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Abstract

Government-industry R&D partnerships can play an important role in advancing the public interest. A widely cited example is the Partnership for a New Generation of Vehicles (PNGV). It was launched in 1993 by the Clinton Administration and three US automakers, with the goal of advancing the development of energy efficient vehicles. It has come to be seen as a model, and in many ways it is: it is proceeding according to schedule; it increased the profile of advanced technology opportunities; and it led to better working relationships between the federal government and automakers. It also indirectly led to technology advancement—by inspiring more aggressive investments by European and Japanese automakers that, in turn, through a boomerang effect, inspired US automakers to do likewise. It is a success in the sense that both sets of partners are pleased. But has it served the public interest? Has it led to the best investment of government R&D funds and has it accelerated the commercialization of socially beneficial technologies? The answers to these latter questions are still uncertain. © 2001 Elsevier Science Ltd. All rights reserved.

1. Introduction

Public-private partnerships are gaining increasing attention for a broad range of goals and applications. This paper addresses public-private R&D partnerships generally, and automotive-government partnerships specifically. The overriding empirical goal of this paper is to assess the role of government-industry R&D partnerships in supporting and guiding technological transformations—in this case, the development and commercialization of high-efficiency, low-polluting vehicle technologies and fuels.

Partnerships between automakers and governments are especially compelling. Automakers face two huge uncertainties. They face escalating social demands, mostly environmental and safety, which they can respond to with a vast set of new and improved technologies. And they face an onslaught of information technology opportunities that link the car to a variety of external services and activities, including road infrastructure management and supply. Decisions to invest or not in these environmental, safety, and information technologies have huge implications. Governments play a central role in determining which strategies and technology investments will be successful. In this ‘fluid’ phase of rapid innovation (Utterback, 1994), compa-

nies naturally look outward toward new sources of engineering expertise and closer relationships with regulators and policymakers.

Governments also have many incentives to partner. They are called on to mitigate shortcomings of the marketplace in bringing cleaner and more efficient technologies to market. They are called on to reduce the free-rider problem of industries under-investing in socially-beneficial research and technology (Rosenberg, 1990), they must design cost-effective standards and rules where the marketplace falls short, they must anticipate indirect effects of rules and policies and revise actions accordingly (Eads, 1974), and they must overcome imperfect knowledge and conservative responses of consumers (Norman, 1996). These are daunting responsibilities, especially given their modest human and financial resources, limited knowledge of technological opportunities and costs, and limited understandings of business behavior. Partnerships with industry help overcome these resource and expertise limitations.

2. History and circumstances

On 29 September 1993, President Bill Clinton and the chief executive officers of Ford, Chrysler, and General Motors announced the creation of what become known as the Partnership for a New Generation of Vehicles (PNGV).

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The primary goal of the partnership is to develop a vehicle that achieves up to three times the fuel economy of mid-size 1993 US cars (i.e. about 80 mpg or 3 l/100 km), with no sacrifice in performance, size, cost, emissions, or safety. A billion or more dollars was to be spent over 10 years, split roughly 50/50 between government and industry. The plan was to select the most promising technologies by 1997, to build a concept prototype by 2000, and a production prototype by 2004. The program has more or less adhered to this schedule.

A confluence of circumstances drew this historic partnership together. In a broad sense, a compelling problem existed, and a compelling solution was at hand. Proliferating auto use was threatening environmental sustainability, but the automotive industry was on the threshold of a technological revolution that promised huge reductions in energy use, greenhouse gas emissions, and pollution.

It was a situation ready made for government initiative and public-private cooperation. Industry was reluctant to invest much in pursuing environmental and energy benefits because, for the most part, they had little value in the marketplace. And the federal government was willing to step forward given its widely accepted mission to reduce market externalities, support long term R&D, and support the nation's international competitiveness. In a joint statement to the US Congress in July 1996, the three automakers argued, 'Although the market does not presently demand high fuel efficiency vehicles, we believe that PNGV research goals are clearly in the public's broad interest and should be developed as part of a mutual industry-government commitment to environmental stewardship' (Chrysler et al., 1996).

The timing was propitious for the Clinton Administration. It would benefit politically from forging a closer relationship with the automotive industry, it would provide a new mission to the nation's energy and weapons laboratories and beleaguered defense industry suffering from the end of the Cold War and, at Vice President Gore's instigation, it saw a means to strengthen its commitment to environmentalism, particularly the greenhouse goals of the 1992 Rio de Janeiro Earth Summit treaty.

The automakers saw PNGV's goals as sufficiently ambitious and distant to fit the legally and judicially accepted model of pre-competitive research.¹ Their true motivations are difficult to document but, as the technical head of the government's side of the partnership says in a Rand report, 'It is fair to say that the primary motivation of the industry was to avoid federally mandated fuel efficiency and emissions standards' (Chapman, 1998, p. 9)—in particular, the national Corporate Average Fuel Economy (CAFE) standards and the Zero Emission Vehicle (ZEV) mandate that had been recently adopted in California, New York and

Massachusetts. PNGV appeared to offer the prospect of leapfrog technology that would make incremental fuel economy standards and battery-powered electric vehicles superfluous and even counter-productive. Other automaker motivations included access to government funding and research labs for long term and basic research, demonstration of industry leadership to stockholders, and a sincere commitment to forge a more positive relationship with government. In the words of a senior government official at a background briefing, 'We're trying to change the relationship of government and industry ... we're trying to replace lawyers with engineers' (Wald, 1993, p. 1). Inspired by the Japanese model of close government-industry collaboration, they were exploring an opportunity to transform a contentious regulatory relationship into a productive partnership.

Both sides of the partnership recognized a need to deal with increasing fuel consumption and greenhouse gas emissions. US oil imports were steadily increasing, contributing over \$150 million per day to the trade deficit; the fuel economy of new vehicles in the US had not improved in almost 10 years; and battery limitations cast doubt on the future of battery electric vehicles and the ZEV mandate. The problem was not just domestic. Global vehicle sales were increasing rapidly, with the vehicle population increasing from 50 million in 1950 to over 500 million in 1990. Virtually all projections anticipated similar rates of growth into the foreseeable future. Worldwide concern was illustrated by the increasing number of cities in European and newly industrializing countries limiting car use on certain days and streets.

It was clear cars would have to become more environmentally benign, and US companies would have to make major changes if they expected to increase market share in the rapidly expanding international automotive market. An innovative solution was needed that sidestepped politicians' fears of new taxes and industry resistance to regulatory intervention.

2.1. Batteries and the ZEV mandate

An initiative in California provided additional motivation, especially to automakers. The State had adopted in 1990, as part of a major amendment to its vehicle emissions rules, the so-called 'ZEV mandate', requiring that 2% of vehicles sold in 1998 by each of the seven largest auto manufacturers be zero emitting, with the percentage increasing to 5% in 2001, and 10% in 2003 and beyond. When adopted in 1990, the only technology thought capable of meeting the zero emission definition was battery electric vehicles. The three domestic automakers, concerned with the inadequate performance and high cost of batteries, pooled resources with the federal government (US Department of Energy) and electric utility industry (via Electric Power Research Institute) to launch the US Advanced Battery Consortia (USABC), formed in January 1991, its

¹ Stephen Zimmer, chief liaison to the project for DaimlerChrysler, was quoted as saying that pursuit of such a challenging, long-term goal 'totally drives you beyond the competitive area' (Quoted in Ball, J., 2000).

mission was to accelerate progress in the development of batteries for electric vehicles. It allocated \$189 million in contracts to battery companies during its first 5 years, and somewhat smaller amounts thereafter (NRC, 1998a). PNGV was a higher profile activity that automakers hoped would obviate battery electric cars and intrusive government mandates.

2.2. *Creating a management structure*

The PNGV organization is a federation of many committees and individuals from the three car companies and seven government agencies. It is overseen by a steering committee of senior representatives from the three automakers and the US Department of Commerce, with a rotating director. One level below the steering committee is a technical committee comprised of members from the companies and seven government agencies. Under the technical committee are about ten technical working groups for major technology subsystems, staffed by engineers and scientists from industry and national labs, with most chaired by an industry person. An independent oversight committee of the National Research Council (discussed later) firmly recommended the appointment of a single industry director and more integrated management. Industry resisted, wisely as it turns out, since technologies were closer to commercialization than appreciated; further integration would surely have led to paralysis over control of intellectual property rights. After about 3 years, the NRC committee acknowledged the management structure to be effective.

Initial coordination problems also existed on the government side, principally between the US Department of Commerce, which was responsible for overall management, and the US Department of Energy, which funded and managed most of the research.

2.3. *Rhetoric vs. reality*

The early rhetoric of PNGV proved overblown. A press release described PNGV as ‘an all-out effort to ensure the US auto industry leads the world ... a technological challenge comparable to or greater than that involved in the Apollo project’ (White House, 1993). President Clinton’s lofty assertion that ‘Today, we are going to launch a technological venture as ambitious as any our nation has ever attempted’ was not backed with money. In fact, PNGV attracted very little if any extra funding. Forced by Washington’s long lead time in budgeting, and later by politics, managers played a shell game, moving a variety of vehicle R&D projects under PNGV, including about \$250 million in multi-year hybrid vehicle research already in place with Ford and GM. The US General Accounting Office estimates that federal support for the partnership averaged about \$250 million per year from 1995 to 1999, but that this sum is overstated since about 45% was for activities only indirectly relevant to the partnership goals

or was not coordinated through the partnership (US GAO, 2000, pp. 4–6).

Political circumstances largely explain the inability to fulfill the rousing rhetoric. PNGV came into being during a period of growing federal budget deficits and skepticism in Congress and elsewhere of governmental capabilities. It was in November 1994 that the Gingrich-led Republicans scored major legislative victories over the Democrats under the banner of less government. PNGV leaders soon reconciled themselves to the hostile political climate and began down-scaling PNGV budget aspirations. Those involved soon recognized that most governmental support for PNGV would have to come from re-programming of existing allocations. Indeed, the prevailing opinion of PNGV insiders was that, given Congressional budget slashing and accusations of ‘corporate welfare,’ it was only because of aggressive behind-the-scenes lobbying by the three automakers that PNGV funding was retained. Congressional concerns about the PNGV program continued through the ensuing years, with the result that funding under the PNGV umbrella remained static. For instance, when the House of Representatives voted 214–211 in June 2000 to eliminate almost half of all PNGV funding (\$126.5 million)—an action not upheld in later deliberations—the Congressional sponsor of the diminished bill, John Sununu, characterized PNGV as corporate welfare.

Meanwhile, PNGV partners continued to meet program targets. In 1997, on schedule, the large set of candidate technologies that had been examined during the first years of the partnership were ‘down-selected’ to a few. Each of the three companies selected diesel-electric hybrids as their preferred technology. In early 2000, again in line with program milestones, each of the three unveiled concept prototypes. Ford’s Prodigy, GM’s Precept, and Daimler-Chrysler’s ESX3 all used lightweight materials and combined small advanced diesel engines with an electric drivetrain, with projected fuel economy of 60–80 mpg (NRC, 2000). The next and final target date is 2004, when each company is to supply a production prototype.

3. *Evaluating PNGV*

3.1. *A model partnership?*

PNGV is widely viewed as a model of national public-private partnerships. The Rand study, authored by Robert Chapman, recently retired technical head of the government’s side of PNGV, notes that ‘Today, with the exception of some special interest advocacy groups [i.e., environmental groups], the PNGV appears to be viewed quite favorably by the public’ (Chapman, 1998, p. 27). Dr Henry Kelley, Assistant Director of the White House Office of Science and Technology and a chief architect of the PNGV program, stated in April 2000, ‘I can’t think of one [public-private partnership] that is more important or has more potential

than this partnership in PNGV. It has not only yielded enormous technological advances but it redefined the way effective government-industry partnerships can be managed' (Kelly, 2000). Indeed, citing PNGV as a model, the US Department of Transportation in December 1997 created a major public-private 'Intelligent Vehicle Initiative', and in 2000, the US Department of Energy launched the PNGV-like 21st Century Truck Initiative.

3.2. *Peer review by National Academy of Sciences*

This image of PNGV as a model partnership has been perpetuated unintentionally by the independent National Research Council (study arm of the National Academy of Sciences). In 1994, NRC formed a standing committee (funded by government sponsors of PNGV) to provide ongoing evaluations, a rather uncommon practice in Washington DC, but recognizing the uniqueness and high profile of this program. Six annual reports were published from 1994 to 2000. The task assigned to the committee was to conduct an independent review of PNGV. The committee interpreted this mission narrowly by taking '... as given the vision, goals, and schedules for the PNGV program that had been enunciated by the president and agreed to by USCAR [the entity representing the three automakers]' (NRC, 1994, p. 1). This initial decision limited the committee to measuring progress toward pre-determined goals. Thus, the ongoing series of NRC reports were focused on the management of the program and relative emphasis placed on different technologies, *given* the enunciated goals. They did not evaluate program design, goals, overall funding, schedule, nor participation.²

3.3. *Benchmarking progress*

It is impossible to accurately specify costs and benefits of the program since it is not known exactly what effect the program had on advanced vehicle development and commercialization. How did automaker behavior change as a result of public infusions of R&D funds and public-private collaboration? In some partnerships and with some public R&D programs, direct program evaluation is possible. In this case, the targeted technologies were central to the companies' business plans—increasingly so over time—with the result that development of these technologies became highly confidential.

The best method available to test the effectiveness of PNGV is to compare the progress of the three US automakers with other automakers in introducing advanced

fuel efficiency technology. General Motors and Ford have been the two largest automotive companies in the world for decades, with annual revenues of about \$180 and \$150 billion in the latter part of the 1990s. And yet, two considerably smaller automotive companies came to market much earlier with mass-produced hybrid electric vehicles—Toyota, with half the revenue of GM, in December 1997; and Honda, one fourth the size, in early 2000. Toyota's gasoline-electric four-door Prius and Honda's two-passenger Insight both sell for around \$20,000 (several thousand dollars more than a comparable gasoline car). By January 2001, Toyota had sold a total of 45,000 Prius cars in Japan and 5000 in the first 6 months in the US, with orders exceeding sales. In 2000, Ford and then GM and DaimlerChrysler announced they would start selling a range of hybrid electric vehicles in 2003 and 2004, 6 years after Toyota launched the Prius.

In the case of fuel cell technology, considered even more promising than hybrid electric technology,³ Daimler Benz, with car sales then about one-fourth that of GM and Ford, pushed ahead of the entire industry. Its fuel cell technology, acquired from Ballard of Canada, is acknowledged to be ahead of the rest of the industry. It has unveiled a series of increasingly impressive prototypes. Now merged with Chrysler (but using little of Chrysler technology), DaimlerChrysler will start selling fuel cell buses in 2002 and announced that it intended to invest around one billion dollars in the development of fuel cell power systems and drivetrains between 2000 and 2004, and to begin selling fuel cell cars in 2004 (Schrempf, 2000).

In summary, what can be said is that other smaller automakers from elsewhere made faster progress in advancing the commercialization of targeted technologies than the US automakers.⁴ It is true that the Japanese companies used smaller cars than the mid-sized sedans targeted by PNGV and fell short of the 80 mpg goal, and that firm plans do not yet exist for placing Daimler's fuel cells in mass-produced cars. But, importantly, these non-PNGV companies made stronger efforts to commercialize advanced energy efficient technology, and they focussed on technologies with superior air pollution benefits.

² The positive effect of the NRC committee's efforts was to keep PNGV in the public eye and hold government and industry managers accountable, much more so than is common for large government programs. The high level of scrutiny was effective in increasing the transparency of the program planning, and encouraging industry teams to stay productively engaged. The negative effect of this continuing stream of relatively benign criticism was to limit debate about its true costs and benefits, and to implicitly endorse the goals and design of the program.

³ William Clay Ford, Chair of Ford Motor Company, said in a 19 January 2000 speech, 'I believe fuel cell vehicles will finally end the 100-year reign of the internal combustion engine as the dominant source of power for personal transportation'. In 1999, when announcing the planned launch of their Prius hybrid electric vehicle, Toyota President Fujio Cho said 'And fuel-cell technology holds even more promise'.

⁴ PNGV partners have made a strong effort to present themselves in the best light. For instance, PNGV published a glossy brochure in July 1996 showcasing its purported technical accomplishments. Most of the accomplishments, however, appeared to be results of ongoing efforts by the Big 3 and their suppliers, featuring, for instance, GM's EV1 electric car (unveiled as the Impact prototype in 1990) and various hybrid vehicle designs funded since well before PNGV.

3.4. Modest benefits

PNGV has clearly provided some benefits and had some successes. It is widely acknowledged that PNGV helped focus the federal government's (DOE) vehicle R&D programs; increased communication and coordination between automakers and regulators, thereby easing somewhat their adversarial relationship; perhaps helped the three US automakers close a gap with European companies in advanced diesel technology; and stimulated some advances in fuel cell technologies.

The magnitude of these benefits is impossible to measure. Consider, for instance, that the discipline of creating a well-defined program with well-defined objectives, while mostly positive, can have downsides. Some argue, in this case, that scarce R&D resources were often diverted away from fundamental, long term problems to near and medium term challenges, with little benefit. They argue that these near- and medium term problems are most effectively handled directly by industry—especially in this case, where the three US automakers were spending many billions of dollars annually on R&D.⁵ This concern was articulated by a different NRC committee, evaluating the USABC, when it stated that ‘... other DOE battery R&D may have been unwisely reduced to cover federal participation in the USABC’ (NRC, 1998a, p. 59).

3.5. The boomerang effect

PNGV's greatest effect, ironically, may have been to motivate itself indirectly. When PNGV was unveiled to great fanfare, apprehensive foreign automakers in Europe and Japan quickly accelerated their efforts. Many executives in European and Japanese companies readily concede that PNGV was clearly seen as a threat, and was the catalyst for increased investment in advanced propulsion technology in their companies. It now appears that a boomerang effect is occurring, whereby US automakers are responding to the aggressive commercialization efforts by Toyota, Honda, and the Daimler side of DaimlerChrysler.

4. Program design lessons

Program design decisions made in 1993 appeared reasonable and appropriate at the time to virtually all observers. But circumstances change. The organizational format and

style that seemed appropriate in 1993—in terms of design goals, timing, and funding strategies—became less appropriate over time. A variety of lessons emerge, as indicated below; most important is the need to create flexibility in institutional mechanisms to enable mid-course corrections.

4.1. Design goals

Consider the vehicle design goal of PNGV: to build affordable family-style cars with performance equivalent to today's vehicles, and emissions comparable to those planned for 2004. While well-intentioned, this goal was interpreted and applied in a narrow and, ultimately one might argue, misguided manner. First, consider affordability. It is a desirable goal, but the reality is that new technologies are almost never introduced initially into mainstream products and markets; they virtually always enter at the upper end of the market—in this case, in luxury or sporty vehicles. By focusing on affordability for the middle of the market, were they missing more promising opportunities?

The goal of equivalent performance undermined innovation in a different fashion. The equivalent performance requirement was imposed to assure that a mass-market vehicle would result. But with proliferating vehicle ownership—over 60% of households in the US own two or more vehicles—equivalent performance is not necessarily an appropriate goal.⁶ For instance, by imposing equivalent range requirements, R&D is directed away from hybrid electric designs that provide extended zero-emissions capabilities, and away from electric cars that use ultracapacitors and batteries, especially small city cars. Some of these applications were being addressed by the US Advanced Battery Consortia (USABC), but even the USABC did not address innovative designs premised on limited driving range and small size. Indeed, the NRC committee reviewing USABC pointed out that ‘If the USABC had viewed the EV not only as a competitor with the gasoline-fueled ICE vehicles [but also the possibility of being a complement], it might have established more attainable performance goals’ (NRC, 1998a, p. 60). The same observation applies to PNGV.

The focus on mid-size passenger cars also inhibited innovation. An NRC committee evaluating the primary government partner in PNGV (Office of Advanced Transportation Technologies of the US Department of Energy), stated that ‘As decisions to narrow the technology focus are made, care must be taken not to discard technologies that are not suited for a mid-sized car but are capable of providing improvements that meet Goal 3 [tripled fuel economy] requirements

⁵ Some research areas with huge potential payoff, that have received minimal funding, include fundamentally new fuel cell designs and nano-technology for storing hydrogen. Geoffrey Ballard, founder of the company whose fuel cell design now dominates automotive applications, notes that he and a handful of engineers settled on the basic architecture of that fuel cell in the mid 1980s (Koppel, 1999). He and other scientists point out that there is no reason to think that the design settled on 15 years ago is the optimal design. More importantly, only about 10–20 theoretical fuel cell types have been seriously explored. There are hundreds others that might be superior, but have not been investigated.

⁶ In the US, limited-range vehicle can be readily incorporated into many of these household ‘fleets’; research suggests that perhaps one-third of all light duty vehicles sold in the US could be vehicles with ranges of under 180 km, even if they were to cost somewhat more than comparable gasoline cars (because of other advantages such as, in the case of battery-powered electric vehicles, home recharging, superior driving ‘feel’, reduced maintenance, and environmental benefits). See Kurani et al. (1996).

in a different segment of the light-duty vehicle fleet' (NRC, 1998b, p. 17). In this case they specifically mentioned sport utility vehicles.

The emission goal of PNGV was also questionable, considering that the intent was leapfrog in nature. The goal used for the 1997 down-select was the projected tier 2 emission standards being considered for 2004. They were not very stringent: they were less stringent than those already being implemented in California, and considerably less stringent than the final tier 2 standards actually adopted in late 1999. Taking advantage of PNGV's conservative emissions requirement, automotive managers and engineers turned to a technology that was nearest at hand but also most polluting: a compression ignition direct-injected (CIDI) diesel engine, combined with an electric driveline and a small battery pack. It is very possible that automakers would not have chosen diesel hybrids if they had adopted more aggressive emissions goals initially—even the tier 2 standards now in place for 2004. The standing NRC committee evaluating PNGV remarks, 'To meet new standards, PNGV may have to shift its attention from the CIDI engine' (NRC, 2000, p. 7) toward the adoption of other internal combustion engines with better potential.

Diesel-electric hybrids were chosen because they provide relatively high fuel economy (though probably falling considerably short of a tripling) and easily allowed a prototype to be built in the PNGV time frame. But they have inherently high emissions of nitrogen oxides and particulate emissions, the principal pollution problems facing our cities. Other more environmentally promising technologies, such as fuel cells, compact hydrogen storage, ultracapacitors, and electric drivelines hybridized with innovative low-emitting engines, were de-emphasized and in some cases eliminated.

Advanced direct-injection diesel engines under development are far cleaner and somewhat more efficient than today's diesel engines, and are already being commercialized. They are likely to play an important role in vehicles of the future in reducing fuel consumption and greenhouse gas emissions. But it is uncertain whether such engines will be able to meet the national tier 2 and 'super-ultra-low' (SULEV) emission standards of California.⁷ More to the point is the fact that they will never match the emissions of fuel cells and advanced hybrid vehicles that use non-diesel engines.

Given performance and design goals established in 1993, PNGV managers behaved rationally. But by 1997, with the Toyota Prius on sale and Daimler Benz announcing plans to produce 100,000 fuel cell vehicles by 2003, the appropriateness of those goals was less certain.

⁷ The particulate and NO_x standards for light duty vehicles in Europe are similar to those of the US and California, except for diesel vehicles. Because European automakers have embraced diesel engines as key technologies for current and future European cars, they lobbied (successfully) for special dispensation for diesel cars.

4.2. Program schedule

Scheduling is another concern with PNGV, especially the procedural requirement that technology to be used in the 2004 production prototypes was to be selected by the end of 1997. At first glance this requirement seems reasonable: it gave assurance that industry would stay on track to meet milestones and the 2004 deadline. In fact, though, the actual effect may have been to subvert the development of leapfrog technology. Because 1997 approached quickly, and only one vehicle prototype design was to be picked by each of the three companies, PNGV managers in those companies and in the federal government were put in the awkward position of having to forego leapfrog technology. They found it safer to build a prototype they knew could be built but fell short of the 80 mpg goal 'that is, the diesel-electric hybrid' than to pursue technologies, such as fuel cells, that were less developed and more revolutionary, but had greater potential to reduce energy use and pollution.

Diesel-hybrid technology embodying advanced direct injection engines is certainly a large technological challenge. But given that other companies are already commercializing hybrid driveline technology and advanced compression ignition direct injection (CIDI) engines for the European market, similar to what PNGV envisioned, it raises a question of the appropriateness of targeting this technology in a leapfrog R&D program. The NRC committee reviewing OATT (the principal government partner in PNGV), stated that 'In the committee's judgement, the [DOE/PNGV] OATT plan assigns an inappropriate role to government in some technology areas where industry is either already doing proprietary work on its own (e.g. ... CIDI engines) or is likely to undertake proprietary work ...' (NRC, 1998b, p. 16). 'The distinction between government and private sector roles in R&D on CIDI engines is of concern to the committee ... The plan should distinguish between government's role in facilitating R&D and industry's role in the final development of a marketable product' (NRC, 1998b, p. 34). Diesel-hybrid technology is potentially attractive and merits strong industrial support, but a compelling argument can easily be made that it should *not* be the principal subject of a government-industry R&D partnership for advanced vehicles.

4.3. Picking partners

A third major issue with PNGV is choice of partners and recipients of government funds. In any automotive R&D program, one must engage the automakers—to ensure compatibility of component technologies and to oversee packaging, especially when production prototypes are to be built, and also because they are the ultimate users of the technologies. In this case, the three automakers were the architects of the program, along with the Clinton Administration, and played a central role, though not necessarily measurable in dollars received. Rob Chapman,

government's technical chairman of PNGV at the time, testified to Congress on 30 July 1996, that of the approximately \$293 million per year that the government was spending on PNGV, about one-third went to the Federal labs, about one-third directly to automotive suppliers, and about one-third to the three automakers. Of the one-third that went to the three automakers, about three-quarters was subsequently subcontracted to suppliers (Chapman, 1996, p. 21). Much of the \$293 million was administered by a variety of agencies through a variety of ongoing programs that have only indirect relevance to automotive applications, and even less to the tripled fuel economy goal. Thus, the vast majority of funds directly related to PNGV went to the Big 3 and their captive suppliers. The Big 3 also controlled, directly and indirectly, a substantial share of lab funding. For instance, until mid-1996, government funding of fuel cell research at Los Alamos National Laboratory was through a subcontract from GM. Thus, the three automakers received a relatively modest amount of money, but they played a large role in determining how the money was spent and by whom.

Major automakers, now numbering about 10 globally, are and will be the ultimate users of PNGV-type technologies. The entry barriers to new companies are so great it is difficult to envision many new companies entering the business, even more so as the technology shifts from internal combustion engines to electric-drive propulsion systems. It reportedly cost Ford \$6 billion to tool up for the 1995 Contour/Mystique, Chrysler \$1.4 billion for the Neon, and GM over \$6 billion for the Saturn. GM reported spending well over \$350 million to develop and launch the EV1, using a simple labor-intensive manufacturing process to build less than 2000 vehicles (including their electric pickup which used the same powertrain). These are the start-up costs for companies with strong engineering capabilities and extensive production, distribution, and service infrastructures. In recent decades, a number of international automakers have withdrawn from automotive markets, with major new automakers emerging (and failing) only in South Korea—funded by that country's huge industrial conglomerates.

But largeness and dominance does not necessarily mean they should be the principal partners of public-private technology R&D partnerships. There are three concerns with ceding too much control to the major automakers.

First, these large companies have competing political agendas. In the case of the three US companies, they had been (and still are) engaged in a long-running campaign to defeat efforts to increase corporate average fuel economy (CAFE) standards and implement California's zero emission vehicle rules. It is well known that they are reluctant to commercialize significant emissions and energy improvements for fear that regulators will codify those improvements in more aggressive technology-forcing rules. This attitude is exemplified by GM's then-CEO, Roger Smith, rhetorically asking at the end of his 1990 press conference announcing the Impact electric car prototype (which was to become the EV1), 'You guys aren't going to make us build

that car, are you' (Sperling, 1995, p. 38)? The industry has argued that with low fuel prices in the US, they have little incentive to take initiative in bringing significantly more efficient technology to market. That attitude may be softening, but still dominates.⁸

Second, R&D budgets of these large industrial companies swamp public funding, reducing the leveraging effect of public funds. The Big 3 spent \$17.3 billion on R&D in 1996 (about 5% of sales) (Chapman, 1998, pp. 13–14; US GAO, 2000, p. 24), about 200 times more than they received from PNGV. Though most of their R&D budget goes to routine engineering and design, some significant share goes to advanced technology. Ford, General Motors, and DaimlerChrysler self-reported that in 1999 they collectively spent about 5% of their total reported research funds, or about \$980 million, on research related to PNGV's goals (GAO, 2000, p. 25; NRC, 2000, p. 9). Smaller companies, with more modest R&D budgets, would presumably value public funds more highly.

Third, most innovation for leapfrog transportation technologies appears to come from outside the major automotive companies and even outside the traditional suppliers.⁹ The automotive industry is gradually becoming less vertically integrated. The days when iron ore delivered to a factory complex would emerge as a Model T are long gone. GM now depends on suppliers for about one-third the value of its vehicles, Ford about half, and Chrysler for two-thirds.¹⁰ The shift toward new technologies—batteries, fuel cells, electric drivelines, ultracapacitors—for which today's automakers have little expertise, will likely accelerate the trend toward outsourcing of technology development and supply. The leading designer of vehicular fuel cells, for instance, is not one of the Big 3, but Ballard Power Systems, a small company in Vancouver, Canada, with less than \$20 million in revenue in 1997. As major automakers move downstream, becoming assemblers, marketers and distributors, they are spinning off supplier subsidiaries and granting more independence and more product innovation responsibility to suppliers. This transition will likely accelerate as PNGV-type technologies are integrated into mainstream vehicle designs.

The net effect is that PNGV seems to have had little influence on the market behavior of the three US carmakers. The major stimulus for accelerating development and

⁸ William Clay Ford, chairman of Ford, has been particularly outspoken about the industry exercising its social responsibility.

⁹ Various studies have found a link between company size and R&D. Smaller firms seem to dedicate relatively larger shares of R&D expenditures to product innovation, and larger firms relatively more to process innovation (Cohen, W.M. and Klepper, S., 1996). Definitive evidence does not exist of advanced technology R&D contributions to the automotive industry by smaller and non-traditional firms, but substantial anecdotal evidence is available.

¹⁰ Precise data are not available, but it is widely recognized that automakers are continuing the trend toward outsourcing: it is becoming more common to outsource entire modules to suppliers, even as large as the entire interior of a car.

commercialization of PNGV-type technologies came from small companies such as Ballard and, via a boomerang effect, from non-US automakers such as Daimler Benz (since merged with Chrysler), Toyota, and Honda. One can debate exactly why this was. The point is not to impugn the Big 3. They are highly successful industrial enterprises with exceptional engineering capabilities. But a compelling hypothesis is that their control of partnership decisions and funds did not significantly accelerate technology development and commercialization; and that funds directed elsewhere—directly to independent technology supplier companies, with smaller amounts to independent research centers and universities—might have created more competition and more pressure to accelerate commercialization. Robert Chapman concludes that ‘the great unsolved problem of PNGV is the inability to deal effectively with small firms and individual inventors’ (Chapman, 2000).

4.4. *Public R&D, firewalls and commercialization*

The pivotal decision point was the 1997 down-select. All three automakers chose diesel-hybrid technology. It is a promising technology. But others, especially fuel cells, would seem to have been a more appropriate choice. The diesel-electric hybrid choice was the result of conservative interpretation of PNGV affordability, performance, and emissions goals, and a reluctance to re-open the discussion about scheduling and goals.

In a larger sense, perhaps it did not matter which of the targeted technologies were selected in 1997. Perhaps the PNGV activities have little effect on the commercialization process.

The automakers, as is common practice in competitive industries, essentially created ‘firewalls’ of varying permeability around their PNGV work. Companies engaging in collaborative work with competitors in their own or related industries routinely create these walls as a matter of course to protect themselves against anti-trust lawsuits and, more importantly, to ensure confidentiality. The concern is, the more government funding and competitors are involved, the more likely it is that companies will lose control of knowledge and technology.¹¹ These firewalls work effectively with small innovations that affect a small part of the business, since the protected knowledge is not central to the business interests of the company. But this situation was different. First, virtually all of the targeted technologies were close enough to commercialization that a company would want proprietary rights to any advances. Second, fuel cell and hybrid propulsion systems promised to be core technologies for these huge companies.

How permeable were those firewalls, how did companies

allocate their human and financial resources between PNGV and internal proprietary efforts, and to what extent did government-funded R&D lead to or influence the development and commercialization of advanced technology? Did the companies fear they would appropriate so little of the PNGV learning for themselves—with new knowledge spilling over too quickly to others—that they limited their resource commitment to PNGV?¹² It may be that the American automakers’ passive, conservative approach to PNGV was based on the perception that the benefits of energy efficiency technologies were small and that R&D learning would quickly spill over to their competitors.

In any case, it is clear that the three automakers were strongly committed politically to the partnership. It is not clear that, in the end, PNGV had much effect on technology development and commercialization.

5. The European experience

In Europe, automakers and governments have engaged in several high profile international R&D partnerships since the mid 1980s. The most recent incarnation, the European Council for Automotive R&D (EUCAR) was launched in 1994, partly in response to PNGV. It comprises 10 automotive companies located in five countries, and is headquartered in a sixth, in Brussels, Belgium. From 1994 to 1999, EUCAR undertook 88 projects, of which 14 were self-funded (by EUCAR members) and 74 co-funded by the European Union (EU). The total budget for the 88 projects was EUR 302 million, about half of which was provided by the EU (half of that going to the automakers and the other half to suppliers, universities and independent centers). EUCAR has created an array of technical and policy committees not unlike PNGV, with only a skeletal administrative staff.

Interviews with a variety of senior officials from the government and automotive partners indicate two major benefits arising from the EUCAR partnership: (1) automakers gain access to European research institutes (which are similar to US national energy laboratories and also largely an outgrowth of nuclear research programs); and (2) increased communication across the industry and between industry and the EU. Actual EU government funding was rarely cited as an important benefit (except for those corporate R&D groups treated as cost centers and required to fund themselves from other corporate divisions or externally).

The EU provides even less public R&D funding to automakers than PNGV. As with PNGV, the principal benefits seem to be independent of funding. EUCAR is principally an organization to share information. That seems appropriate. With the challenge of managing the politics and

¹¹ The financial and legal claim by government on publicly-funded innovations varies greatly. The European Union, for instance, rarely asserts a claim to technologies developed by automakers with their public funds. The US government, in contrast, has become quite aggressive at asserting a claim.

¹² A growing literature examines this issue of appropriability of learning (Duke and Kanmen, 2000). It is unclear to what extent this is a concern with automakers.

interests of a wide variety of countries and a broader array of companies, the ‘cultural’ commitments of some countries to their major car companies, and the variety of existing relationships between governments, universities, and companies, it is difficult to imagine EUCAR expanding into an integrated R&D partnership. EUCAR has also played a pivotal role in maintaining communication between the European Commission (executive arm of the EU) and automakers regarding follow-up to their voluntary agreement to reduce CO₂ emissions (per vehicle-kilometer) by 25% between 1998 and 2008. As with PNGV, EUCAR’s greatest success may be in promoting communication.

6. Conclusions and suggestions

PNGV, like EUCAR, has been a fruitful partnership in the sense that both sets of partners are pleased. PNGV indeed inspired some accomplishments and set in motion a dynamic that accelerated commercialization of advanced energy-efficiency technology. A sympathetic view would be that any shortcomings could be explained by unforeseen changing circumstances. But there remains the troubling question: In the end, did the creation of PNGV serve the public interest?

Did PNGV lead to the best investment of government R&D? Was Congressional R&D funding diminished from what it might otherwise have been because of the inability to escape accusations of ‘corporate welfare’? Were regulatory initiatives to reduce fuel consumption undermined? In summary, did the creation and activities of PNGV accelerate the commercialization of socially beneficial technologies? These questions remain unanswered and perhaps unanswerable.

In any case, the PNGV experience provides the following insights and lessons:

- unforeseen indirect effects (the ‘boomerang effect’ in this case) may prove most important;
- mid-course corrections are essential;
- targeted technologies should be far from commercialization (and/or have large social benefits) because government funds will otherwise have little effect;
- more progress results with partners wholly committed to the technology development and commercialization goals of the partnership;
- great effort must be devoted to recruiting small, innovative companies (with hopefully large paybacks); and
- societal benefits of public-private R&D partnerships are difficult to specify.

Is it realistic to think that these lessons can be applied in a variety of circumstances? If not, what does that imply? For a technology development partnership to succeed, it requires an unlikely confluence of insightful designers, flexible and

accommodating partners, and astute and effective leaders. It also requires huge resource and institutional investments.

Given these daunting challenges and the earlier cautionary thoughts on societal benefits, perhaps the principal lesson of PNGV is that public-private technology R&D partnerships as presently conceived may be an outdated concept—not only for the automotive industry, but also other large, concentrated industries. It may be that the awarding of public R&D funds in a broad partnership context may be unnecessary and even counter-productive. But in this globalizing and networking world, communicating and partnering is more essential than ever. Apart from the awarding of public R&D funds, are there sufficient incentives for major industrial companies to participate in public-private partnerships? The EUCAR example suggests so.

The essential components of a restructured PNGV-like partnership might be:

- inclusion of small innovative companies, universities, and independent research centers as project principals;
- inclusion of energy suppliers (who greatly influence the design and choice of advanced technology);¹³
- requirements that an automaker or major automotive supplier be a partner in virtually all projects;
- broadened participation in the partnership’s policy and technical committees, including more industry, government and non-governmental (NGO) participants.
- Few or no public R&D funds disbursed through the partnership—rather all public R&D funds would be awarded on a competitive basis outside the realm of the partnership as seed grants to small innovative companies, non-traditional automotive suppliers, universities, national government labs, and independent research centers.

The automotive industry may be less enthusiastic and less committed to a partnership of the type described above (though it is interesting to note that those companies themselves state that ‘... the lack of talented people is a greater handicap than the lack of adequate funding and that they need ideas (breakthroughs) more than dollars’ (NRC, 2000, p. 9). But the sort of arrangement suggested here may lead to a more stable relationship, encourage more public investment in socially beneficial technologies, and motivate a broader and better-informed public debate over vehicle energy consumption and greenhouse gas emissions.

¹³ Energy suppliers play a central role in these technology choices. The supply of a very clean diesel fuel, for instance, will make it much easier for automakers to design a very-low emitting diesel engine. Likewise, automaker decisions to invest in fuel cells are on hold now principally because it is uncertain which fuel will be preferred for fuel cells (hydrogen, methanol, or a petroleum-like fuel) and when and where they will be made available.

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