium-duty flatbed-type trucks	Ford	UC Riverside CECERT

Source: LeTavec et al. 2000.

## **Program Results**

The interim results of the EC-Diesel program, published in a June 2000 Society of Automotive Engineers (SAE) paper, showed that the combination of catalyzed particulate filters and ECD fuel produced 91% to 99% less PM than CARB-fueled vehicles without filters. Hydrocarbon and carbon monoxide emissions were also significantly reduced (LeTavec et al. 2000). In terms of operations and maintenance, the retrofitted vehicles operated reliably during the one-year program. Some retrofitted vehicles did report a 2-3% fuel economy penalty, but the penalty was attributed the ECD fuel's lower energy density compared to CARB diesel (LeTavec et al. 2002).

In February 2001, the second part of the program began. It planned to repeat emissions tests and to study unregulated diesel exhaust emissions from vehicles running on different types of fuel, with and without particulate filters. A chemical characterization study beginning in spring 2001 compared the exhaust emissions of diesel vehicles and CNG vehicles. Results from these studies were published as SAE papers in 2002 (LeTavec et al. 2002, Lev-On et al. 2002).

## **Impact on the Regulatory Process**

### **EPA Rulemaking – Slight influence**

The Regulatory Impact Analysis for the 2007 Final Rule on heavy-duty engines and diesel fuels mentioned the EC-Diesel program as an example of fuel sulfur effects on catalyzed diesel particulate filters. At the time of the RIA, the test vehicles had been on the road for over 6 months. Although the final results were not yet available, EPA could refer to the June 2000 interim report. The EC-Diesel program provided evidence that catalyzed diesel particulate filters, when used in conjunction with ultra-low sulfur diesel fuel, substantially reduce PM emissions in diesel trucks and buses.

The nature of EC-Diesel as a technology demonstration program meant that its role in the regulatory process was to illustrate technological feasibility rather than develop new technology. During the 2007 Rule comment period, several commenters, including such diverse organizations as the Alliance for Automobile Manufacturers, the American Lung Association,

and International Truck and Engine Corporation, referred to the EC-Diesel program as evidence that refiners have the technological ability to reduce sulfur levels, in effect defending EPA's 15 ppm sulfur cap (U.S. EPA 2000a, Comment 8.1.2(A)). EPA agrees with this assessment, and remarks further: "If desulfurizing diesel fuel was not feasible nor cost-effective, these companies and these other countries would not have taken such proactive steps" (U.S. EPA 2000a). Throughout its response to comments, EPA frequently cites ARCO's early introduction of low sulfur diesel fuel in California as evidence of refiners' ability to meet the 15 ppm cap.

### **CARB Rulemaking – A More Substantial Role**

The California Air Resources Board Diesel Risk Reduction Plan mentions the EC-Diesel Program in its Fuels Report. It explains that ECD reduces regulated emissions compared to the CARB diesel fuel blend, which it was attributed to EC-D's "very low-sulfur content, low aromatic and PAH contents, a high natural cetane number, and low density" (CARB 2000b). The one-year test program was not complete at the time the Fuels Report was published. However, CARB was able to view the initial test results, which contributed to CARB's recommendations for changes to fuel specifications. The differences between ECD and CARB fuel most likely led to this comment: "Directionally, lower aromatic hydrocarbon and PAH contents and lower fuel-density may help to reduce engine-out diesel PM emissions. These fuel specifications should be evaluated for further control" (CARB 2000b, IV-26). The preliminary success of the EC-Diesel test program clearly demonstrated the benefits of very low-sulfur fuel for existing vehicles retrofitted with aftertreatment devices. This realization made its way into CARB's recommendations: "Very low-sulfur (<15 ppm sulfur) CARB Diesel may need to be required for all engines to be manufactured or retrofitted with diesel PM after-treatment" (CARB 2000b, IV-25). CARB's consideration of both manufactured and retrofitted engines stands out because EPA primarily concentrates on newly manufactured engines, and truck and bus retrofits are voluntary.

CARB approved its Final Diesel Risk Reduction Plan on September 28, 2000. It set out to reduce diesel exhaust emissions from new and existing vehicles by 75% in 2010 and 85% in 2020 (CARB 2000a). In order to achieve these ambitious goals, the plan mandates the

installation of diesel particulate filters in existing vehicles, where it is technically feasible and cost-effective.

On February 24, 2000, California passed its public transit bus fleet rule, with a PM retrofit phase-in requirement starting in 2003. Transit agencies have to meet a much more stringent PM standard, 0.01g/bhp-hr, as early as October 2002. They can choose between retrofitted diesel buses or alternative fuel buses. If they choose diesels, they are required to use ultra low sulfur fuel (< 15 ppm) by July 2002. Three of the fleets selected for the EC-Diesel program tests were bus fleets – the San Diego School District school buses, the Santa Monica Big Blue buses, and the LA County MTA buses. By demonstrating that retrofitted diesel buses could run much more cleanly on ultra-low sulfur fuel, the program kept the option of diesel vehicles open alongside natural gas (CNG) vehicles. EC-Diesel was mentioned in the staff report of the “Initial Statement of Reasons” for the public transit bus fleet rule and emission standards for new urban buses. The report documents Johnson Matthey’s CRT diesel particulate filter and Engelhard’s DPX catalytic soot filter, the two filters tested in EC-Diesel, as promising new technologies, and it refers to PM emissions reductions of greater than 90% demonstrated by the program (CARB 1999).

EC-Diesel demonstrated the effectiveness of combining ultra-low sulfur fuel and particulate filters to reduce diesel exhaust emissions. The program kept the door open for clean diesel technology in California, leading to regulations that would generate demand for ARCO’s ultra-low sulfur fuel and Johnson Matthey and Engelhard’s filters. Although upcoming state and federal emission standards were finalized prior to the program’s completion, the organizations involved could take advantage of a “first-mover” strategy to demonstrate their technologies’ ability to meet the regulations.

The next chapter compares DECSE, APBF-DEC, and EC-Diesel based on a set of 7 criteria that would likely influence partnerships’ ability to influence policymaking. On one hand, the subject matter of the R&D in the three partnerships is similar – the effects of sulfur on emission control technologies – and many of participants are common across the three partnerships. Yet, the differences in their impact on the regulatory process can be explained in the context of the seven criteria.

## CHAPTER 5: COMPARATIVE ANALYSIS OF PARTNERSHIPS

I compared the three partnerships against a set of criteria that the literature review, background research, and interviews indicated would affect the partnerships' influence on the regulatory process. Explained in greater detail in the methodology chapter (Chapter 3), those criteria are the following:

1. Fulfillment of goals
2. Development of data and/or technology useful to future technology development
3. Public availability of results and communication of those results outside the partnership
4. Influence on regulations
5. Credibility to regulators and the rest of industry
6. Generation of further research or partnerships
7. Contribution to formal and informal knowledge networks

This chapter will use the comparison across this set of criteria to identify common characteristics that enable partnerships to offer input into the regulatory process.

### ***1. Fulfillment of Goals***

If the results of an R&D program are to be used as input for regulatory policy, the program must be perceived as reliable and successful. Consequently, the fulfillment of goals would be a minimum prerequisite.

The DECSE and EC-Diesel programs benefited from their very focused objectives. Although this required some sacrifice in the broadness of their scope, their focus allowed them to demonstrate their progress in a methodical and timely way. DECSE sought to determine the impact of diesel fuel sulfur levels on emission control systems and the reduction of PM and NOx. The program results did demonstrate that high sulfur levels have an adverse effect on the performance of emission control systems. EC-Diesel set out to evaluate the use of passive regenerative catalyzed diesel particulate filters using ARCO's own ultra-low sulfur diesel fuel. The program found that vehicles equipped with filters and fueled with EC-Diesel emitted over 90% less PM than vehicles without filters fueled with typical California diesel fuel.

Both programs had direct implications. DECSE participants could use their results to make the case for ultra-low sulfur diesel fuel standards. EC-Diesel participants could use their results to demonstrate that diesel vehicle retrofits, coupled with ultra-low sulfur diesel fuel, could be very effective in reducing PM emissions.

Although APBF-DEC is still in progress, its broader and more ambitious agenda makes it more difficult to meet all its goals. It is an expansion of DECSE – it continues to consider sulfur effects with more durability testing; includes heavy-duty vehicles as well as passenger cars and light-duty trucks/SUVs; investigates other fuel properties besides sulfur; plans to enable technology to meet 2007 standards but also means to address post-2010 standards and regulatory emissions. Although the APBF-DEC projects are not yet complete, the research plans, quarterly reports, and funding situation indicate that APBF-DEC may fall short of its ambitious goals. While durability testing for sulfur effects is going as planned for the different vehicle types, sulfur content is still the main fuel property being investigated. Since research plans accounting for post-2010 standards and unregulated emissions have been deferred to the second phase of APBF-DEC, starting in 2004, there is no sure guarantee that these elements will be included in later projects. Moreover, the current administration has not provided any FY2004 funding for APBF-DEC. The FY 2004 Amended Budget Request for Advanced Petroleum Based Fuels, the program to which APBF-DEC belongs, is \$0, compared to \$8,224,000 in FY 2003 (U.S. DOE 2003d). The fate of the second phase of APBF-DEC (2004-2010), and perhaps also the completion of the first phase (2000-2003), is highly uncertain. The budget cut may mean a premature ending for APBF-DEC.

Compared to DECSE and EC-Diesel, APBF-DEC is a considerably longer-term research program, which means that it is more susceptible to budget cuts and administrative changes. APBF-DEC's long-term goals may never be reached. Since the fulfillment of goals is largely dependent on the types of goals set, partnerships meant to have policy influence may benefit from focused goals, achievable in a short time period.

## **2. *Contribution to Future Technology Development***

Partnerships may contribute to future technology development by developing data and/or technology useful to industry. Because of the way their research projects were designed, the DECSE and APBF-DEC programs had more potential to generate “technology-advancing” results, i.e. results that push technology beyond what is currently possible. Both programs tested a technology that was not yet commercially available, the NO<sub>x</sub> adsorber. The scarcity of public information about NO<sub>x</sub> adsorbers positioned DECSE as a potentially cutting-edge partnership.

While individual companies may have been conducting their own research, much of these results were kept in-house. Generating data publicly could help industry see which technologies were worth pursuing further. Partnership results help companies who are not performing parallel research in-house or who want to understand the possible technology paths industry may pursue. Even companies outside of the partnerships can use the data in shaping their own R&D decisions.

In terms of understanding technology, the emission control manufacturers had a lot to gain from DECSE because they could better understand how their technologies worked with various engines and fuels. DECSE was an opportunity for member companies in the Manufacturers of Emission Controls Association (MECA) to get research done for their technologies. Emission control manufacturers gained access to engines for more realistic evaluations of NO<sub>x</sub> adsorber operating characteristics, an important part of their product development feedback process. The DECSE results provided them a guide for future product

development.<sup>11</sup> Each industry – fuels, emission control, and engine manufacturing -- understands its own technologies, but participants can gain valuable technical knowledge from the partnership's integration of those technologies.

The outcome of the SCR and NOx adsorber testing in APBF-DEC could play a large role in industry's choice of technologies to meet the 2007 NOx standards. Engine manufacturers differ about which NOx control technology to pursue. Some are concerned about the infrastructure if SCR is selected as the dominant NOx control strategy, since SCR systems require adding urea or aqueous ammonia to the exhaust stream. It seems that industry and EPA favor NOx adsorbers, but manufacturers are worried about their durability. APBF-DEC is testing both SCR and NOx adsorber technologies to mitigate that debate, even though the preference towards NOx adsorbers resulted in more funding and resources for NOx adsorber testing than SCR testing.<sup>12</sup> The results of APBF-DEC could play a major role in either strengthening or questioning the rationale behind favoring the NOx adsorber.

Since most of the technologies used in the EC-Diesel program were already commercially available, the program had a greater effect on marketing decisions than technology development. Although EC-Diesel fuel (ECD) was not sold commercially, ECD-1, which has a slightly different formulation, did become commercially available in 1999 in certain California metropolitan areas. The two types of catalyzed diesel particulate filters (CDPFs) supplied by Engelhard and Johnson Matthey had already been fully developed by these manufacturers. All the trucks and buses tested were already owned by their respective vehicle fleets, and CDPF retrofits were performed on existing engines. Since the program's technologies were already developed, the partnership results did not significantly contribute to technology development. However, it did assist ARCO and the emission control manufacturers with marketing decisions.

The superior emissions reduction performance of the ECD fuel complemented ARCO's decision to widen its distribution of ECD-1 in the Los Angeles and San Francisco areas. ECD-1 is being sold commercially for 5 to 10 cents more than the typical California diesel fuel. Because of a higher energy density, ECD-1 has less of a fuel economy penalty than ECD. As for

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<sup>11</sup> Based on an interview with the DECSE Deputy Program Manager, National Energy Renewable Laboratory, January 2003.

<sup>12</sup> Based on an interview with the DECSE Program Manager / former APBF-DEC Program Manager, National Energy Renewable Laboratory, January 2003.

Engelhard and Johnson Matthey, they had their CDPFs verified by CARB on August 2, 2001, which means their CDPFs can be used in California's heavy-duty diesel retrofit programs. As a result of California's Diesel Risk Reduction Plan, CARB has mandated diesel retrofits for heavy-duty vehicles, which will increase the demand for CDPFs. The CDPFs cannot operate with fuels having sulfur content over 50 ppm. As a result, ARCO's 7 ppm ECD-1 will gain a larger market share since typical CARB diesel has 120 ppm sulfur (Chandler 2001). International Truck and Engine Corporation, which managed the San Diego School District Bus Fleet in the EC-Diesel program, tested its new Green Diesel Technology™ on the buses' 530E engines. In 2001, it received EPA and CARB certification for its Green Diesel Technology™, which uses Engelhard's diesel particulate filter and runs on ultra-low sulfur fuel. International is the first company to receive certification from EPA and CARB for an engine meeting the MY2007 particulate matter standard (International Truck and Engine 2002). EC-Diesel gave all these companies the opportunity to show off their technologies and to convince both regulators and the public that clean diesel is possible.

### **Partnerships as a Check on Internal R&D**

Based on general comments by industry professionals familiar with DECSE, APBF-DEC, and EC-Diesel, the partnerships function as a check on internal R&D as opposed to advancing technology on their own. Cooperative research, in the form of partnerships, reduces redundancy and secrecy. A partnership allows companies to test promising technologies together instead of each company spending substantial time and effort doing it independently. Data produced by the partnerships can be instrumental in helping companies progress in the technology development. While the data generated from these collaborative efforts are all pre-competitive, the competitive advantage comes from the application of that data to commercial products.

Partnerships can verify or repudiate a company's internal R&D. A company can check its own work against publicly available results from a partnership. If a company is doubtful about a technology and a partnership also points out that technology's shortcomings, the company feels more confident about its own findings. Discrepancies between partnership results and in-house results may lead to confusion and debate. However, the transparent nature of

public-private partnerships allows for a public discussion of the results whereas private company testing results may not be shared as freely.

R&D costs pose a constraint on the internal research projects in which companies can invest. This limitation goes back to one of the reasons why companies choose to pursue collaborative activities – to share costs. Partnerships have built-in efficiencies, like multi-source funding. Individuals involved in the program take the knowledge back to their respective companies and enhance their own technology development.

Some question whether public-private partnerships are really technology-advancing, or even necessary, since the engine manufacturers and emission control manufacturers are presumably doing their own in-house testing. Among those interviewed, there was no general consensus about whether partnerships influence industry's convergence towards specific technologies. Some felt that public-private partnerships seldom drive technology, unless the projects are cutting-edge. Others felt partnerships were very influential in generating data that assisted individual companies and entire industries in evaluating the effectiveness of certain technologies.

Although a technology-advancing partnership may confer benefits to companies' technology development, a partnership does not have to advance technology in order to influence policy. Most technology-advancing R&D occurs within individual companies. Public-private partnerships can be used as a forum to avoid redundant R&D or to resolve conflicting R&D results from different companies or industries. While this section has mostly concentrated on partnerships' benefits to industry's technology development, Chapter 6 will discuss how people from different organizations – national labs, government, academia, and industry – view the contribution of partnerships to their understanding of technology development.

### ***3. Public Communication of Results***

The Department of Energy relies on three main technology transfer mechanisms to share knowledge about its research programs: (1) Licensing of patented technologies, (2) Publications in technical and trade journals, and (3) Presentations at technical society meetings, workshops, and contractor coordination meetings (U.S. DOE 1998). Since the three partnerships' results

were publicly available and pre-competitive, licensing of patented technologies was left up to industry participants' own technology development following the partnerships. Instead, the partnerships relied on publications and presentations to relay their results outside the partnership. Communication of progress and results familiarized the rest of industry and government regulators with the programs. As discussed in the previous chapter, published reports and technical papers were often used as supporting documents for federal and state rulemaking.

## Publications

DECSE was particularly prolific in its publications. The program released four Phase I interim reports, one Phase II report, and a final report in the span of two years.

**Table 10: DECSE-Reports**

Report	Date released
Phase I Interim Data Report No. 1	August 1999
Phase I Interim Data Report No. 2: NO <sub>x</sub> Adsorber Catalysts	October 1999
Phase I Interim Data Report No. 3: Diesel Fuel Sulfur Effects on Particulate Matter Emissions	November 1999
Phase I Interim Data Report No. 4: Diesel Particulate Filters	January 2000
Phase II Summary Report: NO <sub>x</sub> Adsorber Catalysts	October 2000
Final Report: Diesel Oxidation Catalysts and Lean-NO <sub>x</sub> Catalysts	June 2001
Final DECSE Program Summary	June 2001

The frequent reports were meant to “expedite development of new technologies,” but they also offered timely input to regulatory decision-making. According to the DECSE Program Manager, the realization that EPA would be using the results of DECSE for regulatory decision-making prompted the rapid dissemination of results. This led to a series of interim reports rather than just one interim report. When data were ready, they were made available to the technical team, statisticians, and analysis team for review. The review time was one to two months for

data to go from the lab to the public domain.<sup>13</sup> DECSE also sent out short biannual project summaries to its mailing list of interested stakeholders.

In addition to its own publications, the DECSE program also produced several technical papers published through the Society of Automotive Engineers (SAE). SAE technical papers are a reputable and widely-read source of information about vehicle technology. Papers are usually accompanied by presentations at SAE meetings. The three June 19, 2001 papers were presented at the SAE International Spring Fuels and Lubricants Meeting and Exposition in Paris, France. The other two papers were authored primarily by project teams at West Virginia University. The timing of these SAE publications in summer 2001 coincides with the completion of the final report in June 2001. The SAE papers were published well after EPA promulgated its Final Rule on diesel fuel sulfur in January 2001. The interim reports, not the SAE publications, were DECSE’s primary knowledge inputs into the rulemaking process.

**Table 11: SAE Publications from DECSE**

SAE Publications	Date	Main Authors
Development of a Desulfurization Strategy for a NOx Adsorber Catalyst System (2001-01-0510)	March 4, 2001	FEV NOx adsorber group
Measuring diesel emissions with a split exhaust configuration (2001-01-1949)	May 7, 2001	WVU diesel oxidation catalyst and lean-NOx group
Statistical issues in the evaluation of the impact of sulfur in diesel fuel on the performance of diesel particulate filter emission control devices (2000-01-1958)	June 19, 2001	Battelle statisticians
Effects of diesel fuel sulfur level on performance of a continuously regenerating diesel particulate filter and a catalyzed particulate filter (2000-01-1876)	June 19, 2001	Diesel particulate filter group
Overview of diesel emission control-sulfur effects program (2000-01-1879)	June 19, 2001	DECSE Steering Committee
Research approach for aging and evaluating diesel lean-NOx catalysts (2001-01-3620)	Sept. 24, 2001	West Virginia University lean-NOx group

<sup>13</sup> Based on an interview with the DECSE Program Manager / former APBF-DEC Program Manager, National Renewable Energy Laboratory, January 2003.

Since winter 2000, APBF-DEC has issued short project summaries similar to DECSE's biannual project summaries, but with greater frequency, sending them out to stakeholders every quarter. The last quarterly report in winter 2003, did mention some interim results for the program's five projects. However, in the past two years of the program, there have been no formal, publicly available reports or SAE publications. The individual projects are scheduled to end on December 2003, so it is expected that some reports will be available then.

EC-Diesel, on the other hand, has resembled DECSE's style of releasing information periodically, as major portions of the research are completed. However, instead of relying on both its own reports and SAE publications for written communication, EC-Diesel has focused mostly on SAE publications. The SAE publications all have multiple authors, typically with representatives from ARCO/BP as the lead authors. Some fleet-specific reports are publicly available, but not in a systematic way. Six months into the one-year validation program, ARCO and NREL released an interim report as an SAE publication (LeTavec et al. 2000). NREL released two reports documenting the start-up experience and final results for the Ralphs Grocery Class 8 truck fleet. The principal investigators on the Hertz Rental medium-duty truck fleet tests have their final report available on BP's ECD website (Durbin and Norbeck 2002).

**Table 12: SAE Publications from EC-Diesel**

SAE Publications	Date
EC-Diesel Technology Validation Program Interim Report (2000-01-1854)	June 19, 2000
Class 8 Trucks Operating on Ultra Low Sulfur Diesel with Particulate Filter Systems: Regulated Emissions (2000-01-2815)	Oct. 16, 2000
Class 8 Trucks Operating on Ultra Low Sulfur Diesel with Particulate Filter Systems: A Fleet Start-up Experience (2000-01-2821)	Oct. 16, 2000
Emission Reductions and Operational Experiences with Heavy Duty Diesel Fleet Vehicles Retrofitted with Continuously Regenerated Diesel Particulate Filters in Southern California (2000-01-0512)	March 5, 2001
Year-Long Evaluation of Trucks and Buses Equipped with Passive Diesel Particulate Filters (2002-01-0433)	March 4, 2002
Chemical Speciation of Exhaust Emissions from Trucks and Buses Fueled on Ultra-Low Sulfur Diesel and CNG (2002-01-0432)	March 4, 2002
Speciation of Organic Compounds from the Exhaust of Trucks and Buses: Effect of Fuel and After-Treatment on Vehicle Profiles (2002-01-2873)	Oct. 21, 2002

Based on the interviews conducted with those actively engaged with issues pertaining to the diesel industry, publications are a key source of information for academics and researchers, but less emphasized by industry professionals and regulators. Not surprisingly, academics and researchers publish more frequently than those in industry and regulatory agencies. The main criticism is that publications are too far behind the technology, either because of the time lag from the publication process or the reluctance to release proprietary information. Those in industry and government agencies tend to rely more on their contacts within the industry to obtain information about the latest research. Meeting someone in person or hearing a presentation at a conference or meeting may prompt an individual to read a publication. Even if publications do not appear to be primary sources of cutting-edge content, they can serve other purposes. Papers can lead readers to people who may be a source of knowledge. Publication in a peer-reviewed paper, like an SAE paper or technical journal, offers legitimacy to a research program. A publication can serve as a reference which regulatory staff cite when preparing rulemaking documents. As described next, a publication can also complement meeting presentations.

## **Conferences**

In many of the interviews, interviewees referred to their attendance at industry conferences and workshops as a source of information about new developments in research and technology. These events serve as gateways for participants to gain knowledge and meet new and familiar acquaintances. The Society of Automotive Engineers (SAE) hosts several meetings every year that are well attended by those in the diesel industry. SAE publications typically accompany technical presentations at SAE meetings. A lot of knowledge may be exchanged by interacting with presenters at individual sessions. On March 6, 2001, the NO<sub>x</sub> adsorber group presented at the 2001 SAE World Congress at a Diesel Exhaust Emission Control Session. At the same session, one hour later, a group involved with the EC-Diesel program presented some results from a heavy-duty vehicle fleet (SAE 2001). At this session, there was also EPA technical staff presenting their research. It is likely that the EPA staff became familiarized with the DECSE and EC-Diesel research there, if they had not known about it already. The EPA representative who regularly attended DECSE Steering Committee meetings was one of the three

EPA representatives presenting. DECSE participants published and presented their SAE papers in the very short span of 6 months in 2001, while EC-Diesel's publications have spanned a 2-year time period as the project progressed. This may be representative of the greater urgency of DECSE to get word out to industry and regulators about its results.

Although APBF-DEC has not yet produced any formal publications, APBF-DEC participants have been communicating progress through presentations at industry meetings. Recently, at the 2002 DOE-sponsored Diesel Engine Emissions Reduction (DEER) Conference, representatives from the NO<sub>x</sub> adsorber, SCR, and lubricant project teams presented their progress. In the 2000 and 2001 DEER conferences, there have been presentations from DECSE representatives. As for the EC-Diesel program, representatives have presented progress updates at every DEER conference since the program began in 2000. Speakers from EPA, CARB, and the South Coast Air Quality Management District attended the conferences, and their representatives included people in policy-making roles, who are responsible for assessing industry's technological progress towards emissions reduction (U.S. DOE 2000g, U.S. DOE 2001a, U.S. DOE 2002d).

At conferences, one mechanism of knowledge transfer occurs when R&D program participants present their work in the presence of attendees from regulatory agencies. Perhaps even more convincing is having a presenter from a regulatory agency feature an R&D project in her own presentation. In Corning's February 2001 Diesel Emission Control Retrofit Users Conference, a CARB representative discussed the California Diesel Risk Reduction Plan and referred to ARCO's EC-Diesel program as an example of a current demonstration program (Steel 2001). With attendees from EPA's Office of Transportation and Air Quality and various California state and regional agencies present, having a CARB representative mention the program probably enhanced the EC-Diesel program's credibility.

#### ***4. Influence on Regulations***

Anticipation of future emissions regulation of diesel vehicles was a significant factor that affected initiation, progress, and reporting of the projects, especially for DECSE and EC-Diesel.

When DECSE began, DOE anticipated tighter emission standards, and lower fuel sulfur standards, but no concrete numbers had been established.

In 1997, DOE had been encouraging EPA to consider regulating the reduction of sulfur levels in diesel fuels. Since EPA was focusing on new gasoline standards, it was not concerned with diesels at that point. However, the DOE Assistant Secretary and the EPA Assistant Administrator negotiated an agreement that if DOE's tests could make a case for ultra-low sulfur diesel, EPA would consider making a low-sulfur rule.<sup>14</sup> This agreement set up DECSE to be a major contributor to EPA rulemaking from the outset. It also parallels the interagency communication that was happening among the technologists at the two agencies. Some of DOE's DECSE participants note that they knew about EPA's intentions to lower the sulfur levels in fuels well before the EPA's public announcement of its proposed rulemaking. The frequent references to DECSE in the Notice of Proposed Rulemaking and the Regulatory Impact Analysis to support the 15 ppm diesel fuel sulfur standard indicate that DECSE did ultimately play a key role in the regulations.

The EC-Diesel program was formed in a response to the regulatory environment rather than as an explicit input into regulation. EC-Diesel was a reactive move by ARCO to demonstrate the potential for clean diesel at a time when public disfavor towards diesel was increasing and CARB had just listed diesel exhaust as a toxic air contaminant. In 1998, this threatened to decrease the demand for diesel fuel and disrupt the balance of petroleum products sold by ARCO. ARCO wanted to demonstrate that retrofitting diesel vehicles and fueling them with low sulfur fuel was feasible, so that CARB would not rule out diesel in favor of natural gas or other alternatives. Unlike DECSE, ARCO's priority was not to demonstrate the need for low-sulfur fuel but to keep diesel on the market for trucks and buses in California.<sup>15</sup> At the time that ARCO began planning EC-Diesel, EPA was already in the formative stages of its Advance Notice of Proposed Rulemaking for the 2007 Rule, which was already perceived as a given.

Both DECSE and EC-Diesel did have a role in the 2007 heavy-duty diesel rulemaking, but DECSE featured more prominently, most likely because it was intentionally designed and timed to have a large influence. Consequently, EPA's rulemaking timeline accelerated DECSE's

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<sup>14</sup> Based on an interview with the former Director of the Office of Heavy Vehicle Technologies, Department of Energy, January 2003.

<sup>15</sup> Based on an interview with the ECD Marketing Manager, BP, February 2003.

progress. DECSE participants had initially intended to get the data out to the EPA officials before EPA's Advance Notice of Proposed Rulemaking. However, the infeasibility of completing the tests in a few months' time made this goal unrealistic. Instead, the Steering Committee aimed to get the information out by summer 2000, so that EPA could have it available before they finalized the rule at the end of 2000. EPA had already issued its Advance Notice of Proposed Rulemaking in May 1999. From this chronology, it is evident that EPA intended to set diesel fuel sulfur standards, without waiting for DECSE to prove that such a move was necessary. By this time, DECSE's regulatory objective would be to indicate how low those sulfur standards had to be. Since the Regulatory Impact Analysis was finalized in December 2000, most of the DECSE results were factored into the report.

Based on interviews with DECSE project team leaders, the desire to provide data in time for EPA rulemaking created substantial time pressure for the project teams. Weekly or biweekly conference calls between the various test sites and DOE representatives kept progress moving along at a steady pace. Program leaders aggressively tackled issues that threatened to delay the project. Teams had to adhere strictly to the original experimental designs, even if interesting tangential questions arose. Researchers in the labs and universities may have liked to further investigate those interesting issues and to gain a fuller understanding of the technologies, but they recognized the need to maintain a narrow focus on aspects directly relevant to the project. Enabling EPA's use of DECSE's findings required the rapid dissemination of the program results. Instead of producing one final report, DECSE produced a series of interim reports before the final summary. As mentioned in Chapter 5, interim reports were issued in August 1999, October 1999, November 1999, January 2000, October 2000, and a final report in June 2001. All but the final report were released before the final January 2001 rulemaking.

Even though the EC-Diesel program had not intentionally set up its timeline to provide input into EPA's rulemaking process, the timing of its June 2000 interim report did offer EPA enough time to consider their interim results prior to the final rulemaking. However, the EC-Diesel program had a much smaller impact on the 2007 Rule because the new regulations were not requiring vehicle retrofits. EC-Diesel had more impact in California, where mandated vehicle retrofits were expected. The nature of EC-Diesel made it more suited to influencing the implementation and operations of vehicles running on ultra-low sulfur fuel than influencing the standards themselves.

For the five APBF-DEC projects currently underway, it is still too early to gage their impact on future regulations. The projects should be completed by the end of 2003. At this point, the 2007 regulations on diesel engine emissions and fuels have been taken as “givens” by the diesel industry. Sources at the EPA have uniformly said that changing or delaying the 2007 Rule is not an option. The current APBF-DEC projects focus on meeting the 2007 regulations rather than considering post-2010 regulations, so APBF-DEC will be less influential in rulemaking than its predecessor, DECSE. Since the 2007 Rule is already set and its reversal is highly unlikely, APBF-DEC will at most be able to provide some publicly available data on the durability of aftertreatment devices and assist in technology development.

Although APBF-DEC may not have influence on engine emission or fuel sulfur standards, it may influence future regulations on lubricants. One project team is working on determining the extent to which high sulfur content in lubricating oil contributes to sulfate and total PM emissions. If their findings show that the contribution is significant, it may lead the EPA to consider regulating lubricants.

APBF-DEC may have missed the opportunity to influence post-2010 regulations on presently unregulated exhaust constituents. This is a stated objective of the program, but no concrete research plan in this area has been formulated.

There has been some speculation that the APBF-DEC testing results may be used to determine whether meeting the 2007 heavy-duty diesel standards is feasible. The tests for durability and robustness may feed into considerations about whether the 2007-10 standards hold for long-term, in-use performance. However, this suggests that industry may use the APBF-DEC results to demonstrate the infeasibility of complying with the 2007 Rule and argue for a postponement or relaxation of the standards. This is a likely reason why regulators would be skeptical of cross-industry partnerships with a bearing on regulations. However, even if the APBF-DEC results indicate that the upcoming standards are too far ahead of technological progress, it is unlikely that EPA would delay implementation. The timing of research programs is unlikely to change or delay the regulations. At this point, changing the regulations would penalize the companies have who have already planned their R&D accordingly. With International Truck & Engine Corporation already having certified an engine meeting the 2007 Rule, it will be much harder for industry to say that meeting the regulations is impossible.

The substantial influence of DECSE on EPA's diesel fuel sulfur standard, compared to EC-Diesel's moderate influence on California diesel retrofits and APBF-DEC's uncertain role in upcoming EPA policy, shows that timing and intent are crucial to influencing policy. Aiming to fulfill a specific knowledge gap in time for final rulemaking should be an explicit component of a partnership's program design if it is to influence policy.

## **5. *Credibility***

Based on the interviews, credibility was one of the most commonly cited reasons for private companies and trade associations to engage in the public-private partnerships studied in this research. The opportunity to produce "unbiased" publicly available data seemed at least as important as the opportunity to pool resources and share information.

Prior to the formation of DECSE, the two trade associations EMA and MECA knew that sulfur levels are a major barrier to emerging aftertreatment technologies. Well before EPA considered lowering fuel sulfur standards, they had pushed for lower sulfur levels. EMA and MECA had discussed sulfur issues with each other before DOE got involved. If the trade associations or their individual member companies provided data on the emission benefits of low sulfur fuels, others in the diesel industry may be skeptical of the results because of the organizations' inherent bias towards ultra-low sulfur fuel. Engine manufacturers would be accused of shifting the regulatory burden on the petroleum industry to produce low sulfur fuels rather than tackling emissions reductions through in-cylinder controls. Emission control manufacturers would be seen as directly benefiting from lower sulfur levels, since it would enable the sales of more emission control equipment, which are rendered ineffective by high sulfur content. Teaming with DOE in a public-private partnership that also included EPA at the table was very attractive. EMA and MECA could make their case for low-sulfur fuel under the scrutiny and validation of government agencies.

The broad stakeholder involvement and transparency of the partnerships contributed to the credibility of the results. Because partnerships are perceived as less biased and more credible, industry may feel that collaborative research carries more weight with regulators than

research from individual companies or trade associations, even if that research is contracted out to an independent consultant. Since the results of public-private partnerships are publicly accessible and often published in widely circulated articles or journals, all interested parties have the chance to evaluate the data. Instead of debating the merits of technologies based on confidential company data, companies can debate the merits based on public data, where the test assumptions and experimental design are also out in the open. While a partnership requires the consensus of the participating organizations, they may still disagree about regulatory policies or technical issues outside the partnership's scope. Even if the partnership results do not support a particular company or industry's prior claims about certain technologies or regulations, each participant would recognize the legitimacy of the results.

DECSE may have increased its credibility had it included the petroleum industry in addition to the engine and emission control manufacturers. The exclusion of the petroleum industry from DECSE caused some resentment. Sources within the DECSE partnership and in the petroleum industry noted that oil companies had expressed interest in participating as formal partners. Since it was expected that DECSE would provide data showing the need for lower fuel sulfur levels, DECSE organizers may have anticipated resistance on the part of oil companies and feared their inclusion would delay the DECSE timeline. Once the program results were released, DECSE came under a lot of attack by API and other petroleum organizations, which is well documented in the comment period for the EPA's diesel sulfur rule. By expanding partnership membership to petroleum companies, chemical companies, and automakers, APBF-DEC has increased its credibility relative to DECSE.

Regulators participated in all three partnerships, either as a formal partner or in a technical advisory role. DECSE and EC-Diesel brought in EPA, and EC-Diesel brought in EPA and CARB early on in the program design process. By overseeing the experimental design, testing, and data generation, the regulatory agencies could trust in the data's robustness and relevance to the regulatory process.

Even though the engine manufacturers and emission control manufacturers agree on the need for ultra low sulfur fuel, they do not necessarily agree on the feasibility of the aftertreatment technologies. Each industry wants to convince regulators of the accuracy of their technology assessment. Emission control manufacturers tend to be more confident about

aftertreatment technologies, because they are in the business of selling them. In the court decision that upheld EPA's diesel sulfur rule, the circuit court judges wrote: "Of course it is no surprise that NO<sub>x</sub> adsorber manufacturers would support a regulation creating a potential for sales of their products" (U.S. Court of Appeals 2002). Meanwhile, engine manufacturers tend to be more skeptical about aftertreatment technologies because they are the ones who must ultimately meet the emission standards and get their engines certified for sale.

From the interviews, there was the general agreement among industry that work performed by public-private partnerships would be weighed more heavily or perceived more credibly by regulators. This observation was confirmed by the partnership questionnaire responses, which are described in the next chapter. However, people at EPA and CARB downplayed the significance of data from public-private partnerships. They assess technologies from a portfolio approach, where they balance publicly available data and studies with confidential company information and their own emissions testing. Chapter 6 will discuss how partnerships fit into regulators' portfolio of knowledge inputs.

Recruiting cross-industry participation, harnessing government participation and resources, and involving regulators in an advisory capacity all contribute to increasing the credibility of a partnership. A partnership with members from all parties with a stake in the technology is more likely to get buy-in from the corresponding industries. All three partnerships took advantage of the management capability and resources from DOE's national labs. Soliciting technical support from regulators from a program's inception helps to make the program design and results more robust for use as input for regulatory considerations.

## **6. *Generation of Further Research or Partnerships***

A successful partnership may generate more questions or knowledge gaps suitable for additional research. Participants may choose to further utilize or build on the existing formal partnership structure. Future research or partnerships have the potential to generate data or information which may in turn influence the regulatory process.

DECSE did generate more research that built on its program design and results. The most obvious byproduct of DECSE is its successor program, APBF-DEC, which is conducting

more research on the two most promising technologies tested in DECSE, the diesel particulate filter and the NO<sub>x</sub> adsorber. APBF-DEC was a way to take advantage of the relationships already developed in DECSE. Once all the participants had invested in developing relationships in DECSE, it seemed worthwhile to continue working together. As DECSE progressed, the groups continued to discuss which projects required further consideration, such that APBF-DEC was planned before DECSE completed its projects.

DECSE also generated more collaborative projects among the national labs and private industry. For example, a group consisting of representatives from DOE, NREL, SwRI, Ford, GM, BP, Marathon Ashland, Philips Petroleum, PDVSA, and Shell, researched the development of an engine control strategy which could take advantage of fuel properties to reduce NO<sub>x</sub> emissions in a light-duty diesel engine. One of the 7 different advanced fuels tested was the DECSE 3 ppm sulfur base fuel. Wendy Clark of NREL and John Garbak of DOE, both members of the DECSE Steering Committee, were listed as two of the authors in the resulting SAE paper: “Impact of Engine Operating Conditions on Low-NO<sub>x</sub> Emissions in a Light-Duty CIDI Engine Using Advanced Fuels” (SAE 2002-01-2884). Research at the Oak Ridge National Laboratory, evaluating the emissions performance of a catalyzed diesel particulate filter and a NO<sub>x</sub> adsorber in a light-duty diesel vehicle, also relied on the fuel specifications developed from DECSE for its experimental fuels (West and Sluder 2001a, 2001b).

EC-Diesel has led to a closer relationship between ARCO/BP and other companies. The program has led to ties that extend beyond technology development: Before EC-Diesel, ARCO had a limited relationship with the catalyst manufacturers Johnson-Matthey and Engelhard. EC-Diesel has brought them closer, such that they help each other with technology development, marketing, and policy. ARCO’s relations with EMA existed before EC-Diesel, but the partnership strengthened their ties and motivated them to pursue more joint efforts. Even though these different organizations do not agree on every issue, they have established channels of communication and trust to improve the understanding behind each other’s perspectives.<sup>16</sup> Meanwhile the ARCO lead on EC-Diesel has now moved from his position as a principal engineer to a marketing manager. According to Quintas and Guy (1995), participation in further collaborative R&D indicates the effectiveness of partnership ties, while the movement of R&D

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<sup>16</sup> Based on an interview with the ECD Marketing Manager, BP, February 2003.

personnel into product development and marketing indicates the movement of knowledge across organizational boundaries.

These experiences demonstrate how a partnership strengthened the ties among the participating companies through the relationships between the individual employees. Further research and partnering grew out of these ties. This leads into the last criterion on which the partnerships were compared, the ability of the partnerships to establish formal and informal knowledge networks among organizations and individuals.

## **7. *Contribution to Knowledge Networks***

The final criterion for which the three partnerships are compared is their contribution to the creation or expansion of formal and informal knowledge networks. Such networks facilitate the flow of knowledge at the organizational or personal level. Formal networks would be shaped by project hierarchies, reporting mechanisms, an organization's responsibilities, or an individual's job function. While informal knowledge networks may be an outgrowth of formal networks, they are driven by trust and familiarity resulting from personal relationships.

The partnerships were instrumental in drawing together competitors from the same industry as well as companies from different but complementary industries. Trade associations played a key role in this regard. DECSE was a partnership among DOE, the Engine Manufacturers Association (EMA), and the Manufacturers of Emission Controls Association (MECA). Although individual companies were involved in contributing equipment, expertise, and other resources, the engine and emission control industries' participation were coordinated by the trade associations. These trade associations have a built-in intra-industry network already established among their member companies. From an organizational standpoint, it was easier for DOE to tap into this network rather than to hold discussions with individual companies. APBF-DEC also followed this model of working through trade associations. Through the American Petroleum Institute (API) and the American Chemistry Council (ACC), APBF-DEC brought in companies from the energy/oil and chemical additive industry. Another indication of the prominent role of the trade associations is that industry's financial contributions came through

the trade associations, not the individual companies. The companies do ultimately contribute to the project, directly with in-kind contributions and indirectly with dues to their trade associations.

In contrast, the EC-Diesel program was a partnership among individual organizations, and did not involve trade associations. This was probably because ARCO/BP was the lead organization, and the only petroleum company involved. ARCO approached participants on a company-by-company basis. Since ARCO had close ties with engine manufacturers from previous interactions, it had the engine companies select vehicle fleets and manage the respective fleets. EC-Diesel's less inclusive structure limited the extent of its formal knowledge network relative to those through DECSE and APBF-DEC. This reflects the difference between a government and a company-initiated partnership, where the EC-Diesel knowledge network tended to be more centered on BP. However, this did not inhibit EC-Diesel from contributing to meaningful formal and informal ties. Even with APBF-DEC's broad inclusiveness through trade associations, it still excluded many foreign firms, automakers in particular. Only the "Big Three" U.S. automakers – GM, Ford, and DaimlerChrysler – and Toyota participated. While including more foreign firms would have vastly increased the network ties, it would have conflicted with DOE's goals of enhancing U.S. industry. Once Chrysler became part of DaimlerChrysler, whether the company should be allowed to continue in industry-government partnerships was a subject of discussion.<sup>17</sup> Therefore, even Toyota's involvement in APBF-DEC seems to be an anomaly.

All three partnerships included regulatory agencies as either partners or active participants. An EPA representative attended the DECSE and APBF-DEC Steering Committee meetings regularly, and EPA provided technical assistance in the experimental design of the program. While EPA also provided technical assistance to the EC-Diesel program, the California Air Resources Board (CARB) was the main regulatory agency participating. Since the program was based in California and had implications for California's heavy vehicle retrofit programs, it made sense that CARB rather than EPA was closely involved. CARB contributed research funds to characterize and measure the chemical species in diesel exhaust. Not only does the involvement of the regulatory agencies add legitimacy to the program, but it offers a

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<sup>17</sup> Based on an interview with a representative from the Department of Energy, January 2003.

channel for which progress reaches the agencies before the programs' completion. The agencies' formal ties to the research programs could help the participants address any weaknesses perceived by the regulators during the program rather than after its completion. As discussed in the previous section, the formal ties to regulators enhanced the credibility of the partnerships.

In a sector where much of the interaction between industry and government agencies relates to policy and regulations, partnerships foster interaction at the technical level. The interaction among technologists can offer a company a better understanding of the information used as a basis for regulations, especially if regulators are providing technical advice about the suitability of the testing and reporting protocols to regulatory decision-making. Policy-relevant discussion not only happens at the higher company management-to-regulator levels, but at the company technologist-to-government technologist level. Many of those interviewed observed that technologists have an easier time communicating to each other rather than to company management or regulatory staff. The theoretical literature covered in Chapter 2 supports this observation. It is usually easier for people with similar functional roles to communicate with each other. Partnerships can be seen operating as an alternative forum to formal rulemaking procedures: Partnership meetings give companies the chance to express their views unofficially to the government before they have to go through the formal comment period on rulemaking. Even though the focus of the partnerships is technology R&D, and not policy, the formal networks of the R&D partnerships enable informal discussion of policy issues in the presence of representatives of regulatory agencies.

While the three partnerships did not create any new ties among organizations, it did bring together individuals from different organizations who had not been familiar with each other. A common response from those involved in partnerships was that they knew about half of those involved and the other half were completely new acquaintances. Many of those interviewed noted that the diesel industry's relatively small size allows them to be well acquainted with some of the key people in each major company. Some of these industries had done joint R&D well before DECSE, APBF-DEC, or EC-Diesel. The most notable example is the Coordinating Research Council's Auto/Oil Program in the early 1990s. A consortia of auto and oil companies came together to research the effects of different fuel formulations on auto emissions. Some of the API and auto company participants in APBF-DEC were first acquainted with each other through the Auto/Oil Program.

Many of the companies already have one-on-one collaborations with the national labs. For example, as of fall 2002, Oak Ridge National Lab, one of the two national labs on the DECSE/APBF-DEC Steering Committee had CRADAs (Cooperative Research and Development Agreements) with Cummins, International Truck and Engine, Detroit Diesel, and Ford (Graves 2002). These previous partnerships laid the groundwork for many of the formal network ties existing in DECSE, APBF-DEC, and EC-Diesel. For instance, DECSE was an offshoot from one of DOE's frequent workshops with industry. In these workshops, DOE and industry participants make presentations and discuss future research. An NREL Technology Manager attended a DOE and NREL-sponsored workshop at San Antonio in February 1998. During lunch, he sat next to members of the EMA Fluids Committee. One of the EMA committee members, with whom he had been acquainted in the past, informed him that EMA had made an internal presentation among their members along the same lines as DOE's presentation on diesel fuels.<sup>18</sup> The NREL Technology Manager, who ultimately became the DECSE Program Manager, saw an opportunity for collaboration. In a matter of months, the experimental design for DECSE had been completed. The combination of DOE's frequent government-industry workshops and existing informal networks enabled this exchange to occur.

There were a few individuals interviewed who felt that the partnerships only marginally increased their informal knowledge networks. They have been in the industry for a long time, and have been actively involved in trade associations, government advisory panels, prior research collaborations, and other activities external to their organizations. Instead of introducing them to new people, the partnerships reinforced existing ties. For instance, the Southwest Research Institute (SwRI) researcher who serves as the principal investigator on one of APBF-DEC's testing projects is very active outside SwRI. He teaches classes on diesel engines and emission controls through SAE four or five times per year. Many companies invite him to teach their employees about the latest technologies. He viewed APBF-DEC as a forum for interaction and an opportunity to strengthen professional ties. In his case, partnerships have

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<sup>18</sup> Based on an interview with the DECSE Program Manager, National Renewable Energy Laboratory, January 2003.

allowed him to work with people who are not only his professional acquaintances, but his friends.<sup>19</sup>

Partnerships were especially influential in expanding networks for people who tended to network within their own industry or organization type, especially for those in the national labs. For example, some of those interviewed had strong backgrounds in one technology area like fuels or engines, but the partnerships helped them to develop expertise in other areas. Some had dealt primarily with light-duty vehicles, so working with heavy-duty diesel engines enabled them to tap into a different set of industry networks.

The overlapping and shifting functional roles of many industry representatives enhanced cross-industry and industry-government interaction. In many cases, individuals moved from predominantly technical or R&D roles to more policy- or strategy-oriented roles. Some of these policy- or strategy-oriented roles were self-initiated after the individual identified a need for that function in the organization. For example, the Manager of Emerging Technology and Regulations invented his current hybrid role at Corning Environmental Technologies. His activities in these two “worlds” of emerging technology and regulation include piecing together summaries of the latest technologies and presenting this information to audiences, which helps to develop his own credibility and opens doors for more sharing. He presents to industry and government, technologists and managers. Like this Corning Manager, many of those respected for their technical expertise have become regulatory advisory panel members, industry association leaders, and sought-after conference speakers or instructors. These individuals often must wear a “technical hat” as well as a “regulatory hat,” which allows them to bridge between technologists and policymakers. They exemplify the definition of “technological gatekeeper” described in the literature review (Allen 1977). However, they go beyond the standard gatekeeper role or the “T-shaped” manager role (Hansen and Oetinger 2001) by applying their technical expertise to the realm of regulatory policy.

Others bridge across industries because of their previous work experiences. The advantage of moving from one industry or company to another is harnessing the previous ties to foster communication and trust. The following example is particularly illustrative. The Clean

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<sup>19</sup> Based on an interview with the Principal Investigator of the APBF-DEC urea SCR+DPF project, Southwest Research Institute, January 2003.

Diesel Independent Review Panel is an independent advisory panel designated to advise EPA on industry's progress towards meeting upcoming emission and fuel sulfur regulations. A Panelist representing an engine manufacturer used his previous work experience in the petroleum industry to facilitate agreement between the fuel representatives and other Panelists. At one point, the panel was at an impasse about the language in the final panel report. Because of his background in fuels, the panelist was able to act as a "translator" between the petroleum industry representatives and the engine and aftertreatment manufacturers.<sup>20</sup> The effectiveness of these "boundary spanning" individuals, whether they bridge across different types of functional or organizational roles, demonstrates the importance of personal relationships and informal knowledge networks in communication.

Although the formal networks of APBF-DEC and EC-Diesel will continue as long as the programs are in existence, the formal relationships shaped by organizational and functional roles have evolved into informal relationships. As mentioned earlier under Criterion 6, EC-Diesel has strengthened the ties between ARCO and engine and aftertreatment manufacturers, such that they are pursuing other collaborative activities.

In most cases, the R&D partnerships reinforced or expanded existing knowledge networks that had already been created by previous activities. While the formal knowledge networks of the partnerships had practical organizational purposes, they enabled the proliferation of informal network ties once the partnerships ended.

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<sup>20</sup> Based on an interview with the Chief Technical Officer, Cummins Inc, February 2003.

**Table 13: Comparing the Partnerships**

	<b>DECSE</b>	<b>APBF-DEC</b>	<b>EC-Diesel</b>	
Duration	1998-2001	2000-2010	1998-2001 (Part 1) 2001-2002 (Part 2)	
Main objective	Evaluate the effects of varying levels of fuel sulfur content on emissions reduction and on up to 250 hours of engine aging for on-highway trucks	Identify optimal combinations of fuels, lubricants, diesel engines, and emission control systems to meet projected 2000-10 emission standards	Evaluate the use of passive catalyzed diesel particulate filters using ultra-low sulfur diesel fuel	
Lead organization	DOE	DOE	ARCO/BP	
Criteria	Fulfillment of goals	YES	UNCERTAIN No FY2004 funding	YES
	Contribution to future technology development	YES Technology-advancing research Recommended 2 technologies out of 4 tested that are worth pursuing	YES Durability data is helpful but only as a check to in-house work that is being conducted in corporate R&D labs	NO Not meant to be technology-advancing but contribute to marketing and production decisions
	Public communication of results	YES Substantial reports, technical papers, and conference presentations	SOMEWHAT No substantial reports or technical papers; some conference presentations	YES Substantial reports, technical papers, and conference presentations
	Influence on regulations	YES, Instrumental in EPA's 15 ppm diesel fuel sulfur standard	UNCERTAIN 2007-2010 regulations are already in place; No concrete post-2010 research plans	YES Slight influence on EPA's 15 ppm diesel fuel sulfur standard; Substantial influence on CARB's attitude toward diesel and retrofit regulations
	Credibility	YES Cross-industry consensus a major plus, but skepticism from the excluded petroleum industry	YES Membership is even more inclusive than DECSE	YES CARB and DOE's involvement enhanced credibility
	Generation of further research or partnerships	YES Inspired APBF-DEC	UNCERTAIN	YES Inspired joint activities between ARCO/BP and other industry partners
	Contribution to knowledge networks	YES Based on trade associations; Some new ties between national labs and industry; Reinforced existing industry ties	YES Expanded existing DECSE network by including more industries; Reinforced existing industry ties	YES Strengthened ties among BP, engine makers, catalyst manufacturers and CARB

## *Chapter Summary*

Of the three partnerships, DECSE and EC-Diesel had significant influence on policy-making in their “targeted” regulatory environments. DECSE provided a strong technical basis for EPA to lower its diesel fuel sulfur standard to 15 ppm, to be implemented in 2006. EC-Diesel showed CARB that reducing diesel exhaust emissions did not require taking California’s diesel trucks and buses off the road and off the market, since substantial reductions are possible with ultra-low sulfur diesel and aftertreatment technology. The partnerships’ ability to meet goals, communicate results to the public, provide data to inform policymaking, garner credibility, and contribute to knowledge networks positioned them to influence regulatory processes. Contributing to future technology development was less critical than the other criteria, even though technology development could eventually affect regulatory policy indirectly, when regulators assess industry’s progress toward meeting regulations. EC-Diesel was not designed to be technology-advancing, and yet it had significant impact on CARB’s policy towards keeping clean diesel as an option, even in the context of its Diesel Risk Reduction Plan. The EC-Diesel experience implies that partnerships can be “policy-influencing” without necessarily being technology-advancing. The generation of further research, performed independently or collaboratively, may also indirectly affect policy down the road, but that depends on those future activities themselves.

What do these insights from the comparative analysis mean for the future of APBF-DEC? Since APBF-DEC is still in progress, it is difficult to say with certainty whether it will influence policy. However, having considered the circumstances that allowed DECSE to inform EPA’s sulfur standard, it seems highly unlikely that APBF-DEC will have the type of impact that DECSE had. Even though it has the credibility and organization that DECSE had, it does not have the advantage of DECSE’s timing. DECSE was positioned right before the final rulemaking of the sulfur standard, with most of the results available in time to fill knowledge gaps. The 2007-2010 regulations are now set, and there is no expectation that they will change. APBF-DEC’s plans to inform post-2010 policymaking are not yet established, as most the projects still focus on enabling technologies for the 2007 regulations. The lack of formal

publications communicating APBF-DEC results may signal that APBF-DEC is not producing data that will be referenced in upcoming regulatory decisions.

The next chapter uses the results of the partnership questionnaire to capture general attitudes about public-private partnerships from the various stakeholders. In many ways, the responses more concretely capture several important overarching issues surfaced in this comparative case study, while drawing attention to other issues that were not addressed in this chapter.

## CHAPTER 6: PERSPECTIVES ON PARTNERSHIPS

### *Introduction*

The previous chapter used a comparison of three specific partnerships to highlight factors important to a public-private partnership's contribution to regulatory policy. This chapter seeks to obtain a broader assessment of public-private clean diesel partnerships, from the standpoint of the various stakeholders in industry, regulatory agencies, DOE/national labs, and academia. Administering follow-up questionnaires to the interviewees provided the opportunity to test themes that rose out of the comparative analysis, namely that (a) participants benefit from knowledge-sharing in partnerships and (b) partnerships can influence policy by virtue of their enhanced credibility and cross-industry collaboration.

The questionnaire was comprised of five multiple-choice questions that reflected these two main themes. Two of the questions referred to the benefits of partnerships to industry and to the understanding of technology development. The other three questions related to policy influence of partnerships. "Partnerships," as defined in the questionnaires referred to public-private partnerships in clean diesel R&D.<sup>21</sup> The questions were transmitted by phone or email to the 22 people previously interviewed, and 18 people responded, an 82% response rate. In two cases, some questions were intentionally omitted, so some questions only have 16 or 17 responses. The number of people surveyed was small, so the results are not to be perceived as statistically significant. Rather, they draw attention to some interesting overall trends. The results of the questionnaire confirmed and further illuminated many of the findings from the comparative case study of the three partnerships.

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<sup>21</sup> A full version of the written questionnaire is in the Appendix.

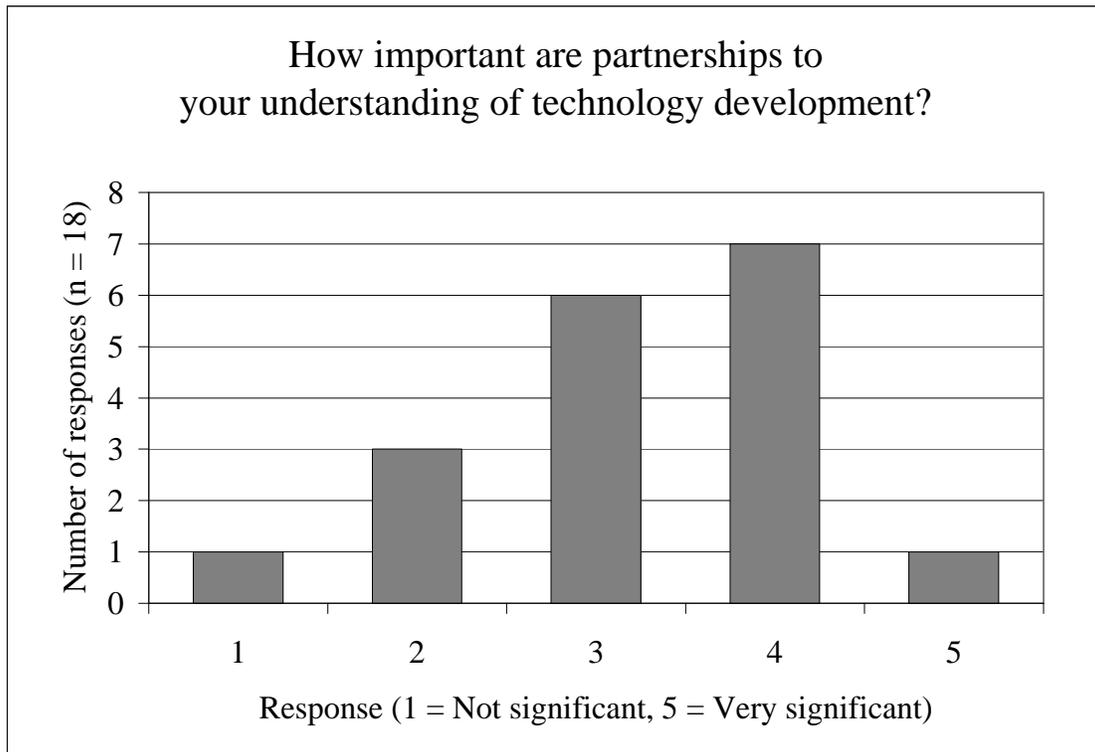
## ***Benefits of Partnerships***

The comparative case study illustrated the role of partnerships in filling knowledge gaps and helping participants understand the technologies, especially those outside of their specific industry. In the interviews, many of those in industry cited the benefits of collectively performing pre-competitive R&D because of cost/resource efficiency and knowledge-sharing within the formal partnership networks. Two of the questions are derived from these findings:

- How important are partnerships to your understanding of technology development?
- How significant are industry's benefits from partnerships?

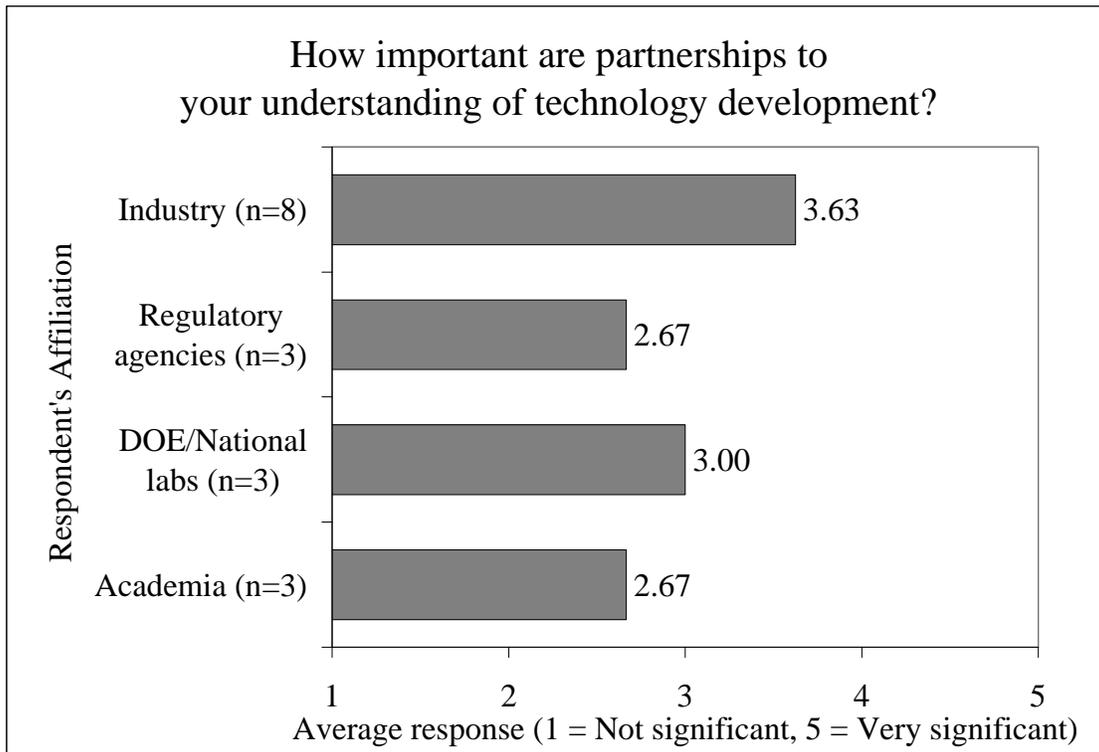
The question on understanding technology elicited a range of responses, skewed more towards those viewing partnerships as significant to their understanding of technology development. However, only one person noted partnerships as “very significant” to his/her understanding, which may reflect the fact that most R&D is still performed internally rather than collaboratively. Those in academia or government may also be relying heavily on personal contacts and publications to obtain knowledge. Also, since public-private partnerships are pre-competitive and not confidential, there are limits to the amount of “cutting-edge” knowledge discussed in partnerships.

**Figure 11: Understanding Technology (by Response)**



Grouping the respondents based on their organizational affiliation (e.g. industry, regulatory agencies, academia, and DOE/national labs) offers a deeper level of analysis. Of the four groups, industry places the most value on the partnerships' contribution to the understanding of technology development. It reflects one of the basic industry motivations to participate in external collaboration – to obtain access to external knowledge and resources, which was discussed extensively in Chapter 1. As mentioned in the previous chapter's comparative case study, companies may understand how their own technologies function, but they know less about other industry's technologies. These technologies are often complementary technologies that must be integrated into one system. Partnerships offer a forum for learning through cross-industry knowledge networks. The questionnaire results appear to corroborate these findings.

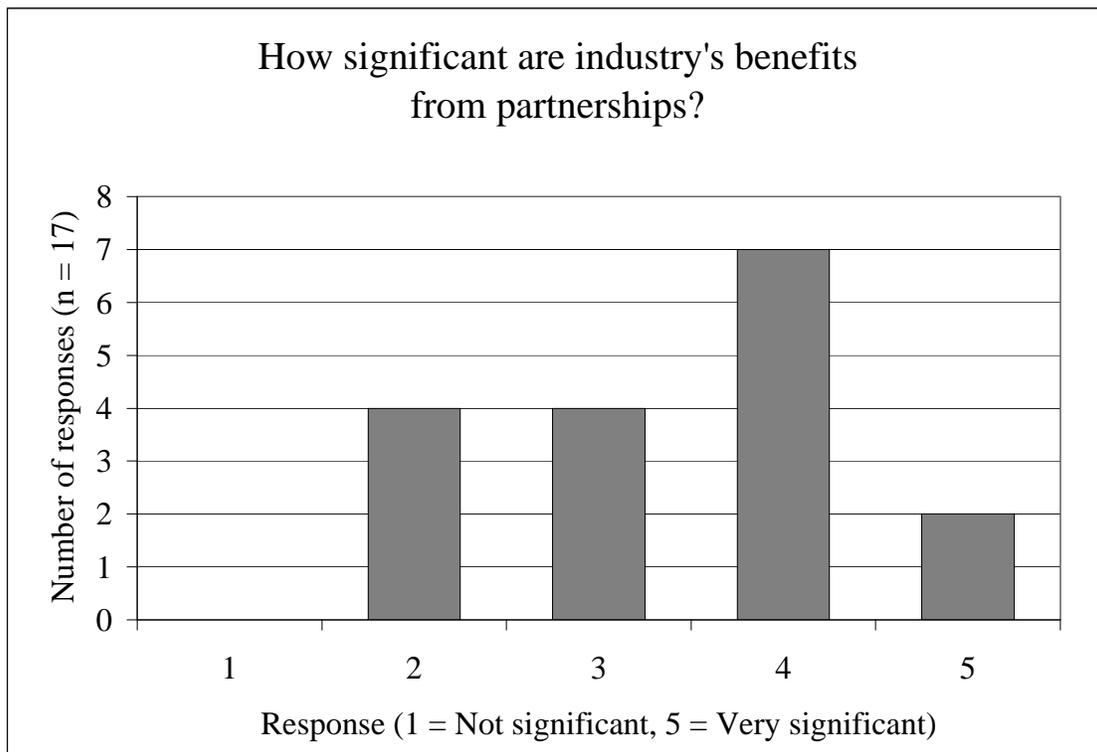
**Figure 12: Understanding Technology (by Affiliation)**



Compared to industry and DOE/national labs, regulatory agencies and academia felt that partnerships were considerably less important to their understanding technology development, each group with an average of 2.67. In the previous chapter, it was noted that academics and researchers rely heavily on technical publications for information, which may explain their relatively lower valuation of partnerships. Also, if the three partnerships in the comparative case study are any indication of other clean diesel R&D partnerships, the industry, national lab, and government partners far outweigh university partners in participation. Lower levels of participation from universities in clean diesel R&D or concentration on a small number of active universities (e.g. West Virginia University) may be keeping academics outside of the formal partnership networks. Regulatory agencies balance many sources of knowledge about technology development; the responses indicate that they may not weigh partnerships as heavily as other sources. This point will be discussed more thoroughly later in the chapter.

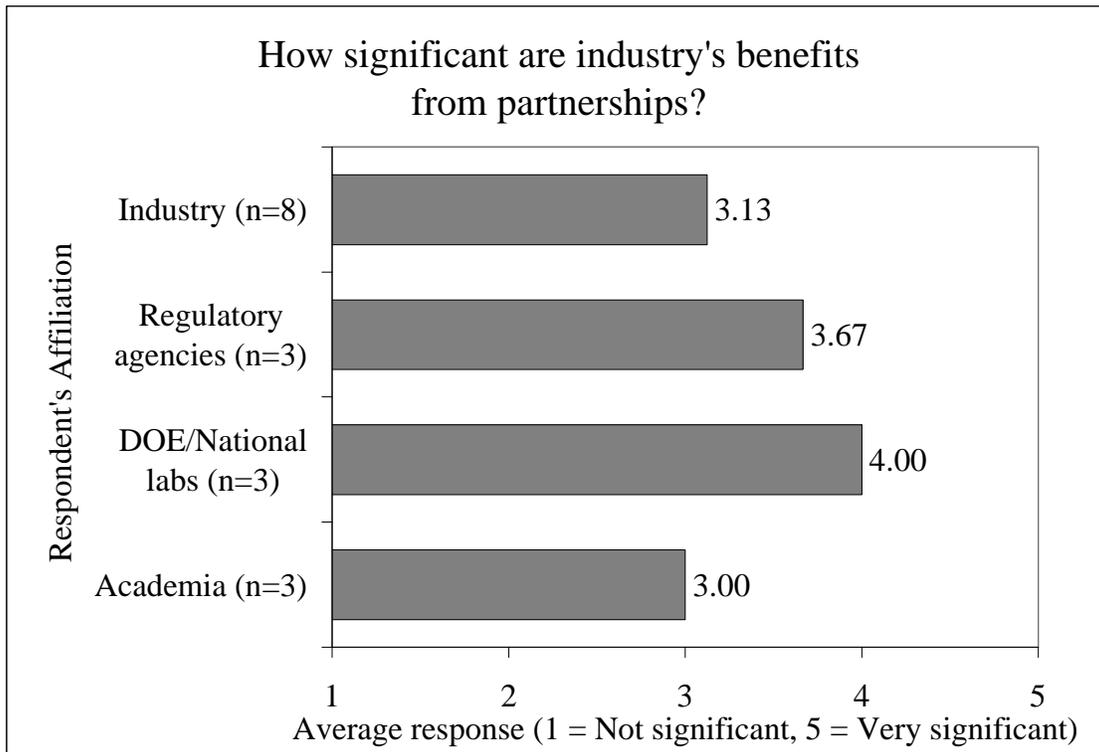
For the second question, all of the respondents perceived that industry had some benefits from partnerships, but the responses varied considerably. This is surprising, given public-private partnerships' emphasis on helping industry meet emission standards. Again, the significance of the benefits may be tempered by industry's reliance on internal R&D, which is more likely to give them a competitive advantage than pre-competitive collaborative R&D.

**Figure 13: Industry's Benefits (by Response)**



When the responses are grouped by affiliation, all the groups view industry's benefits as at least somewhat significant, with the DOE/national labs and regulatory agencies being the most optimistic. Industry generally views its benefits as lower than other groups would believe.

**Figure 14: Industry's Benefits (by Affiliation)**



As discussed in Chapter 5, partnerships may often be a check or confirmation of in-house R&D, from which industry may derive more benefit, in terms of cutting-edge technology and competitive advantage. That DOE and its national labs would place a higher significance in industry's benefits is not surprising, given their leadership and organization of many public-private partnerships. As mentioned in Chapter 4, DOE's OHVT had three major rationales for its support of public-private partnerships. Interest in helping industry is behind two of those three major rationales: To enable coordination among industry actors that would otherwise not collaborate, and to help industry meet emissions requirements in a timely and cost-effective way (U.S. DOE 1997, 2000e).

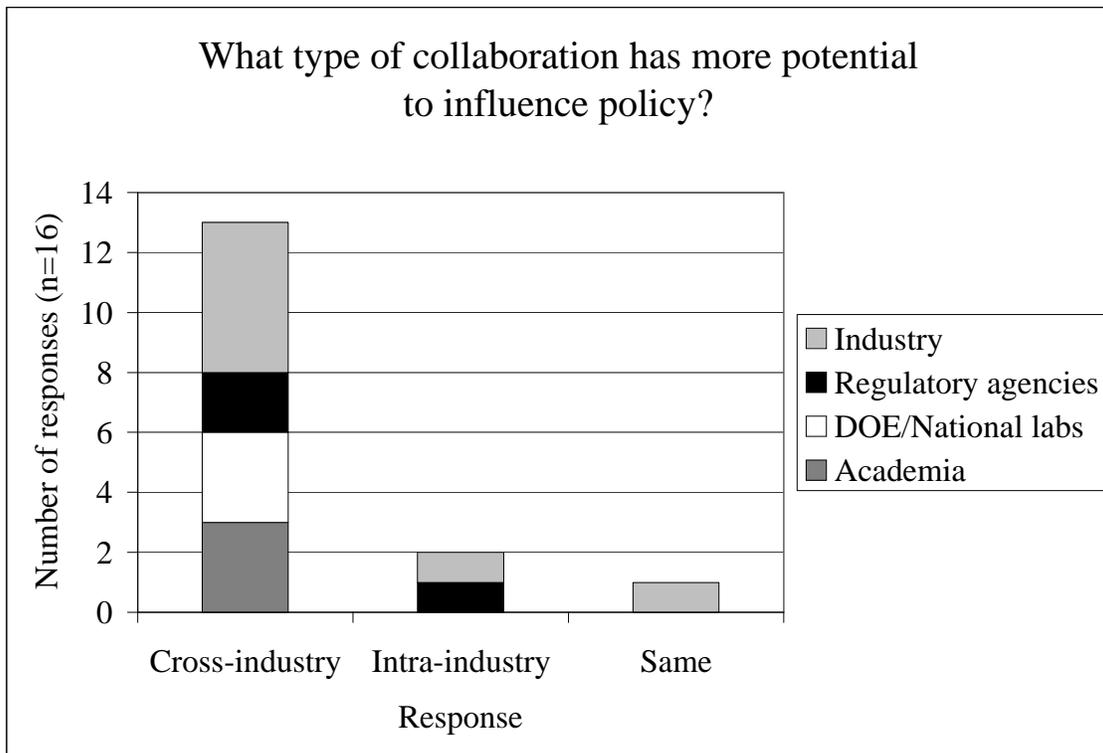
## ***Policy Influence of Partnerships***

The comparative case study demonstrated that some partnerships influence regulatory decision-making but that influence depends largely on the circumstances of the partnership and its regulatory environment. Based on the case study and the interviews, credibility and cross-industry collaboration were key reasons for participants, especially those in industry, to pursue R&D through partnerships rather than as an individual company or as a single industry. The remaining three questions in the questionnaire focused on partnerships' policy influence, which really reaches to the core of my research focus.

- Which type of collaboration has more potential to influence policy?
- Does doing research through a partnership increase the credibility of the results in the eyes of the regulators?
- How significant is the influence of partnerships on regulatory policy?

Because of the emphasis on cross-industry and cross-agency involvement in partnership membership, it was expected that cross-industry rather than intra-industry collaboration would have more potential to influence policy. The questionnaire responses, which are shown grouped by affiliation in the next figure, show that most respondents support this idea.

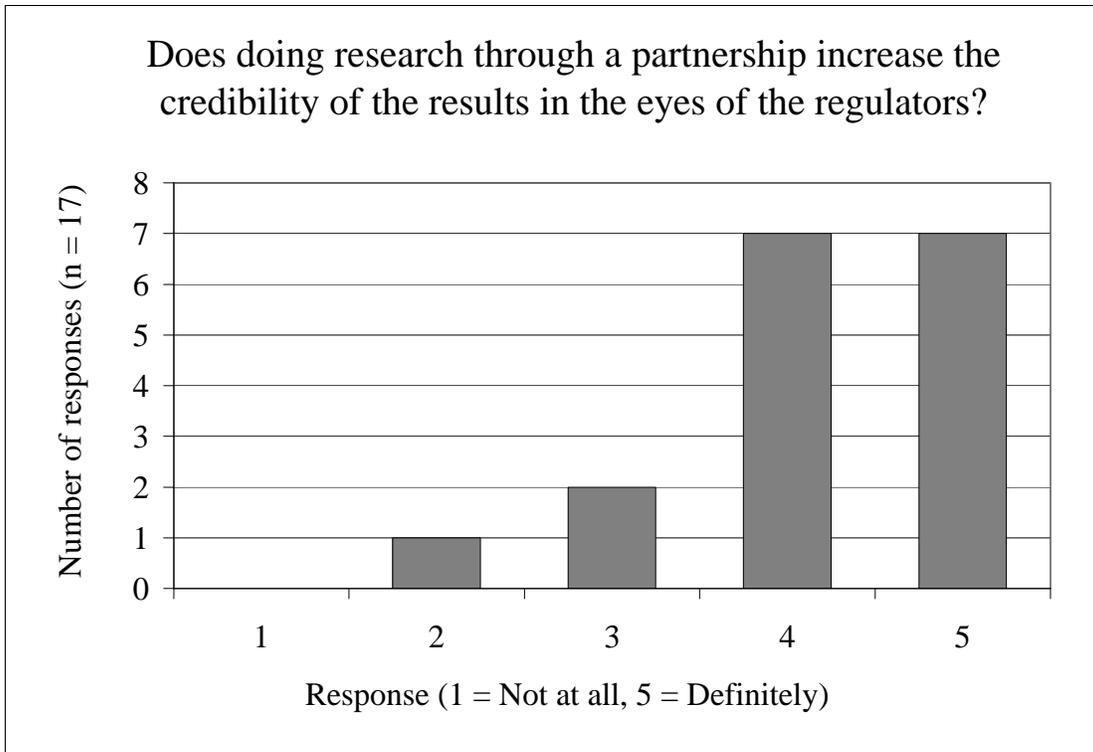
**Figure 15: Collaboration Type (By Affiliation)**



Gathering multiple industries with diverse expertise and points of view was seen to be effective in resolving conflicting technology assessments in the three case study partnerships. Collaborative R&D with publicly accessible results is perceived as more robust against accusations of single-company or single-industry bias.

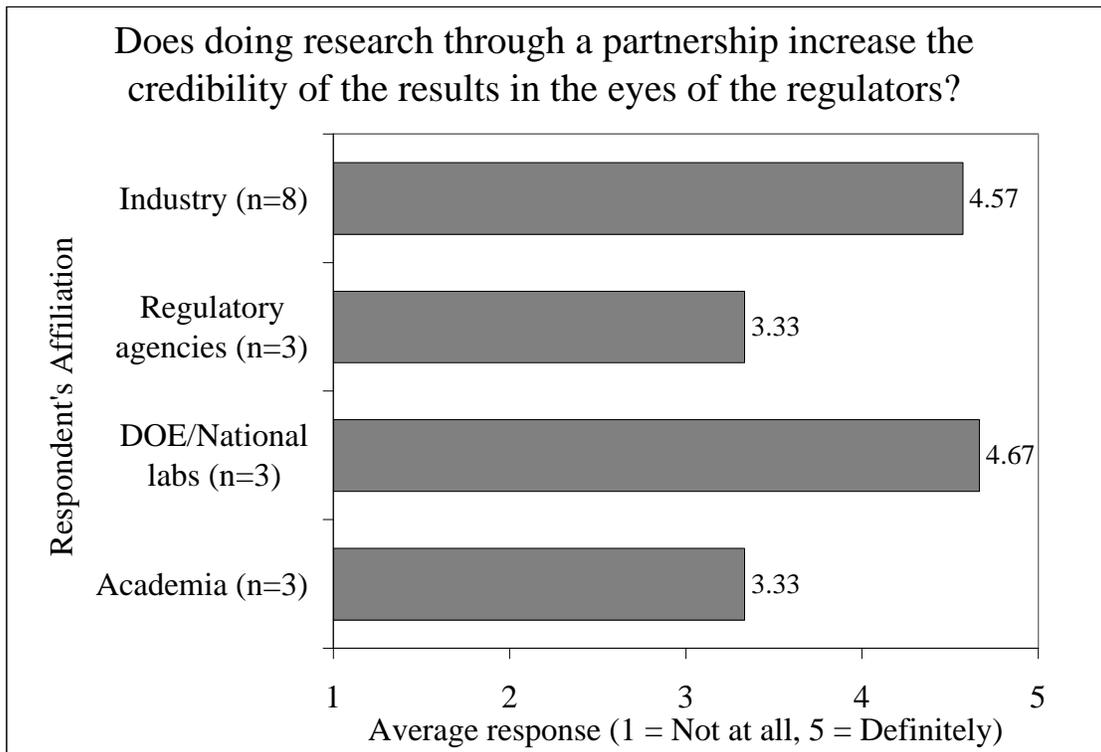
This leads to the next question of whether collaborative research is viewed more credibly by regulators. The responses reveal a commonly held perception that conducting research through partnerships significantly increases its credibility in the eyes of regulators.

**Figure 16: Credibility (by Response)**



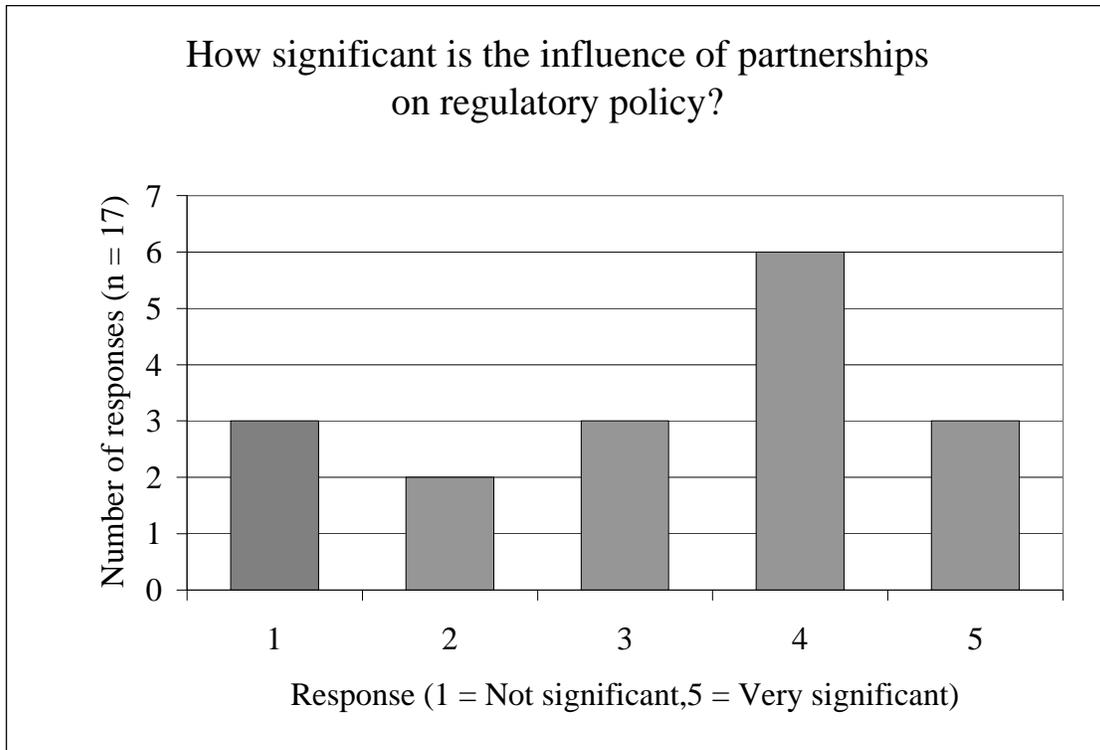
However, the intensity of the responses is largely dependent on organizational affiliation. Industry and DOE/national labs are the most convinced that partnership research is perceived more credibly by regulatory agencies. While responses from regulatory agencies and academia still seem to support the idea that partnership research increases credibility, they were less convinced than the other two groups. Regulatory agency staff and academia may feel that they are in a position to weigh whether a piece of information is credible. For reasons that will be explained later in this chapter, regulators may be reluctant to endorse partnerships as a means to enhance credibility and exert policy influence.

**Figure 17: Credibility (by Affiliation)**



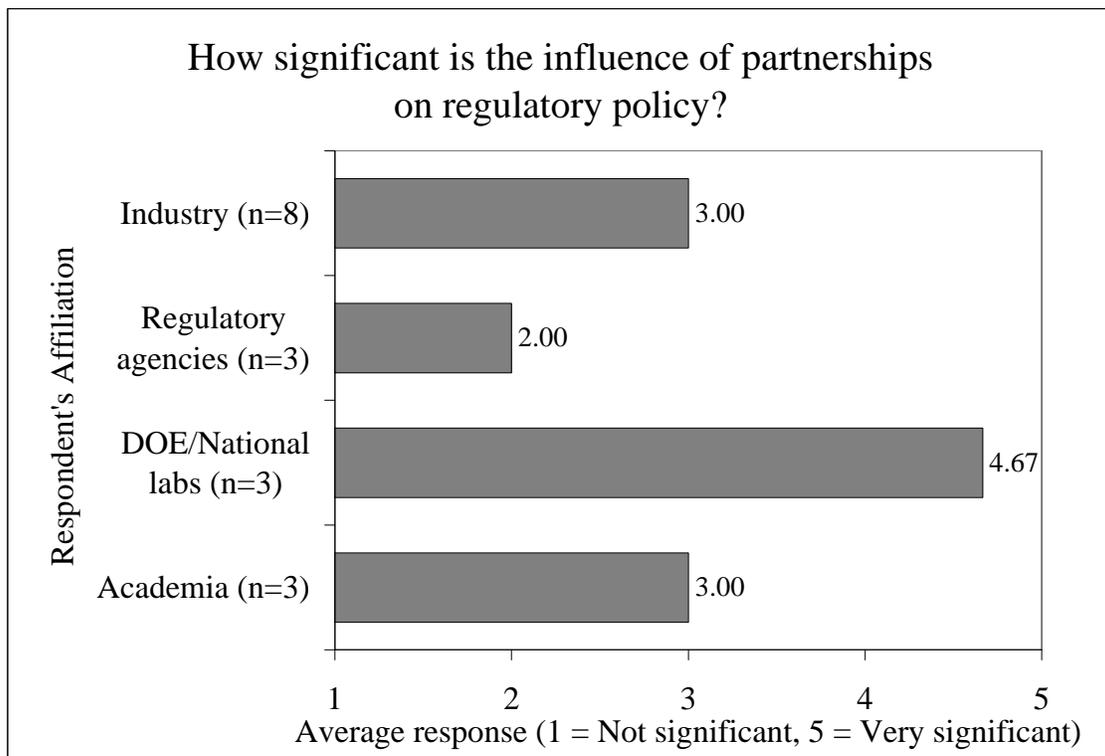
The question about the significance of partnerships on regulatory policy elicited the broadest range of responses of any question, with a slight leaning towards partnerships' influence on regulatory policy as significant.

**Figure 18: Policy Influence (By Response)**



Once the responses were categorized by organizational affiliation, the results were quite striking. Of all the groups, DOE and its national labs believe most strongly that partnerships have significant influence on regulatory policy. Their attitude on policy influence resembles their positive appraisal of industry’s benefits from partnerships. Earlier in this chapter, two of DOE’s rationales for heavy-duty vehicle research partnerships illuminated DOE’s optimism in industry’s benefits. Likewise, the third major rationale for DOE’s investment in public-private partnerships can illuminate the DOE/national lab response to this questionnaire response. That third rationale is to better inform standard-setting and policy-making by EPA and to improve coordination with other agencies (U.S. DOE 1997, 2000e).

**Figure 19: Policy Influence (by Affiliation)**



According to the questionnaire responses, industry and academia take a neutral view of partnerships’ policy influence. However, in interviews with industry professionals and academics, their anecdotal references to past partnerships suggest that some partnerships have

substantial policy influence while some have virtually none. The “neutrality” of the responses may result more from an aggregation of a range of experiences than a broad assessment of somewhat significant influence across many partnerships.

Perhaps the most significant finding from this questionnaire, when considered in conjunction with interviews, is that regulators do not place much significance in the influence of partnerships on regulatory policy. Of all the groups, they have the lowest average response: 2.0 out of 5. Interviews with regulators generally support this result. Understanding the reasons behind the different responses in this policy influence question is central to understanding the limitations of partnerships in influencing policy. The rest of this chapter explores this issue further.

### ***Limitations on Policy Influence***

An understanding of regulatory decision-making and insights from the comparative case study and interviews with regulators may help to put the responses to the policy influence question into context. They may explain the reasons behind the variations among the various groups’ responses.

Regulators feel that partnerships have less influence on policy than people in industry, academia, and DOE/national labs think. Regulatory and technical contacts at EPA and CARB stressed in the interviews that public-private R&D partnerships have minimal influence on rulemaking. They saw the partnerships as having their main influence later in the course of events, during technology development or operations. The general sentiment was that partnerships typically did not pursue the latest technologies, and therefore were less likely to inform regulations that are based on making projections about future technological progress. Industry may overestimate the influence that industry-government partnerships have on regulations.

The actual circumstances of the partnerships show that partnerships do matter in policymaking. The comparative study of DECSE, APBF-DEC, and EC-Diesel demonstrated that DECSE and EC-Diesel provided data useful to rulemaking. Both were cited in EPA’s Regulatory Impact Analysis for the diesel sulfur rule. DECSE data showed that EPA’s proposed

diesel engine emission standards could only be met with sulfur levels below 15 ppm; the previous level of 30 ppm favored by EPA was not low enough. After the final rule was passed, EPA used DECSE results to defend its rulemaking when some industry associations and companies took EPA to court. Partnerships did matter more in the later phases of the regulatory process, since DECSE did not gain momentum until industry and DOE became aware that EPA was contemplating fuel sulfur regulations. EC-Diesel was more of a reaction to CARB's designation of diesel particulate matter as a toxic air contaminant, but it did influence how CARB sought to implement its Diesel Risk Reduction Plan. For example, would CARB steer municipalities and businesses towards an alternative-fuel path or leave the door open for diesel-fueled vehicle fleets? The substantial PM emission reductions possible by using engine retrofits and ultra-low sulfur fuel made the case for not shrinking the market for diesel engines and diesel fuel.

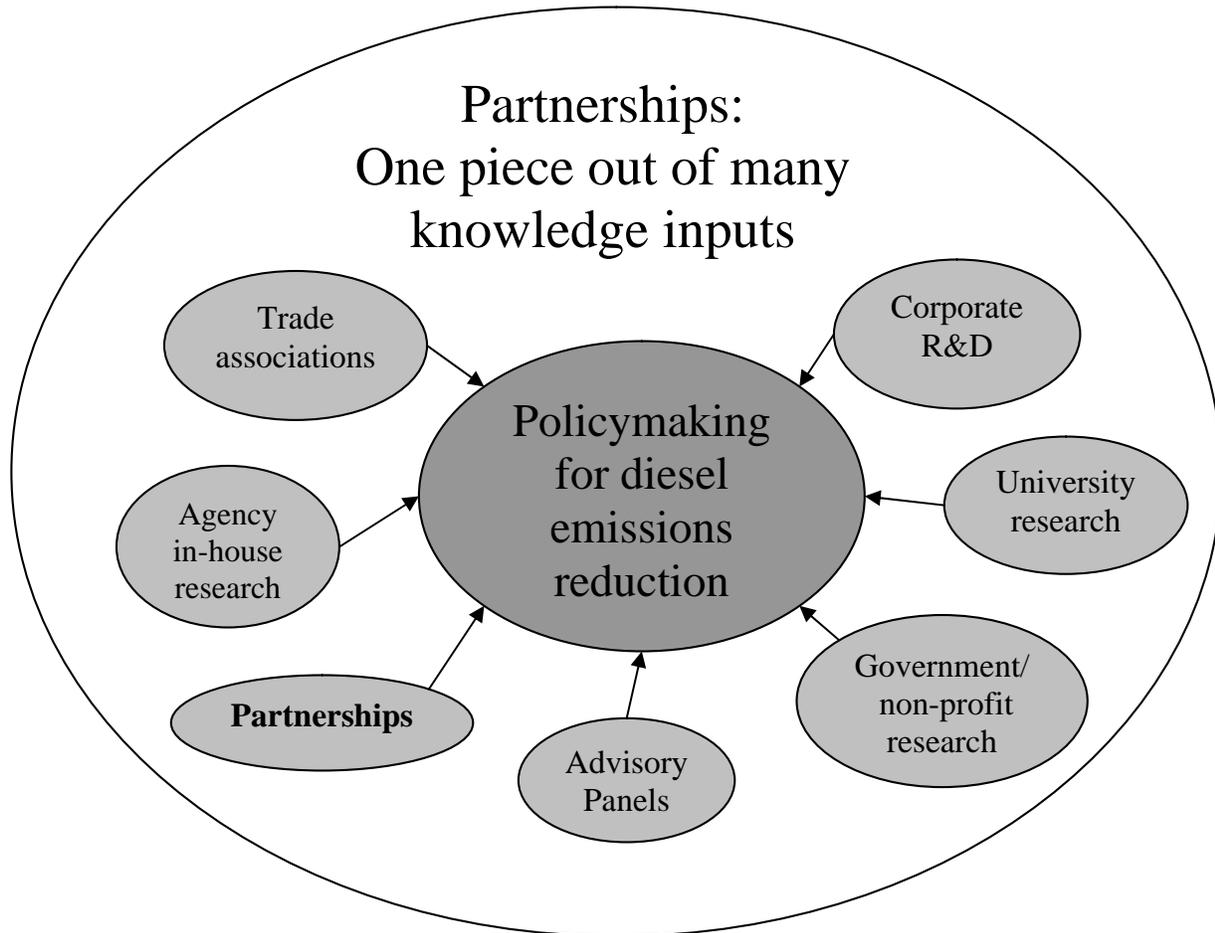
A central question posed by this thesis is whether conducting research through a partnership would allow knowledge-sharing across organizational and functional levels. While partnerships have facilitated sharing at the technical levels among different organizations – private companies in different industries, national labs, regulatory agencies, and academia – there are limits to sharing across the boundary between technology and policymaking. EPA draws a distinction between its technical activities and its regulatory activities. At the beginning, the industry participants in 21<sup>st</sup> Century Truck, the overarching DOE heavy vehicle partnership that now includes APBF-DEC, may have thought that the partnership was a way to influence the EPA to back off the 2007 heavy-duty emissions rule. However, to maintain its credibility and independence, EPA intentionally creates a firewall between its regulatory and research arms. EPA keeps its research personnel separate from its policy-making personnel.<sup>22</sup> Regulatory activities are conducted independently from technical activities. A company technologist would have difficulty transferring knowledge to a policymaker through a regulatory agency's technologist. This poses a barrier to the reach of knowledge networks, but it may be necessary for EPA to make sure that its regulations are driving industry R&D and not the other way around. Some level of separation is necessary such that EPA is not too close to the companies that it is regulating.

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<sup>22</sup> Based on an interview with the Senior Policy Advisor, Office of Transportation and Air Quality, U.S. Environmental Protection Agency, January 2003.

Instead, EPA relies on an assortment of technical knowledge inputs on which to base its policymaking decisions. Partnerships just make up one piece of the total picture.

**Figure 20: Knowledge Inputs to Policymaking**



Based on interviews with both regulators and industry representatives, regulators put a lot of weight into in-house research and private company information compared to some of the other inputs. According to regulators at EPA and CARB, the agencies base emission standards on their own internal research. Regulators emphasized the importance of having their own labs to independently validate manufacturers' claims rather than relying solely on data supplied by manufacturers. It may be difficult to get a clear picture of industry's capability to meet regulations if industry does not invest in further emission control technology development until regulations are promulgated.

Regulators meet with individual companies one-on-one, where confidential information is often discussed. Most of these meetings are EPA-initiated when EPA wants to assess industry's progress toward upcoming regulations. Sometimes companies individually approach EPA with an idea for meeting regulations and request feedback from EPA. Companies with superior technology may support stricter regulations and inform EPA of their ability to exceed existing standards. This type of knowledge-sharing is very different from sharing in partnerships, which is transparent and non-proprietary. Since EPA often promulgates technology-forcing regulations, it must query companies about their most advanced technology, which is usually proprietary, and not shared in partnerships. As many in industry and academia have also asserted, pre-competitive public-private R&D partnerships are not perceived as cutting-edge because they focus on generic and enabling technologies rather than near-market, commercializable technologies (Quintas and Guy 1995, Chen 1997). Anything that is very advanced would confer competitive advantage to a single company interested in keeping its technology confidential.

Companies often mobilize as a group based on their collective interest in regulatory action. This collective action is usually organized through a trade organization. For example, emission control manufacturers have a vested interest in tighter regulations because they can sell more products. They are eager to showcase the performance of their advanced technologies, and may provide information to regulators about their technologies prior to a proposed rulemaking. The information may give regulators confidence to pursue stricter regulations, knowing that specific companies have the technological capability of meeting them. Knowing that EPA and CARB tend to base regulations on the most advanced technologies, other parts of the industry – engine and vehicle manufacturers, especially – are skeptical of the emission control industry's optimistic claims. Cross-industry partnerships may provide a more transparent and credible means to test these claims, but the technologies chosen for testing may not be representative of the ground-breaking research happening in a company's private R&D laboratory. As part of their regulatory responsibilities, they visit company laboratories and collect company-specific data. Regulatory agencies also use their in-house testing facilities to check industry's claims.

Many of those interviewed, from government and from industry, felt that it is important that regulators find people that they trust in industry representing different sides of any given issue. Regulators can then assess the situation for themselves, recognizing each side's inherent

bias. From CARB's perspective, much of the information about current or future technologies comes from CARB's close relationships with individual companies, which go beyond consortia or partnerships.<sup>23</sup> This mechanism of obtaining knowledge depends on fostering informal relationships based on long-term familiarity and trust. It is evidence of the necessity of knowledge networks that connect organizations as well as individuals. One interviewee from a domestic auto company representative emphasized the importance of common views and trust in his building his own informal network. Once he finds people with whom he agrees, together they can build coalitions with a few people at different organizations, including those from the auto industry, oil industry, regulatory agencies, and environmental groups. These informal networks may allow these people to be more open about their different perspectives; much of the dialogue is based on trust.

Another reason for regulators' wariness of using partnerships as a basis for regulatory decisions is that the collaborative activities may slow down progress. While bringing in all the interested parties increases the perceived credibility and fairness of the partnership, the sheer number and diversity of participants makes consensus and decision-making more complex and time-consuming. Some companies or industries may participate merely to keep an eye on competitors or other industries. Others may participate in public-private partnerships to prevent others from unduly influencing government. Industry may use data generated in a partnership to criticize an upcoming regulation on the grounds of infeasibility, and argue that the broad-based, cross-industry nature of their results justifies their claim.

Partnerships among mostly American firms may have the unintended effect of making the participants complacent and inspiring outsiders to be more technologically aggressive. Collaboration may decrease competitive pressures to innovate because the companies involved can keep track of their competitors' progress (Link and Scott 2001). The Partnership for a New Generation of Vehicles (PNGV) was a 1990s automotive partnership among the three U.S. automakers, Ford, GM, and Chrysler (now DaimlerChrysler). While the three companies were still working on prototypes for 80-mpg diesel-powered passenger cars, Honda and Toyota introduced smaller, hybrid-electric vehicles to the marketplace (TRB 2001). Arguably, Honda and Toyota's exclusion from PNGV placed pressure for them to work harder to innovate.

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<sup>23</sup> Based on an interview with the Mobile Source Division Chief, California Air Resources Board, January 2003.

Even if regulators' consideration of partnerships is less than DOE or industry assumes, the questionnaire results indicate that regulatory agencies do believe that collaborative research is more credible than research performed by a single company or a single industry. However, the consensus and transparency necessary for a partnership will usually require some sacrifice of the cutting-edge technical knowledge and broad scope that are needed for regulatory decision-making.

## **CHAPTER 7: IMPLICATIONS – PAST, PRESENT, AND FUTURE**

The main objective of this research was to determine the role of public-private clean diesel R&D partnerships in the U.S. regulatory process. This meant answering a series of related questions – Do partnerships have a role? If so, what is that role? Under what conditions do partnerships influence the regulatory process?

The comparative case study of three partnerships, interviews with representatives from industry, government, and academia, and the follow-up partnership questionnaire revealed that public-private partnerships do have an influential role in the regulatory process. However, that role is limited by the circumstances of each partnership and regulators' preference to rely more on other sources of knowledge for technical input. The following sections apply the lessons learned about the mechanisms and conditions for policy influence to past, present, and future R&D partnerships.

### ***Mechanisms of Policy Influence***

There are various mechanisms in which partnerships may have a role in the regulatory process. The most direct and transparent way is the provision of technically sound and relevant data for specific regulations. DECSE was the best example of this, because its results were used to support the EPA's diesel fuel sulfur standard of 15 ppm. DECSE played a role in several phases of the sulfur rule, during the rulemaking, public comment period, and court challenges.

Less direct but as relevant is partnerships' influence on industry's technological progress. Although partnerships are not necessarily technologically cutting-edge, they can help regulators assess the current or near-term state of the technology in a transparent way. Since their other knowledge sources are often confidential information held by individual companies, the industry as a whole has difficulty evaluating the various technology claims. Regulators routinely rely on technology assessments to gage whether industry is progressing satisfactorily towards an

upcoming rule or whether industry is capable of achieving an even higher standard. On the other hand, partnerships may be perceived as a way to discourage further regulation, or to even demonstrate technical infeasibility of regulations, two reasons why regulators may be skeptical of partnership results.

The flow of knowledge through networks of personal relationships is an indirect way that partnerships can influence the regulatory process. The organizational structure of partnerships creates formal knowledge networks to facilitate the flow of communication during the projects. These formal networks often formalize existing informal relationships and prior collaboration. They create or enhance informal knowledge networks among industry and government participants. These networks tend to be partitioned based on people's functional roles – managers and policymakers communicate with each other, and technologists and researchers communicate amongst themselves. Many of these findings affirm the theoretical literature on knowledge networks.

While industry has mechanisms in place to facilitate the flow of technical knowledge up through their organizations, (i.e. conferences, R&D management, internal reporting), regulatory agencies purposely create boundaries between their technical staff and regulatory staff, most likely to prevent undue influence by industry. Accounts differ about how much is transmitted from technical staff to the regulatory staff, typically with industry more optimistic about the knowledge flow. However, since regulators meet with individual companies one-on-one, partnership-initiated knowledge networks among organizations can still help to build trust and familiarity among individuals, which carry over to regulatory settings.

Finally, formal partnerships can lead to additional formal and informal partnerships and relationships based on the success and trust already cultivated. Not all subsequent partnerships have the potential to influence policy, but as mentioned earlier, even contributions to technology development have a large influence on regulators' technology assessments and attitudes toward future regulations.

## *Conditions for Policy Influence*

Even though the comparative case study was a limited, in-depth study of three partnerships and not an exhaustive study of all past and existing diesel partnerships, three conditions emerged as critical if partnerships are to influence regulatory policy.

### **Condition 1. Clear understanding of upcoming regulations and the ability to incorporate regulatory considerations in program design.**

All three partnerships studied had the intention of influencing policy in some way. Participants had to anticipate regulatory changes prior to rulemaking to have the most impact (e.g. DECSE), but recognizing the implications of policy changes on implementation (e.g. EC-Diesel) could also position a partnership to influence policy. Trade associations and company environmental/regulatory staff play a crucial role in keeping track of regulatory developments. Informal workshops with EPA, CARB, and other environmental regulatory agencies can be a good forum for communication between regulators and companies. Trade association meetings, technical conferences, and DOE workshops to which regulators are invited also can give an opportunity for regulators to explain where regulations may be headed. Such regulatory foresight affects the program design and timing. Partnerships require more time to set up than internal R&D projects because of the multi-industry, multi-agency cooperation required. Sometimes this requires sacrificing a broad scope or an ambitious research agenda to target a narrow list of issues relevant to rulemaking. Meanwhile, partnerships which time their results after regulations are already set and lack a clear plan for influencing future regulations have a diminished policy influence.

### **Condition 2. Inclusion of all relevant industry and government stakeholders, with special attention to involving the appropriate regulatory agency or agencies.**

Since diesel emissions reduction requires a systems approach to fuels, engines, and emission control equipment, the corresponding industries must be involved in the R&D partnerships, both to provide their unique technical expertise and to lend credibility to the work. Partnerships can be used to resolve discrepancies or gaps in earlier research. Leaving out

important groups can easily lead to resentment, especially if the implications of program results are a subject of debate. Teaming with DOE and its national labs provided the partnerships with additional funding, organizational structure, and facilities. DOE is the primary government agency to which industry turns for technical and financial support. Participation from universities and independent test labs also provided testament to the scientific rigor and accountability of the work. Although regulatory agencies are cautious of being too involved in industry R&D, their input early on in the program design can help to improve the program's applicability to regulatory decision-making. Cross-industry and cross-agency participation also widens the formal knowledge network of the partnership, which can lead to more dialogue and collaboration even after a partnership ends. Technologists, regardless of their organizational affiliation, tend to be very open in their communication to each other, so their relationships have the potential to improve the relationships between their respective organizations.

### **Condition 3. Public accessibility and dissemination of program results.**

A partnership that produces timely results, in the forms of reports, technical papers, and conference presentations, offers tangible evidence of a program's progress. Regulatory agencies can keep an eye on the partnership, and use the publicly available results as a technical basis for rulemaking. The public accessibility of interim and final results allows the stakeholders to debate the technical issues out in the open, rather than guessing about confidentially held information. Frequent progress reports and rapid turnover of results help keep the information fresh. Since partnership results are made public, there is less likelihood that they include cutting-edge technology, which usually remains proprietary to each company. However, the comparative case study demonstrated that partnerships do not necessarily have to further technology development in order to influence the regulatory process.

### ***Illuminating Past Partnerships***

These conclusions can help explain the outcome of past partnerships that were not the focus of this study, but involved many of the same participants. They reveal the importance of

fulfilling the three conditions discussed earlier, and also help to illustrate how knowledge is transferred to enable policy influence.

In 1997, DOE launched a light-duty truck program in which Caterpillar, Cummins, and Detroit Diesel, three heavy-duty engine manufacturers, partnered with the U.S. auto companies, Ford, GM, and Chrysler (now DaimlerChrysler) to develop prototype light-duty diesel engines that could be used in light-duty trucks, vans, and SUVs. The program goal was to increase the fuel economy of this class of vehicles by 50% over the 1997 gasoline powered light-truck vehicles. The main challenge was to meet the future Tier 2 Bin 5 emission regulations at the same time.<sup>24</sup> In the absence of formally established emission standards, participants had to estimate future 2004 Tier 2 regulations. The original target emission goals were set at 0.5 g/mi NO<sub>x</sub> and 0.05 g/mi particulate matter (PM) over the federal transient emissions cycle (Miller et al. 1999). This became the target for the program. When EPA announced the upcoming 2004 regulations in 1999, the Tier 2 Bin 5 standards for NO<sub>x</sub> and PM were far more stringent than the industry had expected: 0.07 g/mi for NO<sub>x</sub> and 0.01 g/mi for PM. These Tier 2 standards made it very difficult for the program to meet its goals. The absence of EPA as a formal participant or at least as an advisor to this development project may help to explain why industry received such a regulatory surprise. Even though this light-duty truck program did not set out to influence policy, the need for a clear understanding of upcoming regulations (Condition 1) and involvement of the appropriate regulatory agency, i.e. EPA, applies to this program as well (Condition 2).

The Partnership for a New Generation of Vehicles began in 1993 under the Clinton Administration. It was a partnership among the USCAR (a consortium consisting of GM, Ford, and Chrysler), 7 federal agencies, and 19 federal labs. The goal was to develop technology to produce passenger cars three times more fuel efficient than the cars of that time, while still achieving low emissions, affordability, performance, and safety (TRB 2001). Although PNGV has been criticized heavily because its 80 mpg prototypes never reached the marketplace, of particular relevance to this research are the knowledge networks established by PNGV. PNGV provided a formal means for industry to exchange information. Because of the U.S. auto

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<sup>24</sup> In regulating passenger vehicle emissions, EPA certifies vehicles under any one of 8 certification “bins” but the average emissions across a manufacturer’s entire vehicle fleet must meet the Tier 2 Bin 5 standard.

industry's tight network, people already share information on an informal basis. Providing an organizational structure makes knowledge transfer more efficient and establishes guidelines for protecting proprietary knowledge. In the case of PNGV, the partnership operates as a formalization of organizational ties that are rooted in pre-existing informal personal ties.

The Coordinating Research Council's Auto/Oil Air Quality Improvement Research Program was a joint research program conducted by automobile manufacturers and oil companies in the 1990s. The program sought to quantify the emission impacts of changes in the quality of gasoline. According to a representative from a domestic automaker who had been involved in the Auto/Oil program, it had substantial influence on policymaking and improved dialogue between technologists and policymakers. A combination of the three conditions that have been previously discussed led to the Auto/Oil program's prominent role in the regulatory process. Auto/oil was specifically targeted to provide technical input to EPA and CARB's anticipated reformulated gasoline (RFG) rules, which would require cleaner-burning gasoline. Participants were aware of the regulatory environment in which their program was situated, allowing them to provide the regulatory agencies with results relevant to the RFG rule (Condition 1). The cooperation among the auto companies and oil companies, and input from regulators, broadened the diversity of expertise and increased credibility (Condition 2). Throughout the 1990s, dozens of reports were issued through the Coordinating Research Council, and many findings were published as SAE technical papers. EPA relied heavily on the publicly available results of the Auto/Oil studies in considering a variety of technical issues, ranging from fuel economy impacts to emission standards (Condition 3). According to EPA, "The results of the Auto/Oil program and numerous other studies conducted by EPA and industry revealed that large emission benefits were indeed possible and cost-effective through RFG. As a result, the emission standards for RFG in the year 2000 go beyond the minimum requirements specified in the Clean Air Act" (U.S. EPA 2003b).

## *An Uncertain Future*

In July 2002, the DOE Office of Energy Efficiency and Renewable Energy (EERE) restructured its vehicle R&D programs. It divided its activities into two overarching industry-government partnerships: FreedomCAR and the 21<sup>st</sup> Century Truck Initiative. Both programs are contained within the FreedomCAR and Vehicle Technologies Program. The activities of the Office of Heavy Vehicle Technologies are now part of this new program, so EC-Diesel and APBF-DEC became part of the FreedomCAR and Vehicle Technologies Program in 2002.

FreedomCAR and the 21<sup>st</sup> Century Truck Initiative are very different from the three partnerships studied in the comparative case study. They are umbrella partnerships that include individual R&D partnerships and projects. However, many of the conclusions drawn from the case study and questionnaire apply to how these umbrella partnerships may unfold.

The 21<sup>st</sup> Century Truck Initiative's struggle to identify long-term stretch goals reflects the tension between short-term and long-term interests. The government prefers to invest in long-term goals since it is expected that industry should invest in short-term goals on their own. However, R&D that has a strong potential for policy influence tends to more focused and short-term. APBF-DEC strived to be long-term by having a 10-year plan, but many of its projects are investigating issues more relevant to meeting the 2007 regulations than influencing post-2010 policy. In the same way, the 21<sup>st</sup> Century Truck Initiative had an ambitious 10-year roadmap (2000-10), but industry participants were hesitant to commit to the initial "2-times and 3-times goals": Doubling fuel efficiency for large trucks and tripling fuel efficiency for buses and small/medium trucks. By the time the partnership was re-announced by the Bush administration in 2002, there was no mention of the 2-times and 3-times goals, because industry was concerned they could get locked into these stretch goals.

On the positive side, 21<sup>st</sup> Century Truck has expanded the knowledge networks beyond the industries that are traditionally involved in heavy-duty vehicle R&D. When it comes to large trucks, DOE predominantly partners with engine manufacturers, catalyst manufacturers, and energy/oil suppliers. Seldom are downstream companies like truck and bus manufacturers and their suppliers included in the R&D partnerships. In expanding this knowledge network, 21<sup>st</sup>

Century Truck has brought together some industry members who had never really worked together to talk about trucks. 21<sup>st</sup> Century Truck has helped the participants gain understanding about each other as well as the various federal agencies involved. All the partnership work leading up to 21<sup>st</sup> Century Truck made it easier for EPA to start SmartWay Transport, a voluntary partnership announced in 2003 that will showcase fuel-efficient, low emissions trucks.<sup>25</sup> Many organizations that participated in 21<sup>st</sup> Century Truck are also participants in SmartWay Transport. In other words, the formal knowledge networks established by 21<sup>st</sup> Century Truck fostered informal knowledge networks, which in turn, facilitated another set of formal networks through SmartWay Transport.

FreedomCAR is the Bush administration's update on the Partnership for a New Generation of Vehicles (PNGV). Whereas PNGV focused on diesel-powered passenger cars, FreedomCAR will focus on hydrogen-powered fuel cell cars and trucks. FreedomCAR will dramatically change the nature of the knowledge networks that were formed under PNGV, because of its choice of technology. However, many of those personnel in government who had worked on petroleum-based research partnerships have been transferred to work on FreedomCAR after the 2002 EERE restructuring. The former Director of Heavy Duty Vehicle Technologies is now the Chief Scientist on FreedomCAR, and the former DECSE/APBF-DEC Program Director is now the Technology Manager of Hydrogen, Fuel Cells & Infrastructure Technologies at NREL. The preservation of these DOE staff in working relationships will provide continuity, but FreedomCAR will have the challenge of creating a new set of networks, because many of the companies with fuel cell technology are not the same ones with internal combustion engine technology. At the same time that \$91.1 million was requested for FreedomCAR in FY2004, a 22% increase from FY2003, \$57.5 million was requested for 21<sup>st</sup> Century Truck, an 18% decrease from FY2003 (U.S. DOE 2003b). Meanwhile, the FY2004 budget for DOE's Advanced Petroleum Based Fuels research dropped from \$8.2 million to \$0, and research funding for Combustion and Emission Control research was cut by almost 40% (U.S. DOE 2003d). This indicates a definite shift in the administration's priorities, with hydrogen and fuel cell technology taking precedence. It also highlights the problems of conducting long-term research projects that are subject to annual budget fluctuations.

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<sup>25</sup> Based on an interview with the Senior Policy Advisor, Office of Transportation and Air Quality, U.S. Environmental Protection Agency, January 2003.

The Health Effects Institute (HEI), an independent non-profit funded jointly by the EPA and the motor vehicle industry, funds research on the health effects of motor vehicle emissions and other environmental pollutants. HEI reviews reports from that research and publishes them with a Commentary by its Health Review Committee, which discusses the strengths and limitations of the research and its implications for human health effects. Although HEI has taken a broader role in air pollution research, it was formed to address issues related to assessing the potential adverse health effects of new motor vehicle technologies. To improve its ability to forecast use of new technologies and fuels, in 2000 HEI's Board of Directors established the Special Committee on Emerging Technologies (SCET). Comprised of emissions and policy experts from industry, academics, and government, SCET advises HEI on the timing and likelihood of use of new technologies and fuels, and their potential negative and positive health and environmental impacts. This includes evaluating whether emissions from use of new technologies or fuels, while improved in some respects, may contain new toxic substances that may cause adverse health effects. SCET communicates concerns about toxic substances to the HEI Health Research Committee, which considers addressing these issues in the HEI research program. According to the Director of Science at the Health Effects Institute, in the past industry has been reluctant to consult health effects researchers about future technologies, but it is definitely a growing trend, especially with the rapid changes in diesel technologies to meet PM and NO<sub>x</sub> standards.<sup>26</sup>

The struggle between short-term and long-term goals, the restructuring of DOE's vehicle R&D, and the growing role of downstream companies and health effects researchers in knowledge networks leave the future of clean diesel R&D open for dynamic change. DOE's de-emphasis of heavy-duty R&D and clean diesel R&D, largely driven by the current administration, may make it more difficult for industry and government to partner on clean diesel programs that will have bearing on regulatory policy.

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<sup>26</sup> Based on an interview with the Director of Science, Health Effects Institute, January 2003.

## ***Further Research***

The research findings prompted more questions that would be worthwhile to pursue. This research focused exclusively on the U.S. regulatory system, so it would be interesting to compare the roles of partnerships in other countries and regions, such as Japan or the European Union. Technological synergies between the light-duty auto sector and the heavy-duty truck and bus sector result in a lot of overlap in R&D personnel and projects. There could be some parallels between the two sectors' approach towards the impact of R&D on their regulatory environments.

The role of trade associations turned out to be much larger than expected at the outset of the research. Many industry interviewees rely on their respective industry associations for technical information, opportunities to discuss regulations, and general camaraderie. Those in DOE and its national labs often contacted the trade associations first when inviting industry to a conference or workshop. Studying the networks created and strengthened by trade associations would be helpful in understanding how those outside the industry (i.e. regulators, researchers) could better communicate to industry.

Additional research may shed light on how public-private partnerships differ from corporate R&D in terms of policy influence. When it comes to technology development, public-private partnerships usually provide a check or complement to in-house R&D, but public-private partnerships are perceived as more credible. Do some companies have a better reputation for being very frank to regulators about their R&D progress? And even more broadly, multiple inputs could be evaluated for their policy influence. As mentioned in the previous chapter, regulators rely on multiple sources of technical information, ranging from advisory panels to agency laboratories.

Based on interviews with both regulators and industry representatives, the proprietary and competitive interests of individual firms limit the extent to which partnerships advance cutting-edge technology. When regulators want to assess the state of the latest technologies, they tend to rely more on private company information than publicly available partnership results. Further research could consider another type of public-private partnership, one that is substantially

different from the types investigated in this research. Instead of broad-based industry-government partnerships that elevate the position of all firms within an industry, an alternative type of partnership would create an alliance among “environmental first-mover” companies, regulators, and environmental groups. It would work alongside the naturally competitive nature of firms, and yet do so in the interest of improving human health and the environment. This strategy would coincide with the growing trend of firms seeking competitive regulatory strategies that seek private and public benefits in moving beyond compliance.

## ***Conclusion***

R&D is generally perceived as being driven by regulation, but this research demonstrates that in the case of public-private clean diesel R&D partnerships, R&D can also play a meaningful role in influencing the regulatory process. Depending on a variety of conditions, such as program design, relevance, timing, membership, knowledge networks, and final outcome, partnerships may significantly contribute to informing policy and improving communication among industry and government participants.

## APPENDIX

### *Commonly Used Acronyms*

APBF-DEC	Advanced Petroleum-Based Fuels – Diesel Emission Control
API	American Petroleum Institute
CARB	California Air Resources Board
CDPF	Catalyzed diesel particulate filter
DECSE	Diesel Emission Control – Sulfur Effects
DOC	Diesel oxidation catalyst
DOE	Department of Energy
DPF	Diesel particulate filter
EERE	Energy Efficiency and Renewable Energy
EMA	Engine Manufacturers Association
EPA	Environmental Protection Agency
FTP	Federal Test Procedure
g/bhp-hr	Grams per brake horsepower-hour
g/mi	Grams per mile
HD	Heavy-duty
HEI	Health Effects Institute
LD	Light-duty
MECA	Manufacturers of Emission Controls Association
NO <sub>x</sub>	Nitrogen oxides

NPRA	National Petrochemical Refiners Association
NREL	National Renewable Energy Laboratory
OHVT	Office of Heavy Vehicle Technologies
ORNL	Oak Ridge National Laboratory
OTT	Office of Transportation Technologies
PM	Particulate matter
PM10	Coarse particulate matter less than 10 microns
PM2.5	Fine particulate matter less than 2.5 microns
ppm	Parts per million
RIA	Regulatory Impact Analysis
SCAQMD	South Coast Air Quality Management District
SCR	Selective catalytic reduction
SwRI	Southwest Research Institute
WVU	West Virginia University

## *Sample List of Interview Questions*

This list is not an exhaustive pool of questions but it is representative of the types of questions asked of the interviewees. Different questions were asked based on each person's background and organizational affiliation.

The questions are grouped thematically:

### Regulatory Considerations

Has the knowledge generated from the partnerships been effective in better informing regulatory decision-making?

Is the potential to influence policymaking a major incentive for organizations to participate in public-private partnerships?

It seems very important for companies to get a sense of where regulations are headed before they are publicly announced. How do you keep track or monitor what regulators plan to do before an official advance notice is issued?

Before the partnership began, what did DOE know about EPA's intentions to regulate sulfur levels in diesel fuel?

How does the EPA determine how much weight to give its various sources of information in making regulatory decisions?

How was the progress of the project affected by the EPA's timelines for technical reviews and rulemakings?

What effect do EPA timelines have on the convergence towards specific technologies?

### Partnership R&D

How did the concept for the partnership begin?

At what point did your organization become interested in research on low sulfur diesel fuels?

How was it decided how much each trade association or company would contribute to the partnership?

What effect does collaborative research have on the convergence of the industry towards particular technologies?

Would the companies not included in the partnerships be at a disadvantage?

## Knowledge Networks

How has the partnership affected your interaction and familiarity with people in industry and government? How is this different from your interaction before the partnership's existence?

How has the partnership affected your organization's relationship with EPA? With DOE? With other companies? With other industries?

How well acquainted were you with people in the leadership roles prior to the program?

How do public-private partnerships affect your understanding of technologies? Of the regulatory process?

How do you keep informed about new technologies? About upcoming regulations?

Has the partnership been effective in improving dialogue between technologists and policymakers?

Through what mechanisms does knowledge at the R&D level get passed onto regulators?

When you want to learn more about a new technology or technical area, who do you usually contact?

How effective are technologists (engineers, scientists) in communicating technical information to policymakers?

## *Questionnaire*

[This was either sent by email or administered by phone.]

### Partnership Questionnaire

If there are any questions that you wish to skip, please leave the response blank. All the responses are on a scale from 1 to 5, except for question c.

Note: "Partnerships" refers to public-private partnerships in clean diesel R&D.

**1) How significant is the influence of partnerships on regulatory policy?**

1    2    3    4    5

(1 = Not significant; 5 = Very significant)

**2) How important are partnerships to your understanding of technology development?**

1    2    3    4    5

(1 = Not important; 5 = Very important)

**3) Which has more potential to influence policy, cross-industry collaborations or intra-industry collaborations?**

1. Cross-industry
2. Intra-industry
3. Same

**4) How significant are industry's benefits from partnerships?**

1    2    3    4    5

(1 = Not significant; 5 = Very significant)

**5) Does doing research through a partnership increase the credibility of the results in the eyes of the regulators?**

1    2    3    4    5

(1 = Not at all; 5 = Definitely)

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