Minnesota Plug-in Hybrid Electric Vehicle Task Force
Report to the Minnesota Legislature
April 28, 2007

During the 2006 legislative session, the Minnesota legislature established a plug-in hybrid electric vehicle (PHEV) task force. The PHEV task force was given the following charge:

> *The plug-in hybrid electric vehicle task force shall identify barriers to the adoption of plug-in hybrid electric vehicles by state agencies, small and large private fleets, and Minnesota drivers at-large and develop strategies to be implemented over one-, three-, and five-year time frames to overcome those barriers. Included in the analysis should be possible financial incentives to encourage Ford Motor Company to produce plug-in hybrid, flexible-fueled vehicles at its St. Paul plant.(Chapter 245, Section 3, subd 4)*

The task force was co-chaired by Edward Garvey, Deputy Commissioner of Energy and Telecommunications, Minnesota Department of Commerce and Lynn Hinkle, Safety Officer, United Auto Workers. Membership was comprised of representatives from the organizations and sectors specified in the legislation. (See Appendix A) The task force was organized in the autumn of 2006 and commenced work in November 2006. Beginning on November 17, 2006 and continuing on every other Friday, the task force held public meetings at the UAW Local 879 Union Hall in St Paul. The task force drew on expertise from a number of Minnesota stakeholders and professionals in the field.

The first task force meetings concentrated on providing members with a background in the current and anticipated state of the technology, Minnesota's PHEV projects, national PHEV research, demonstration and promotions as well as on factors that could be used to promote the reuse of the Ford Motor plant to a prospective PHEV or related business. The task force heard presentations by many PHEV project leaders describing their efforts and discussing these efforts in the larger context of target markets, and the opportunities and barriers to commercialization of PHEV technology. The following section provides a brief background on PHEVs, extracted from the educational segment of the task force meetings.

BACKGROUND ON PHEVS

A PHEV is a vehicle that is based on a full hybrid electric vehicle, like the Toyota Prius, but has a larger battery pack that may be charged either by the vehicle's gasoline engine and regenerative braking system during operation, or from plugging it into an electric outlet when not in operation. In most cases, a standard 110-volt outlet is used to recharge the battery.

As reliance on gasoline becomes an increasingly important issue due to price spikes, supply risks, potential for supply shortages and emissions, the effort to commercialize technologies that reduce its consumption takes on more urgency. PHEV technology is gaining interest because it has the potential to reduce gasoline consumption to a greater degree than existing hybrid vehicles, particularly on short, start-and-stop type trips, which are typical of many urban commuter trips. PHEVs also reduce emissions. But, because PHEVs rely on electricity as a replacement for gasoline, it is more difficult to estimate and compare emissions produced by PHEVs to other vehicle technologies. The emissions profile of a PHEV, like other vehicles, includes refinery and tailpipe emissions, but, in addition, includes the emissions produced during the generation of electricity to recharge the PHEV battery.

Until recently, only a few utilities, universities, and environmental organizations were actively involved in developing PHEV technology. This activity included some small, but well promoted demonstration projects. The publicity from the demonstration projects, in turn, created enough public interest and demand that it actually prompted the startup of a few small, customized conversion kit businesses that sell conversion kits to do-it-yourselfers and/or offer conversion services. The kits, in turn, facilitated the expansion of PHEV demonstrate vehicles around the country while boosting both government and public interest. The first conversion kits were developed for the Toyota Prius, but conversion kits for other hybrids like the Ford Escape and Mercury Mariner have recently become available.

Minimal investment has been made in developing PHEV technology and, until recently, car manufacturers have shown little interest in it. This year the landscape has changed as DaimlerChrysler developed and began testing a plug-in Sprinter Van prototype with an all-electric range of 20 miles. GM has followed suit by announcing that it would have a plug-in version of the Saturn Vue hybrid on the market by next year (2008) and unveiling a new PHEV concept car, the Chevy Volt, at the Detroit Auto Show. These announcements have created a flurry of interest and now auto manufacturers and original equipment manufacturers are also beginning to turn attention toward solving some of the technical barriers for PHEV commercialization.

The range that a PHEV can drive on a battery charge is a major factor in a PHEVs ability to reduce gas use. The batteries included in today's PHEVs have enough capacity that commuters who drive less than 20 miles a day can potentially drive exclusively with the electric motors for their daily commute. As battery technology evolves towards higher performance, longer life, and especially, lower cost, PHEVs become more attractive because they provide their greatest benefits when operating in the electric mode. Experts from Argonne National Laboratory, the national laboratory that is leading the U.S. Department of Energy's PHEV program, think that PHEVs will displace more fossil fuel use than hybrids alone.

CalCars, a non-profit organization formed to spur adoption of efficient, non-polluting automotive technologies, was an early leader in the PHEV research and development. CalCar built the first Prius PHEV conversion kit in 2004. They also spawned other

PHEV promotions such as the Plug-in Partners national campaign to promote production of PHEVs. Promotional efforts have been boosted by recent reports from the Electric Power Research Institute (EPRI) and Pacific Northwest National Laboratory that show most of the electric grid has sufficient capacity overnight to recharge a significant portion the cars that are on the road today. (*Impact Assessment of Plug-in Hybrid Electric Vehicles on the Electric Utilities and the Regional U.S. Power Grid,* Pacific Norwest National Laboratory, 2006; *Comparing the Benefits and Impacts of Plug-in Hybrid Electric Vehicle Options,* EPRI 2001)

Scientific research to advance PHEVs technologies and help lower vehicle cost is growing, as are efforts to accelerate the adoption and use of plug-in hybrid electric vehicles. New York State has one of the larger programs aimed at accelerating adoption of PHEVs. New York State Energy Research and Development Agency (NYSERDA) was provided with $10 million of funding by the New York legislature to convert 600 vehicles in the state's fleet to plug-in technology. NYSERDA recently issued a request for proposals for hardware and services necessary to convert existing state-owned hybrid electric vehicles to PHEV operation and hopes to establish a national standard for testing and monitoring these vehicles.

NYSERDA told the task force that the main obstacles to commercialization of PHEV technologies were:

1. Battery technologies,
2. Higher costs to produce plug-in technologies; and
3. Infrastructure for plug-ins.

NYSERDA pointed out that only about half of the vehicles in the U.S. are garaged overnight. Thus, recharging a battery by plugging it in at the home garage will work for only a portion of America's vehicles.

MINNESOTA'S INVOLVEMENT IN PHEV TECHNOLOGIES

Local interest in PHEV technology is growing and a few Minnesota organizations have initiated demonstration projects. In August 2006, St Paul Neighborhood Energy Consortium's HOURCAR became the first car sharing organization to include a PHEV vehicle. HOURCAR's Toyota Prius was converted by Hymotion, using a kit based on a 5 kWh lithium-ion battery pack that supplements, rather than replaces, the car's original nickel metal hydride battery pack. Minnesota State University at Mankato is also sponsoring a PHEV conversion project. Senior students from the Department of Automotive Engineering, under the direction of Dr. Bruce Jones and Dr. Vince Winstead and with funding from Xcel Energy, are currently converting a Minnesota Department of Natural Resources (DNR) owned Prius, into a PHEV. The students are using a 7.9 kWh lead acid battery pack that will replace the original nickel metal hydride battery pack. The lead acid pack was selected primarily based on cost and durability. The vehicle will also be modified to have Flex-Fuel capability. This will allow it to use fuels ranging from 0% ethanol to 85% (E85). The students will conduct a series of emissions and performance tests at the Minnesota Center for Automotive Research (MnCAR) located at Minnesota State, Mankato before returning the PHEV Prius to DNR for demonstration purposes.

PHEV courses for engineering students have recently become available at the University of Minnesota. In September 2007, the mechanical engineering department launched the first vehicle design class for PHEV technology under Dr. David Kittelson's advisorship. In the first semester of 2007, the electrical engineering department began a senior design class related to PHEVs under Dr. Bruce Wollenberg. Both Dr. Kittelson and Dr. Wollenberg are involved in the effort of this PHEV Task Force.

MINNESOTA PHEV TASK FORCE PROCESS

The task force used its first few meetings to familiarize members and participants with background issues, national projects to convert, measure and monitor PHEV performance and policy efforts in other states to commercialize PHEVs. The task force then broke down into sub-committee working groups to identify major issues from a Minnesota perspective, develop strategies for attracting Ford Motor Company or start-up PHEV manufacturer to the state, to identify barriers to PHEV commercialization and to determine strategies that would work in Minnesota for reducing those barriers. The sub-committees, described below, explored the issues in their respective areas to identify major barriers to commercialization and develop strategies to overcome the barriers and develop strategies to attract a manufacturing or related function to the Ford plant site or to the state.

- **Technology and Policy Sub-Committee** – what are the technological areas that Minnesota could impact and how? What are the market segments/niches that would gain the greatest benefit from conversion to plug-in hybrid technology and how could Minnesota affect that market?

- **Industrial Development Sub-Committee** – what kinds of vehicle manufacturers or green technology companies might be interested in the Ford site? How can the state promote the Ford Plant site's availability and what kind of incentives would be needed to attract an appropriate manufacturing or assembly plant?

The task force incorporated the results of the sub-committees into their process and developed the following list of barriers. They also used the work of the sub-committees to determine strategies, supported by a project action plan that the state submitted for funding that would reduce barriers and help PHEV commercialization.

BARRIERS TO THE COMMERCIALIZATION FO PHEVS AND POLICY OPTIONS

The Task Force identified four major barrier categories to development and placement of PHEV technology in the marketplace.

- Technical barriers
- Economic barriers
- Competitive barriers
- Infrastructure barriers

Technical Barriers

Batteries present the most significant technical challenge to PHEV commercialization. Some of the challenges that remain are:

- **Battery life:** currently too short (about 5 years under typical driving patterns); presents warranty risks; and with the additional costs associated with larger battery packs, they become too expensive to replace at short intervals.
- **Battery safety**: Some safety issues in lithium ion batteries remain.
- **Energy/driving range:** Current batteries do not provide a great enough driving range to fully attain benefits.

Economic Barriers

Higher cost is the primary impediment to commercialization of PHEV technology. Some of the cost components that affect the price of PHEVs are:

- **Cost of energy (fuel and electricity)**: effective economics of conventional fuel economy vs. unknown economics of electricity use plus battery replacement (also how to treat battery replacement vs. "engine replacement" and other costs associated with engine operation).
- **Energy tax structures (fuel, electricity)**: What are the effective tax rates on an energy basis? What would be the appropriate treatment of electricity used as a "motor fuel"?
- **Vehicle cost, depreciation and maintenance**: Does the additional cost associated with a PHEV produce additional benefits of comparable worth? If so, what are these benefits and their values and where would they be best realized?
- **Battery cost:** need for larger, more expensive batteries may raise price point of PHEV too high to be competitive with other advanced engine technologies.
- **Production and warranty costs:** The additional cost for the battery pack and the risk of need for battery replacement may impede production.

The projected higher cost for PHEV technologies (estimated at a range of $3,000 to $5,000 higher per vehicle) is an over-riding concern of commercialization efforts and must be weighed against the anticipated additional benefits offered by PHEV over other advanced engine technologies. PHEVs do not yet have a track record that allows for a reliable assessment of costs and benefits but demonstration PHEVs are providing some performance measures on which assumptions can be made.

Competition

In recent years the automotive industry has made great strides toward developing clean, efficient vehicle technologies. Advancements such as ultra low sulfur diesel fuel combined with new diesel engine and emission control systems, and new hybrid technologies for both internal combustion and diesel engines are arriving on the market at prices only slightly higher than older technologies. PHEVs must be able to compete with these vehicles on factors including performance, durability, safety and convenience, as well as cost, in order to gain market share. Competition from other advanced vehicle technologies is one of the primary barriers to commercialization of PHEVs. Some of the questions that will determine market competitiveness are:

- **Vehicle utility***:* How do we foresee PHEVs developing compared to existing HEVs, in terms of vehicle range and speed, passenger payload, capacity, comfort and performance? Will anticipated benefits outweigh the extra costs of a PHEV?

Infrastructure

Electric Capacity and Infrastructure may be adequate for a low volume of PHEV to be recharged during off-peak hours but the following items remain to be examined before large-scale market penetration can occur.

- **Electrical generating capacity and sources***:* Does Minnesota have spare generation capacity? What are its limitations and time variables (e.g. assume night-time charging more favorable, more summertime limitations than winter)?
- **Transmission infrastructures**: At what levels would PHEV recharging impact transmission vs. generation capacities?
- **Battery charging infrastructures***:* Would residential houses need to be rewired to provide 220V or higher at the garage to speed recharging? Do typical fleet garages / parking facilities have the required service capacity? Would infrastructure need to be extended for urban street parking, parks and recreation parking?
- **Vehicle to grid (V2G):** What electric infrastructure advancements are needed for the electric grid to receive power back from vehicles? What interconnection devices will accommodate V2G? How will V2G impact electric capacity and grid operation?

OPTIMAL MARKET FOR PHEVS

Successful commercialization of PHEVs is dependent on identifying the optimal markets for PHEV technologies, assessing consumer segments that are most likely to purchase them at various price points and determining policies directed at target markets that can offer adequate push or pull factors to incentivize desired market demand. Within those markets, vehicle applications that maximize the use of the lower priced fuel – in this case, electricity to recharge the battery – and minimize the use of gasoline are most likely to get a positive payback from a PHEV, and thus are more likely to be purchased. Vehicles that are typically driven on short start-and-stop trips where most of the daily miles can be powered by the battery are good target markets. But, even in these short start-and-stop applications, the payback period for the additional cost of PHEV technologies is dependent on the price of gasoline. With gas prices at $3/gallon, payback could take years.

Policy directed at developing incentives with adequate value to provide a reasonable payback could tip the scale of the short trip vehicle market toward PHEV purchase. But the economic variables for PHEVs are dynamic and, in some cases, it is difficult to determine whether the benefits outweigh the costs.

The value of the environmental and security benefits, such as lower emissions, less reliance on oil, and quieter operation that PHEVs offer may not be as important to the consumer as the economic factors. Currently the environmental values are externalities -- they have value to society but are not directly factored into the cost of the technology. Yet these benefits must be taken into consideration, especially if government considers offering incentives to buy down the price of a PHEV.

The task force identified the following markets for further study. Some of the issues related to these markets are briefly discussed below.

Fleet Markets for Passenger Vehicle

The task force discussed the possibility of targeting markets that procure fleets of vehicles for PHEVs. Fleets are an easily identified niche market and their operators tend to procure multiple vehicles when they make a purchase. Utility, reliability, maintainability and life cycle operating costs are the most important factors in a fleet operator's decision for vehicle procurement. The most cost effective use for a PHEV is the kind of application that entails mostly urban driving with a lot of starting and stopping. Fleet vehicles used for this kind of driving will make up only a subset of total fleets. Identifying these fleets and estimating the size of the short trip fleet vehicle market is one of the research needs that the task force identified.

Private Passenger Vehicle Markets

The private passenger market has far more drivers who take short trips, the kind of trips that maximize a PHEVs benefits. The private passenger market tends to be pricesensitive, especially in the smaller, sub-compact and compact sized vehicles. If the current additional cost estimates for PHEVs are correct, the economics of PHEVs in the small passenger car market may not prove positive until anticipated manufacturing costs decease. To gauge the size of this market in Minnesota, the task force reviewed a survey of driving behavior from the Metropolitan Council that characterizes private passenger trips in the Metro area. This data set included factors (such as average trip length and miles driven per year) to assess the number of vehicles that are on the road today in the Metro area that, if transitioned to PHEVs, could attain the most benefits.

Niche Markets of PHEVs

There are many niche applications that may also be good markets for PHEVs. Some of these include off-road vehicles used for parks, golf courses, industrial complexes and campuses. Others might be for use in neighborhoods, especially areas where clean air is important. Currently there are a number of all-electric vehicle manufactures that service this market. An important question is whether a PHEV, with the added expense of an engine, would be more attractive to these applications and if they would be willing to pay a higher cost for a vehicle with a greater driving range and more reliability.

Mass Transit Market for PHEVs

A final market that the task force considered was the mass transit vehicle and shuttle vehicles. There are a number of advanced technologies that are being developed for these markets and, the general thought is that PHEVs may not be the best fit for these applications due to the extended daily operating range of these vehicles. The electric load for these vehicles is relatively high, the range requirements comprise all-day shifts, and battery technology is unlikely to be able to effectively address these markets for the foreseeable future.

Other Advanced Engine Technologies

The task force discussed a number of emerging vehicle technologies that have the potential to provide significantly improved mileage. Examples of these technologies include flex fuel vehicles (E85, which effectively improves gasoline fuel mileage by offsetting 85% of the gasoline with ethanol), advanced diesels, and evolving hybrids. It must be assumed that these vehicles will constitute competition for PHEVs. These technologies are important and need to be considered in a PHEV market assessment. The task force decided to view advanced vehicles that offer similar benefits to PHEVs and may be commercialized in a shorter time frame or at a lower cost than PHEVs in the context of barriers to PHEV commercialization. Within the context of policy, these technologies also offer societal benefits.

Renewable Fuels and PHEVs

Combining high ethanol or biodiesel blends with PHEV technology is expected to provide additional environmental and security benefits but adds an extra layer of complexity to assessment of policy options for PHEV technology. Will PHEVs be designed for E85 or bio-diesel fuels? If not, how would the emissions and other benefits from PHEVs compare to those offered by flex-fueled and renewably fueled vehicles? How the question of how renewable fuels are incorporated into PHEV technologies or other advanced engine technologies is important to the state because of the role that Minnesota's renewable fuels industry plays within the state's economy.

BARRIER REDUCTION

The task force developed a list of potential "pull" factors that would encourage the introduction of PHEVs in Minnesota once they become commercially available and help move the market. In addition, the task force considered the role that Minnesota could play in preparing the ground work for commercialization. Minnesota's extreme climate presents many challenges to PHEV technology, particularly in terms of battery life and performance, and could be used to entice testing and demonstration projects to the state. The University of Minnesota and Minnesota State University at Mankato may also have a role to play in research and demonstrations of the component technologies for PHEVs or other energy efficient vehicles. Other ideas to reduce barriers are:

Acquisition Incentives

- **Federal PHEV Tax Credit**: The federal tax credit that was directed at influencing purchase of hybrid vehicles was originally set at $3000. That credit decreased as the demand for hybrids increased. It is currently at $1575.
- **State sales tax exemption** for PHEVs (6.5%)
- **Reduced price** or free **license plates**
- **Fee-bates:** Develop and implement a graduated fee-based system that penalized dirty technologies and reward clean technologies. Fee-bates are tax neutral fee-incentive combinations.
- **Plug-in-partners type coalition**: Collecting shadow orders for PHEVs to influence production
- **"Try Before You Buy" program**: loaner or short term lease programs for potential PHEV buyers to gain experience and confidence in the technology before purchase
- **Small demo opportunity**: deploying in "HOURCAR" program for PHEVs as part of the "Try before you buy" for consumers.
- **Assessment of externality value of Twin Cities air quality**: use as a guide to value of state support for avoidance

Use Incentives

- **Free parking** in publicly owned garages
- **Free battery recharging in** publicly owned garages or parking lots
- **Gas Taxes**: free or reduced for PHEVs

- **Reduced electric rates** for transportation /state purchased electricity for transportation (free to user)
- **Free access to commuter lanes**
- **Fee for access** to non-attainment or congested urban areas and **the fee is waived for PHEVs**: The fee for access concept is used in London. Transponder technology could be used to track trips and record access.
- **Require U of MN vehicles** and other state university vehicles (on campus) must be **renewably powered**
- **Lottery for a PHEV give-away**: to attract attention and provide publicity
- **Create a special designation** for clean transportation and **recognize communities** for public service fleets that meet criteria; could be modeled after the ENERGY STAR rating for appliances.
- **Insurance pool**: develop and finance an insurance pool that would reduce or offer free insurance rates for PHEVs
- **Free public transit** for owners of PHEV
- **Packaging a number of incentives together** to create enough value to buy down PHEV pay back time

Some of the above incentives have been used in the past by various governments to create demand for other vehicle technologies and information on their efficacy may be available. The task force recommends further investigation of incentives offered by other states or countries and the impacts of these incentives on the market in its Year One Strategies, which are specified later in this report.

Incentives are typically used to increase demand for a product or technology after it becomes commercially available. Auto manufactures have recently made a number of announcements that could change the manufacturing landscape in the near future. Yet because PHEVs are not yet at the commercialization stage, policy and incentives directed at the market are a bit premature.

To help the advancement of PHEV technology and prepare the Minnesota market for acceptance, the task force recommended strategically developed demonstration projects. The task force felt that coordinated demonstration projects with targeted outcomes would provide performance and functional intelligence specific to Minnesota while building market awareness. The task force developed the following set of criteria for Minnesota demonstration projects.

Demonstration Project Criteria

- Demonstrations should create a positive public relations impact, including utilization of vehicles that potential purchasers and operators perceive as aesthetically attractive and capable of fulfilling operational expectations.
- Demonstrate and document potential for economic and functional feasibility, including life cycle operating costs, reliability, maintainability.
- Replicability (i.e. based on production vehicles).
- Demonstrate, verify, and document emissions reduction potential.

- Conformance to regulatory standards (safety and emissions) for vehicles operated on public roads.
- Foster public-private partnerships.

Standards and techniques for monitoring and measuring demonstration vehicles will be developed and applied to demonstration project to assure effective program management. The task force also decided that the engineering specification and monitoring standards for the demonstration vehicles would be publicly available so others can duplicate the project.

Other collateral efforts could include educational programs, at all levels, so that students not only understand their energy use choices but also are exposed to the science and engineering issues that can advance the technologies. Finally, Minnesota will build partnerships with other states and metro areas to achieve the critical mass necessary to move the market. There is strength in numbers, especially when those entities can develop common product specifications and consistent incentives to build a strong coalition of stakeholders and broaden the market.

INDUSTRIAL DEVELOPMENT AND THE FORD PLANT SITE

The task force developed a number of ideas on the re-use of the Ford plant and strategies for attracting a PHEV or other environmental friendly manufacturing or assembly functions to the site. The task force worked with St Paul's economic development team that is charged with developing three to four multi-use options for re-use of the Ford Motor plant site. St Paul has appointed a vision team to begin work.

The Ford plant site has a number of assets, including the hydro plant and training center that could be sold off separately. Although the hydro plant could be sold to a private entity, regulations require that the electricity from the hydro plant be sold though a regulated utility. The Federal Energy Regulatory Commission (FERC) needs to approve the sale. The FERC process allows for entities such as the City of St Paul to have input.

There are four immediate study needs to conduct in preparation for attracting a new assembly or manufacturing function to the sites:

- Environmental Assessment and Abatement Plan – the Ford plant has a number of environmental problems that need to be identified, assessed and strategies for abatement must be developed. Ford has told the committee that it will conduct an environmental assessment with required state involvement and they would also share the information with City of St Paul. No action is needed by the PHEV task force on this item.

- Feasibility and Market Assessment Study – This study would assess trends in "green" technologies to identify growing technical industries. It would look at the manufacturing and assembly processes for these technologies to identify ones that could employ workers with the skill sets of current Ford employees. It would identify the types of "green" technologies that could expand in the Minnesota market and their likelihood to open a plant in Minnesota, given the proper incentives.

- Feasibility and Cost Study for a Ford Plant Retrofit – This study could begin as a generic study to estimate the gross costs involved in retrofitting the Ford plant for re-use as an assembly or manufacturing plant compared to the cost if the plant was torn down and rebuilt. Once a subset of industries are identified in the above mentioned Feasibility and Market Assessment study, a more detailed assessment of the costs could be undertaken for a particular type of industry or even a specific application.

- Business Development Incentives – This study would examine the types of incentives such as industrial development bonds, revenue bonds or a new "green" bond, and the amount that would be needed to attract businesses identified in the above studies to the plant.

Information from these studies is needed to identify potential manufacturing opportunities for the Ford plant site and determine financial incentives needed to capitalize on potential opportunities. The task force addressed the need for these studies in their Year One strategies, which are discussed later in this report.

PHEV INTEGRATION INTO STATE OWNED AND PRIVATE FLEETS

The task force consulted with the fleet managers of the Minnesota Departments of Administration, Transportation and Natural Resources as well as other task force participants involved in private fleet management to develop strategies that address ways that the state fleet and other private fleet mangers could overcome barriers to incorporation of PHEVs into their fleets. Introduction of new vehicle technologies that have different operation, maintenance or infrastructure needs can be far more problematic for a fleet manager than for an individual passenger car owner. The best way to overcome this barrier is to provide fleet managers with a chance to learn about the technology first hand, in this case through a demonstration project that would convert a small number of state owned fleet hybrid vehicles to PHEVs, so the fleet managers can plan accordingly before the vehicle is introduced in quantities. Experience with demonstration vehicles will allow the fleet managers to set up adequate processes to determine their best use and subsequently to manage, monitor and maintain the new PHEV technology when it is commercially available. Other municipal fleet managers participating in the PHEV task force process agreed and requested that the state develop a funding program to assist them also in demonstrating and monitoring PHEV technologies so the technology is tested in other application and promoted to constituents around the state.

ONE-, THREE-, AND FIVE-YEAR STRATEGIES TO OVERCOME BARRIERS

The task force concluded that strategic demonstration projects, combined with market intelligence are primary action areas in the near term that can help reduce barriers. Demonstration PHEVs within key organizations in Minnesota would provide needed experience, build awareness, gauge market signals and begin to reduce barriers for PHEV commercialization. Within both of those action areas, the task force built in strategies to link PHEV task force efforts to business start-up or expansion opportunities within the new plan for the Ford Motor site, and either with Ford Motor Company or another automotive related industry partner. Because of the potential for other advanced vehicle technologies to provide similar environmental benefits at lower cost and thus gain easier entry in the market, the PHEV task force did not want to eliminate the potential for business development from a competing technology. Thus, the task force's first year demonstration projects were drafted using broad language so as not to exclude a potential opportunity for business development in the state. The task force also expanded the scope of the market intelligence strategy to include investigation of other green manufacturing opportunities for the Ford site or other locations in Minnesota.

One Year PHEV Task Force Strategies:

- **Build strategic intelligence** about advanced vehicle technologies including environmental benefits, economics, markets and growth areas to foster market transformation in appropriate markets and to assess future business development opportunities; broaden strategic intelligence to identify other green manufacturing business opportunities for the state including assessment of site needs, start up costs, ability to fit within an urban setting, labor skills, and appropriateness for location at Ford site.
- **Build market awareness** through development of partnerships throughout the state, which demonstrate PHEV technology for targeted applications.
- **Verify PHEV performance** in Minnesota's challenging climate and verify environmental benefits by monitoring, measuring and analyzing performance data from task force sanctioned demonstration projects; particular attention will be given to developing and monitoring standard measurement protocols that evaluate technical, cost and electric infrastructure barriers identified by the PHEV task force in this report and analyzing results.
- **Develop infrastructure and knowledge** for incorporating PHEVs into state fleets: introduce state agencies and state employees to PHEVs in order to build awareness of technology; provide state fleet management staff with experience in PHEV operations and maintenance; develop expertise within MnDOT and State Fleet Council to integrate PHEV into the state fleet when PHEVs become commercially available.
- **Design and demonstrate** extended functionality of a Minnesota-made neighborhood electric vehicle so that it can serve new markets and expand its business.

- **Develop** industry, government, university and state **partnership**s to share expertise and guide policy initiatives and promotion of clean vehicle technologies.
- **Provide seed funding** for PHEV or other advanced vehicle demonstration projects that offer business opportunity or other needed benefits to the state.
- **Develop standard methods to assess available electric capacity** for PHEVs throughout the state, identify appropriate electric incentives and begin planning for Vehicle to Grid capability through teaming with Minnesota's electric utilities.

Year One PHEV Task Force Projects and Funding Request

The following projects were developed by the task force to further the one-year strategies. These projects are included in Governor Pawlenty's Next Generation Energy budget for FY 2007-2008:

PHEV Technology Demonstrations: $985,000 over two years to develop and demonstrate Plug-in Hybrid Electric Vehicles (PHEV) within functional markets that can best influence the commercialization of the technology. This project will:

- **Develop vehicle measurement standards** and oversee the measurement and analysis of emissions and performance data for PHEV Task Force sanctioned projects.
- **Assess PHEV technology, build expertise and awareness and develop PHEV infrastructure** within state government to prepare state fleet managers for incorporation of PHEVs.
- **Design and develop systems components** to extend the operation, expand functionality and provide greater reliability to a Minnesota manufactured neighborhood electric vehicle so it can serve new markets.
- **Demonstrate PHEV technology** by providing competitive, cost-share grants for PHEV demonstration projects; or demonstration projects of other advanced, energy efficient vehicle technologies, which rely on broadly available infrastructure, especially Minnesota produced E85 or bio-diesel, and have potential for business development.

How Year One Projects Fit Demo Project Criteria

	Demonstration Project Criteria					
Year One Projects	**PR Value**	**Econ/Perform**	**Replicable**	**Emission Reduction**	**Meets Standards**	**Partnerships**
Develop Standards	n/a	YES	YES	YES	YES	YES
Demos within State Fle	YES	YES	YES	YES	YES	YES
Demo of EV Hybrid	YES	YES	YES	YES	YES	YES
Grants for Demo Proje	YES	YES	YES	YES	YES	YES

PHEV and Green Manufacturing/Business Market Opportunity Study:
$350,000 over 2 years to identify best markets for PHEV commercialization and investigate other green manufacturing opportunities for the state:

- **Assess driving/vehicle trip trends and recommend markets** for Plug-in Hybrid Electric Vehicles (PHEVs) in MN and identify user segments, vehicle functions and fleet types that are best target markets.
- **Identify potential growth areas** for applied research for green manufacturing industries for alternative and renewable energy technologies; green building products, components for PHEVs; and other products that are environmentally sound and develop an implementation plan and market assessment study to determine the feasibility of locating green manufacturing or assembly businesses at the Ford Plant site in Saint Paul or other appropriate locations in Minnesota.
- **Identify strategies and/or incentives to overcome barriers** to the startup of such businesses and develop qualified sales leads for state and regional economic development agencies that would be compatible with the City of St Paul's proposed multi-use plan for the Ford site or suitable for other locations within the city or state.
- **Retain High Wage Jobs** by attracting or expanding businesses/industries that require workers with skills similar to the skills of employees of the Saint Paul Ford Plant or for which Ford Plant employees could be retrained.
- **Estimate costs to convert existing manufacturing plants**, such as the Ford plant, into environmentally oriented manufacturing facilities through retooling/retrofits.

Both above projects (the PHEV technology demonstration projects and the green manufacturing/business market opportunity study) have been introduced to the 2007 legislature and funding for them has been requested.

MN PHEV TASK FORCE THREE-YEAR STRATEGIES:

- **Develop plan for awareness building**, familiarization and incentives to transform vehicle markets within the segments identified in market intelligence study so that PHEVs or other clean technologies comprise a greater share of their vehicles.
- **Build outreach system** to provide qualified sales leads of expanding businesses involved in PHEV or other green manufacturing to economic development agencies throughout the state.
- **Determine optimal applications and locations** for PHEVs within the state owned fleets.
- **Prepare infrastructure within state government** for incorporating PHEVs into state-owned fleets.
- **Develop State of Minnesota procurement specifications** for PHEVs or other appropriate clean vehicle technologies if commercially available.

- **Determine appropriate incentives** that can help market penetration of PHEV technologies, especially in optimal applications, in partnership with Minnesota electric utilities.
- **Develop a clearinghouse and outreach effort** for information on PHEVs, especially when they become commercially available.

MN PLUG-IN HYBRID ELECTRIC VEHICLE (PHEV) TASK FORCE FIVE YEAR STRATEGIES:

- **Design and develop "Vehicle to Grid" demonstration project** in collaboration with Minnesota utilities and appropriate industry and university partners.
- **Review and revise state procurement plan for PHEVs** and other clean vehicle technologies.
- **Set market penetration goals** for targeted market segment.
- **Expand incentives** to achieve market penetration goals.
- **Promote use** of commuter plug-in hybrid vehicles by encouraging and co-funding programs by which the businesses offer incentives to employees who purchase PHEVs and use them for commuting to and from work.

PHEV TASK FORCE ENVIRONMENTAL IMPACT ANALYSIS

The PHEV task force legislation gave specific direction to the Minnesota Pollution Control Agency (MPCA) to provide estimates of the anticipated air emissions that Minnesota could expect if market penetration of PHEVs was to reach certain levels within the Minnesota marketplace. The Minnesota legislature, under Chapter 245 Section 3 tasked MPCA with the following emissions analysis:

> *The commissioner of the Pollution Control Agency shall analyze and report to the task force the environmental impacts of purchasing plug-in hybrid electric vehicles for the state-owned vehicle fleet and at penetration rates of ten percent, 25 percent, and 50 percent of all motor vehicles registered in this state. The analysis must compare, for plug-in hybrid electric vehicles and current fleet vehicles, air emissions of sulfur dioxide, nitrogen oxides, particulate matter less than 2.5 microns in width, volatile organic compounds, and carbon dioxide.*

At the request of the MPCA, the task force authorized a sub-group to work with MPCA to identify the assumptions that would guide that analysis.

Background for Emission Study

PHEVs have an unusual air emission profile because they offset some gasoline consumption with grid electricity. Thus, in addition to the vehicle operations emissions, the emissions caused by generation of electricity must also be taken into account. Factors such as fuel type, plant efficiency, time of day, capacity, seasonal load and type of electric generation affect emissions. Estimation of emissions at a point of use (in this case at the point where the vehicle battery is recharged) is even more complex because electrons from the different generators are mixed together on the grid. Within Minnesota, estimates of emissions from electric generation vary widely depending on the fuel mix used.

MPCA ran five different scenarios involving varying ratios of clean emitting electric generation to electricity generated using coal to estimate the emission profile produced to recharge a PHEV battery: a worst case scenario, assuming 100% of the electricity for PHEV battery recharging came from coal generation; an intermediate scenario, assuming 80% from coal and 20% from wind; a most likely scenario, with a 60% coal to 40% wind mix; an optimistic scenario in light of Minnesota's new renewable energy objective with a 40% coal to a 60% wind scenario; and, finally, a best case scenario, assuming that all of the electric was produced using wind or a comparable non-emitting source.

Emissions for a PHEV are affected by factors such as driving behavior, vehicle type and weight, and battery range. These factors had been previously investigated by EPRI and the results have been used by other organizations involved in PHEV analyses. The EPRI model assumed a low end for a PHEV's battery range of 20 miles before recharge, which current technology can achieve, and the high end at an anticipated 60-mile battery range. MPCA incorporated the EPRI PHEV models into its analysis.

MPCA used a 2004 data set on mobile source emissions as the data source for the analysis use. More recent data set would need testing and verification, requiring additional time. The task force agreed that the 2004 data set was adequate for the analysis.

Minnesota Passenger Vehicles- Emission Study Results

MPCA released a draft emissions analysis, *Air Emissions Impacts of Plug-in Hybrid Vehicles in Minnesota's Passenger Fleets,* in mid-March, 2007. (See Appendix B for Executive Summary and www.????? to download full report.) The study compared emission profiles, specifically criteria pollutant and greenhouse gas emissions, for three hypothetical passenger car-sized PHEVs derived from the EPRI models, ones that have a 20-mile electric driving range, a 40-mile range and 60-mile range, respectively, to a typical gas powered passenger car with an internal combustion engine. MPCA staff also compared the three PHEV models to a similarly modeled hybrid electric vehicle. The profile of a typical passenger vehicle in Minnesota was developed based on county level data from the Minnesota Department of Public Safety that reflects urban and rural driving patterns and then computed average annual emissions.

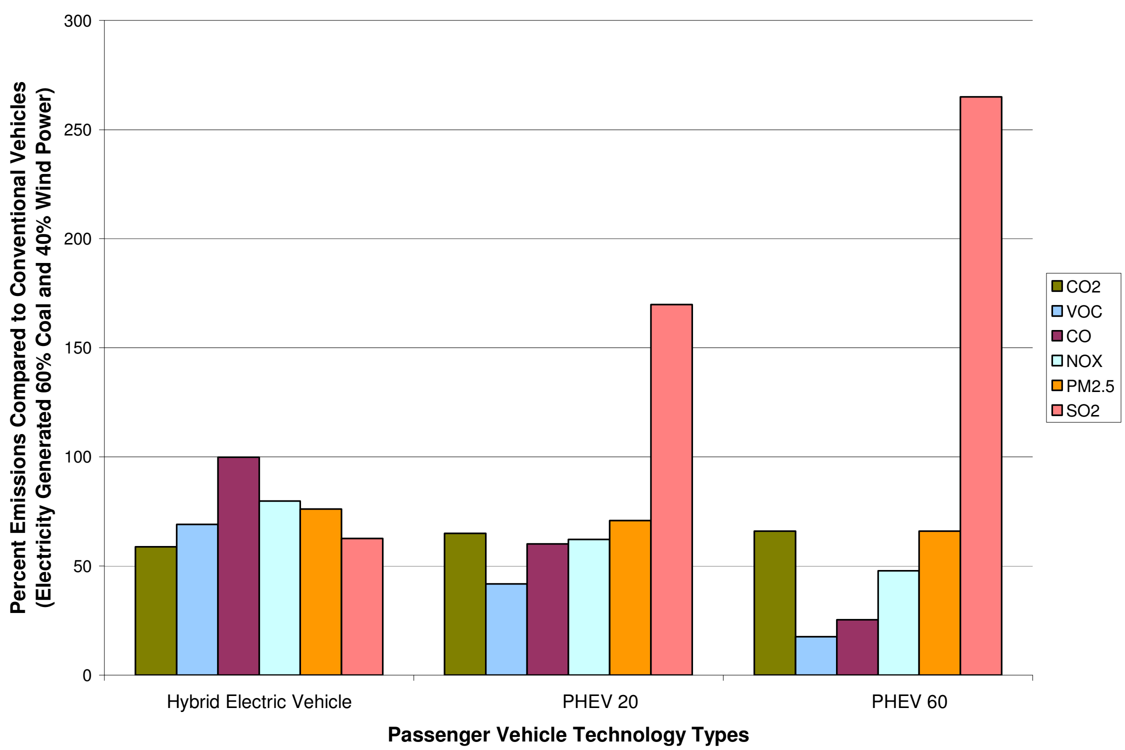
The study used nationally accepted emissions estimation models (Argonne National Laboratory's Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation model, or GREET; and U.S. EPA's MOBILE6, Vehicle Emission Modeling Software) to calculate emissions from the tailpipe, as well as emissions from the production of the energy to power the plug-in car. For the gasoline used in the vehicles, the model estimated the emissions released by both the oil refineries to produce gasoline and the ethanol plants to produce the 10% blend required in Minnesota. In the case of a PHEV, the models calculate an emissions profile for the electricity produced to recharge the battery from the electric grid. The study also developed four different scenarios for the mix of electric on the grid to power the PHEV models: 100% of electricity generated by coal; 20% of electricity generated by wind (or other zero-emission technology) and 80% generated by coal; 40% wind and 60% coal; and 100% wind power. The emissions profile included analysis of CO_2, CO, SO_2, NO_2, VOCs and particulate matter less than 2.5 microns.

The emissions profile for the PHEVs, one with a 20 mile range and one with a 60-mile range, regardless of electric mix, compared favorably to emissions from a typical internal combustion powered passenger car for all emissions that were modeled, except for SO_2. The higher level of SO_2 emissions attributed to PHEVs over conventional internal combustion engine (ICE) vehicles is due to the need to recharge a PHEV's batteries on the electric grid. Generating electricity from coal releases SO_2 into the air. There are two primary factors that influence SO_2 emissions from PHEVs: the portion of electricity generated from coal, and the range of the electric motor. The analysis assumed an average SO_2 emissions rate of .2 lbs of SO_2 per MMBtu of energy input, which is the level that Minnesota would require from power plants under Clean Air Interstate Rules (CAIR). Minnesota power plants currently release approximately 0.5 lbs of SO_2 per MMBtu input. Once the new regulations are in place, SO_2, NO_x and (now) mercury emissions from the electric power sector will be limited to these levels by state and federal regulation, and, except for a few caveats, will not be allowed to increase on an overall, net basis due to new sources of electric demand. Furthermore, the increase in SO_2 is not a major concern because release of SO_2 can be controlled at the power plant with investment in off-the-shelf control technologies.

Further analysis is needed to both determine the degree that SO_2 emissions would need to be lowered for PHEVs to achieve net neutral SO_2 emissions and to estimate the amount of investment dollars in control technology needed at power plants to achieve the target level. Overall, the models show that emissions from a PHEV for the other pollutants were generally 30% to 60% lower than emissions per mile from the conventional ICE passenger vehicle. (See Figure 1 below.)

The study also compared the emission profiles of the PHEV models to a typical hybrid electric vehicle (HEV) and a typical HEV to a conventional ICE vehicle. Results showed that HEV vehicles have positive impacts on air emission for all measured emittants when compared to conventional ICE vehicles. When an HEV was compared to a PHEV, the PHEV attained marginally lower emissions than an HEV for all emittants other than CO_2 and SO_2. In this comparison, SO_2 emissions were considerably higher for PHEVs, once again influenced by the mix of electricity used to recharge the battery and the driving range of the PHEV model. CO_2 emissions were also found to be slightly higher for a PHEV than a HEV in three of the four electric generation scenarios (100% coal; 80% coal and 20% wind; and 60% coal and 40% wind). (See Figure 1 below.)

Figure 1. The alternative vehicle emissions described as a percent of conventional vehicle emissions for the scenario where 60% of electricity is generated by coal and 40% is generated by wind.



State of Minnesota Owned Fleet Passenger Vehicles- Emission Study Results

The second part of the PCA study assessed the impact on air emissions that could be achieved if the State of Minnesota replaced specified portions of its vehicles fleet with PHEVs. PHEVs were modeled to represent 10%, 25%, and 50% of all passenger vehicle miles driven. PCA used the same methods as were used to estimate emissions for the passenger vehicles. In this case, modeled air emissions for the year 2020 declined for all emittants except for SO_2. Because the state passenger vehicle fleet is small, totaling about 2,100 vehicles, the study found that reduction of net air emissions at any penetration rate was negligible. CO_2 was reduced by about 250 tons while other changes in emission levels resulted in reductions of only a few tons or less in the most likely scenario. (See Table below.)

Total Annual State Owned Fleet Emissions and Change in Emissions at 10% Alternative Vehicle Penetration

	Conventional Vehicle Fleet	Hybrid Electric Vehicle		PHEV 20		PHEV 60	
		10% Penetration		10% Penetration		10% Penetration	
	Annual emissions (tons)	Annual emissions (tons)	% Change	Annual emissions (tons)	% Change	Annual emissions (tons)	% Change
CO_2	7250	6952	-4.1	6996	-3.5	7003	-3.4
VOC	13.1	12.7	-3.1	12.3	-5.8	12.0	-8.2
CO	195	195	0.0	188	-4.0	181	-7.5
NO_x	7.60	7.44	-2.0	7.31	-3.8	7.20	-5.2
$PM_{2.5}$	0.449	0.438	-2.4	0.436	-2.9	0.434	-3.4
SO_2	1.42	1.36	-3.7	1.51	7.0	1.65	16.5

Note: State owned and leased fleet total annual emissions and percent emissions change with 10% fleet penetration compared to conventional passenger vehicles, for each class of technology and electricity generated by 60% coal and 40% wind power. The percent decrease or increase in emissions is equal for the state owned fleet and for the statewide vehicle fleet; the total emissions for the statewide and state owned fleets are proportionally scaled.

NEXT STEPS FOR PHEV TASK FORCE

The PHEV Task Force submitted a funding request to the Minnesota legislature. That request has been included in the Governor's recommendations and introduced in the legislature. The task force will reconvene after the current 2007 legislative session to coordinate and oversee development of legislatively approved projects resulting from 2007 legislative action.

Appendix A

Participants in the Minnesota Plug-in Hybrid Task Force Process
November 2006 – March 2007

1ST Name	Last Name	Organization
Paul	Adelmann	Xcel Energy
Roger	Aiken	CREED
Bob	Ambrose	Great River Energy
Chris	Apdi	Charter
Chris	Bahn	MSU, Mankato
Ken	Bradley	Fresh Energy
Bemjamin	Braus	MN Senate Staff
Mike	Bull	MN Department of Commerce
Anne	Caflin	MPCA
Peter	Cibirowski	MPCA
Merritt	Clapp-Smith	City of St Paul
Mary	Culler	Ford Motor
Scott	Dibble	MN Senate
James	Eagle	UAW
Jerry	Fruin	UMN
Edward	**Garvey***	**MN Dept of Commerce**
Tim	Gerlach	American Lung Assn
Andrew	Gibbons	UMN
Charles	Griffith	Ecology Center
Amy	Grimsrud	Ford Motor
Dan	Hayes	SMMPA
Dick	Hemmingsen	UMN
Lynn	**Hinkle***	**UAW**
Frank	Hornstein	MN House
Anne	Hunt	City of St Paul
Bruce	Jones	MSU, Mankato
Claudia	Juska	Ecology Center
David	Kittelson	UMN
Larry	Krause	3M
Sandra	Kresbach	Citizen and City of Mendota Heights
Jacob	Kriesel	MSU, Mankato
Rod	Larkins	3M
Craig	Lietha	eride Industries
Linda	Limback	MN Department of Commerce
Dick	Livermore	City of Minneapolis
Luke	Markham	MSU, Mankato
Laurie	McGinnis	UMN - CTS
Rob	McKenzie	UAW
Bob	Moffitt	Americal Lung Assn
David	Morris	ILSR
Tim	Morse	MN Admin
Mary	Morse	Neighborhood Energy Connection

Sandy	Neren	Alliance of Auto Mfgrs
Daniel	Norrick	Cummins Power Gen
John	Peters	MnDOT
Paul	Plahn	Cummins Power Gen
Melissa	Pollak	UMN
Gayle	Prest	City of Minneapolis
Rajesh	Rajamani	UMN
Tony	Reichel	MSU, Mankato
Mike	Rhodes	Honeywell
William	Robbins	UMN
Scott	Rolar	UMN-ME
John	Scharffbillis	MN/DOT
Dave	Schiller	MN DNR
Nate	Starkson	MSU, Mankato
Joseph	Steffel	City of Buffalo, Municipal Utilities
Steve	Sussman	DEED
Jamal	Thompsu	Cummins Power
David	Thornton	MPCA
Jim	Turnure	Xcel Energy
Vincent	Winstead	MSU, Mankato
Bruce	Wollenberg	UMN

*** Co-chair**

APPENDIX B

Air Emissions Impacts of Plug-In Hybrid Vehicles in Minnesota's Passenger Fleet: Report to the Plug-In Hybrid Task Force, March 2007

Summary of Findings

Single Vehicle Comparison

Comparing alternative vehicle emissions per mile is the basis for calculating the impacts of incorporating the vehicles into the state fleet. Table 1 shows GREET-modeled PHEV emissions as a percentage of modeled 2020 emissions for a conventional ICE vehicle; these results are shown graphically in Figure 1. As noted above, emissions for the conventional ICE vehicle were developed using MOBILE6. The emission estimates shown in Table 1 are for comparable mid-sized sedans (GREET average passenger car). Emissions estimates were calculated from the emissions produced by fuel production and vehicle operations (Appendix A).

The following conclusions can be drawn from a vehicle-to-vehicle comparison:

- With the exception of SO_2, emissions for both the PHEV and the HEV are lower than emissions from the conventional ICE vehicle.
- A PHEV has marginally lower emissions for all emittants, except CO_2 and SO_2.
- Emissions from PHEVs per mile decrease as the all-electric range increases from 20 miles to 60 miles, again with the exception of SO_2.
- Emissions per mile from PHEVs are generally 30% to 60% lower than emissions per mile for the conventional ICE vehicles.

PHEV Air Emissions as a % of Emissions from Conventional Vehicles			
	Hybrid Electric Vehicle	PHEV 20	PHEV60
		60% Coal, 40% Wind	60% Coal, 40% Wind
CO_2	59%	65%	66%
VOC	69%	42%	18%
CO	100%	60%	25%
NOX	80%	62%	48%
$PM_{2.5}$	76%	71%	66%
SO_2	63%	170%	265%

Table 1: Relative percent of total conventional vehicle emissions emitted by alternative technology vehicles for each class of technology at the future scenario where electricity is generated by 60% coal and 40% wind power.

Per-mile PHEV emissions of SO_2 are higher than for either the conventional gasoline-driven ICE or the hybrid electric vehicles due to the high sulfur content of the coal that is assumed to be combusted at the power plant. In the example shown in Table 1, 60% of the electricity consumed by the plug-in electric side of the vehicle is assumed to be generated through coal combustion. For purposes of this calculation,[1] an average SO_2 emission rate of 0.2 lbs per MMBtu of energy input was assumed. This was developed from an analysis of the likely regional rate of emission in 2020 under the Clean Air Interstate Rule (CAIR) issued in 2005 by the U. S. EPA.

PHEV CO_2 emissions are lower than the conventional ICE vehicle emissions but are marginally higher than the hybrid electric vehicle emissions. This is due in part to the relatively higher carbon content per MMBtu of coal compared to the carbon content of gasoline. A conventional passenger vehicle in 2020 releases 5.4 tons of carbon dioxide annually; a hybrid vehicle (HEV) releases 3.2 tons annually; a PHEV 20 (60% coal, 40% wind) 3.5 tons per year; and a PHEV60 (60% coal, 40% wind) 3.6 tons per year[2].

Carbon dioxide emissions are also dependent on fuel efficiency. Fuel use by single vehicles of each type can be represented as gasoline fuel efficiency and kWh per mile (Table 2). Gasoline and electric sides of the vehicle are separated so that the fuel efficiency is for the miles traveled on the gasoline or electric side only. Considering that the PHEVs only use gasoline for a portion of miles, the fuel efficiency is often advertised as gasoline used over all miles traveled, resulting in much higher fuel economy. (Appendix E provides detail on fuel consumption, fuel efficiency, and miles traveled under gasoline ICE and electric power.)

Fuel Efficiency Projections from GREET and EPRI Models (Miles Per Gallon Gasoline Equivalent where electricity is used)				
	Conventional Vehicle	Hybrid Electric Vehicle	PHEV 20	PHEV 60
GREET ICE side mpg	25 mpg	43 mpg	43 mpg	43 mpg
GREET Net Fuel Efficiency	25 mpg	43 mpg	56 mpeg	68 mpeg
EPRI ICE side mpg	34 mpg	42 mpg	45 mpg	47 mpg
EPRI Electric side kWh/mi			0.299 kWh/mi	0.296 kWh/mi
EPRI Net Fuel Efficiency	34 mpg	42 mpg	74 mpeg	194 mpeg

Table 2: Fuel efficiency estimates for a GREET modeled passenger vehicle (average sedan) and an EPRI modeled compact car, for both gasoline and electric sides, expressed in gasoline equivalent gallons. Efficiency based on average fleet efficiency. The gain in fuel efficiency from regenerative braking is seen in the hybrid vehicle and the reduced dependence on gasoline because of electric power is shown in the increased fuel efficiency of the PHEV models.

[1] Current SO_2 emissions are approximately 0.5 lbs per MMBtu. For a PHEV, SO_2 emissions must be less than 0.1 lbs per MMBtu for a PHEV 20 using 60% coal electricity to outperform the modeled conventional vehicle.

[2] Carbon dioxide emissions were additionally calculated with a range of possible fuel efficiencies. For the emissions listed in the text, an on-road average fuel economy of 23.8 miles per gallon was used taken from the EIA Annual Energy Outlook 2005, representing a more conservative prediction. GREET predicts a higher fuel efficiency of 25.3 mpg. Using this higher fuel efficiency, 3.0 tons are emitted annually from an HEV, 3.4 tons of CO_2 are emitted annually from a PHEV 20 and 3.8 tons from a PHEV 60 where 60% of electricity is generated by coal; a conventional ICE would emit 5.1 tons annually. A more optimistic view of average on-road conventional vehicle fuel economy, 35 mpg, further reduces carbon dioxide emissions to 4.0 annual tons from a conventional vehicle; 2.3 annual tons from an HEV; 3.0 annual tons from a PHEV 20 where 60% of electricity is generated by coal; 3.6 annual tons from a PHEV 60.

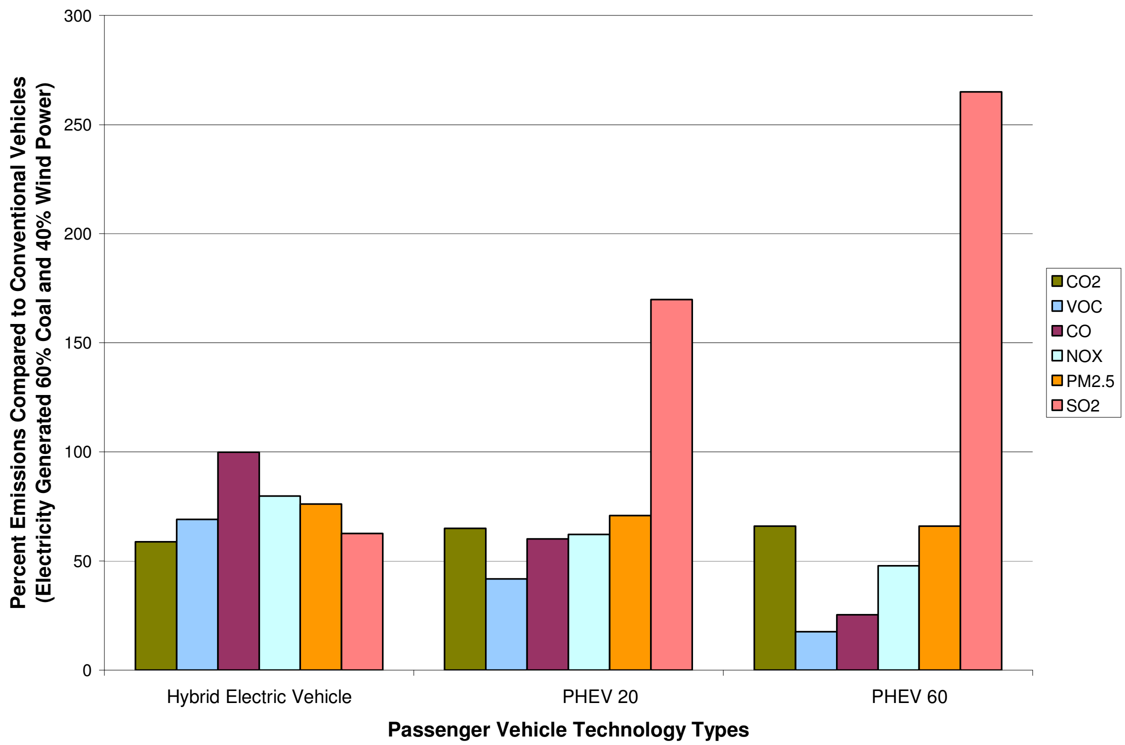


Figure 1: Relative percent change in total pollutant emissions per vehicle compared to conventional passenger vehicles, for each class of technology in the future scenario where electricity is generated by 60% coal and 40% wind power. Emissions greater than 100% represent an increase in emissions over a conventional ICE vehicle.

Change in Fleet Emissions

To estimate the fleet effects of the introduction of PHEVs, the emissions changes identified in Table 1 were introduced into the conventional vehicle base emission forecast. This base emission forecast was developed using MOBILE6.

The following was assumed:

- Total statewide VMT increases from 56.5 billion vehicle miles traveled (VMT) in 2006 to 75.5 billion VMT in 2020.
- Passenger car VMT is a percentage of total 2020 VMT (34.59%); this was taken from the 2004 U. S. EPA CAIR VMT Projection modeling.
- Passenger car VMT is then 26 billion miles in 2020.

The fleet penetration calculation was performed for 10%, 25% and 50% penetration of PHEVs into the fleet, based on miles traveled. The 10% fleet penetration scenario is shown in Table 3. With only 12 years remaining before 2020, it seems unlikely that more than 10% of the fleet in fact could be PHEVs. At higher penetration rates, the impacts are proportionally greater. (The higher penetration scenarios are shown in Appendix B –

Statewide Fleet Penetration Effects, and Appendix C – State Owned Fleet Penetration Effects).

The following conclusions can be drawn from the 10% fleet penetration scenario, where electricity is generated by 60% coal and 40% wind power:

- Fleet emissions with 10% PHEV penetration are generally lower than emissions from conventional vehicle fleets. Across most pollutants, fleet emissions are 3% to 8% lower with 10% PHEV penetration.
- With the exception of SO_2 and CO_2, fleet emissions are generally lower with 10% PHEV penetration than 10% HEV penetration.
- Fleet SO_2 emissions increase 7% to 17% with 10% PHEVs; this results from dependence on coal electricity generation in the scenario.
- PHEV emissions of CO_2 are lower than for the conventional ICE by about 400,000 tons.
- Fleet emissions of CO_2 using 10% hybrid electric vehicles are about 0.5% lower than with 10% fleet penetration with PHEVs.

Total Annual Statewide Fleet Emissions and Change in Emissions at 10% Alternative Vehicle Penetration

	Conventional Vehicle Fleet	Hybrid Electric Vehicle		PHEV 20		PHEV 60	
		10% Penetration		10% Penetration		10% Penetration	
	Annual emissions (tons)[3]	Annual emissions (tons)	% Change	Annual emissions (tons)	% Change	Annual emissions (tons)	% Change
CO_2	11,749,182	11,265,392	-4.1	11,337,384	-3.5	11,348,903	-3.4
VOC	21,207	20,550	-3.1	19,972	-5.8	19,459	-8.2
CO	316,779	316,736	0.0	304,141	-4.0	293,126	-7.5
NO_x	12,311	12,061	-2.0	11,845	-3.8	11,668	-5.2
$PM_{2.5}$	728	710	-2.4	707	-2.9	703	-3.4
SO_2	2,295	2,209	-3.7	2,455	7.0	2,673	16.5

Table 3: Statewide fleet total annual emissions and percent emissions change with 10% fleet penetration, compared to conventional passenger vehicles, for each class of technology and electricity generated by 60% coal and 40% wind power. The percent decrease or increase in emissions is equal for the state owned fleet and for the statewide vehicle fleet; the total emissions for the statewide and state owned fleets are proportionally scaled. Emissions changes shown in red are increases compared to a completely conventional vehicle fleet.

Emissions changes depend on how quickly PHEVs are assumed to enter the fleet. Figure 2 shows the effect of different PHEV penetration rates for PHEV 60 vehicles. If by 2020, 50% of the fleet of all privately- and publicly-owned passenger cars was comprised of PHEVs, most emittants would be 15 to 40% lower than for a fleet of 100% conventional ICE vehicles. However, in the case of SO_2, emissions would actually increase by 182%.

[3] Total annual statewide tons of pollution emitted from all sources (2001 data): CO = 2,342,279 tons, NO_X = 450,693, $PM_{2.5}$ = 203,492, SO_2 = 148,827, VOC = 413,204. Data available at EPA AirData.

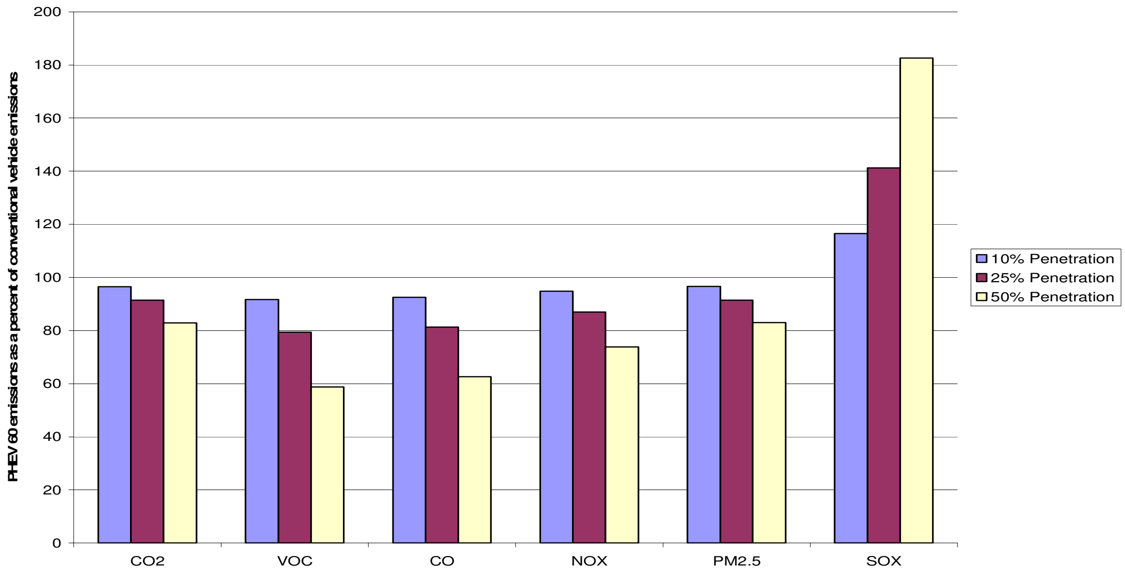


Figure 2: Effects of penetration rates on emissions from a PHEV 60, electricity generated by 60% coal, 40% wind power. Percent emissions compared to a conventional vehicle fleet for penetration rates of 10%, 25%, and 50% of the fleet.

The effect of PHEV penetration on fleet emissions from passenger cars owned or leased by the State of Minnesota is shown in Table 3. We used the same methods as were used to estimate emissions for all privately-and publicly-owned vehicles traveling Minnesota highways. Modeled air emissions at 2020 declined for all emittants but SO_2. Due to the extremely small number of vehicles owned or leased by the state—2,099 total vehicles in the passenger car class—the associated emission reductions were small in absolute terms. The largest reductions were for CO_2, which declined by about 250 tons. All other changes were a few tons or less.

Total Annual State Owned Fleet Emissions and Change in Emissions at 10% Alternative Vehicle Penetration							
	Conventional Vehicle Fleet	Hybrid Electric Vehicle		PHEV 20		PHEV 60	
		10% Penetration		10% Penetration		10% Penetration	
	Annual emissions (tons)	Annual emissions (tons)	% Change	Annual emissions (tons)	% Change	Annual emissions (tons)	% Change
CO_2	7250	6952	-4.1	6996	-3.5	7003	-3.4
VOC	13.1	12.7	-3.1	12.3	-5.8	12.0	-8.2
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NO_x	7.60	7.44	-2.0	7.31	-3.8	7.20	-5.2
$PM_{2.5}$	0.449	0.438	-2.4	0.436	-2.9	0.434	-3.4
SO_2	1.42	1.36	-3.7	1.51	7.0	1.65	16.5

Table 4: State owned and leased fleet total annual emissions and percent emissions change with 10% fleet penetration, compared to conventional passenger vehicles, for each class of technology and electricity generated by 60% coal and 40% wind power. Emissions changes shown in red are increases compared to a completely conventional vehicle fleet.

To summarize, generally the use of PHEVs in place of conventional gasoline-driven ICE vehicles will reduce air emissions. The sole exception appears to be SO_2 emissions, which rise due to the high sulfur content of coal combusted to generate electricity. The effectiveness of PHEVs depends on the all-electric range capability; a PHEV with a 60 mile range has greater impacts on emissions than a PHEV with a 20 mile range. In comparison to hybrid electric vehicles, PHEVs emit less NO_x, VOCs, CO, and particulate matter, but more CO_2 and SO_2. This results from the high sulfur and carbon content of coal per MMBtu. Depending upon our choices for electricity generation in 2020, it is possible that the impacts on carbon dioxide and sulfur dioxide could change.

Given the uncertainty of vehicle technology development, alternative vehicles offer benefits, but no single technology currently stands out as a clear choice. Further development and research for all types of vehicles is necessary to find the most efficient vehicles and fuels.

This report was prepared by the Minnesota Pollution Control Agency by legislative request for the Plug-in Hybrid Task Force.

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For full report, go to: www.commerce.state.mn.us > Energy Info Center > Plug-in Vehicles >
Air Emissions Impacts of Plug-In Hybrid Vehicles in Minnesota's Passenger Fleet