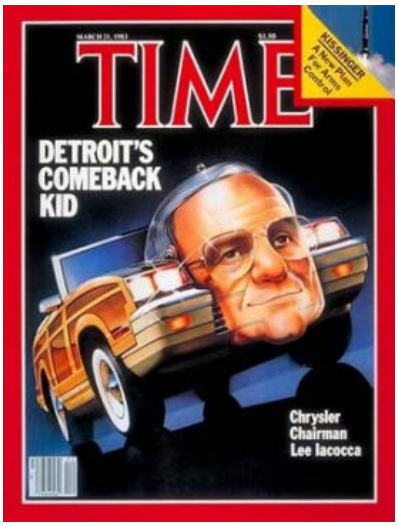
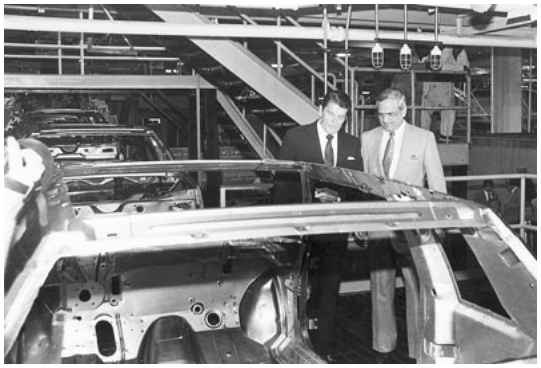
Ake Almgren, Orkas Inc. January 2009.

Plug-In Vehicles Crossing the Chasm.
Looking ahead from lessons learnt.

Trying to predict the future, it helps to know the history. Looking forward I like to share some lessons learnt based on my experiences from new technologies in general and plug-in hybrid vehicles in particular.

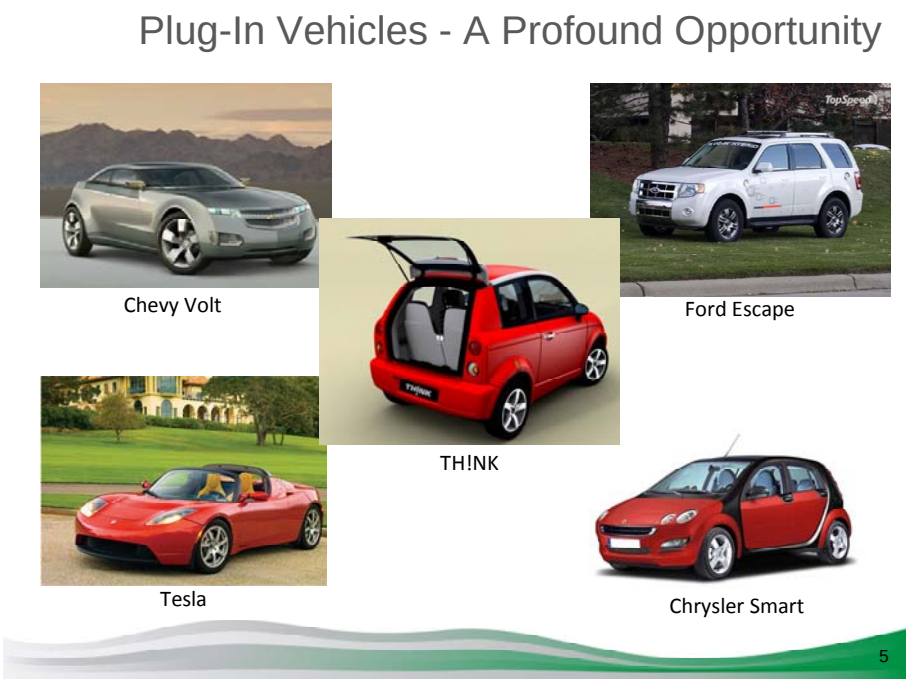
Lee Iacocca led in the 80s Chrysler through a major turn-around. The money Chrysler had borrowed from the federal government in 1979 was paid back in 1983. Several actions, including reducing his salary to one dollar, contributed to the turn-around.





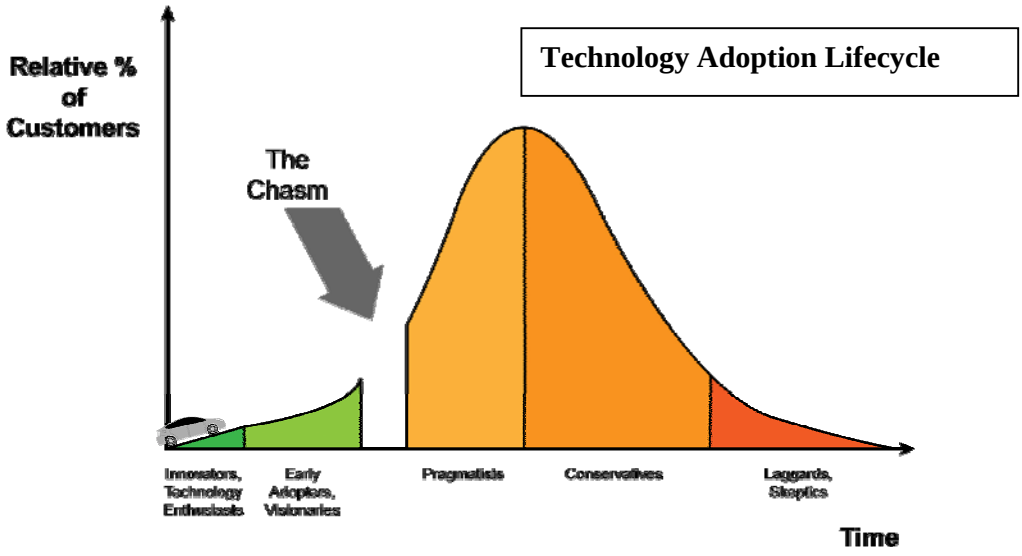
After the turn-around Chrysler searched for ways to get into leadership positions. The legislation of Supplementary Restraint Systems (SRS), signed 1984 by the then Secretary of Transportation, Elizabeth Dole, gave Chrysler such an opportunity. While most of the other automakers chose the less costly alternatives of passive seatbelts or motorized belts, Chrysler decided to be the first major car maker to have driver-side airbags installed on all their vehicles by 1990. Chrysler's decision more than anything else led to a consumer driven demand, contrary to a legislation driven demand. It made airbags a de facto worldwide standard on all cars.

In a similar but even more profound way the plug-in electric and plug-in hybrid vehicles represent now a unique opportunity not only for the US automotive industry but for the US society as a whole.



The plug-in vehicles offer “fuel costs” at less than one dollar a gallon, improved air quality and reduced green-house gases. Today we import well over 60 % of our transportation fuel. Plug-in vehicles using electric power produced in USA, using domestic feedstock will also go a long way towards energy independence.

It starts to sound like a “no-brainer”, but like any major technology change there is a chasm of acceptance to cross. In his book ‘Crossing the Chasm’ Geoffrey More describes the technology adoption lifecycle. Technology enthusiasts and visionaries are the first to embrace a new technology. Broader acceptance comes when the pragmatists start to utilize the technology, later followed by the conservatives and finally by the skeptics. The most critical step, crossing the chasm, is the adoption by the pragmatists.



Many technologies never cross the chasm. In this case, plug-in vehicles, I believe that the stage is set for crossing the chasm within the next 5 – 10 years. Some may say it is about time. The process started over a decade ago.

In the mid 90s Chattanooga introduced an all electric bus route in the downtown. It was one of several initiatives to dramatically improve the air quality. The buses were 22 feet buses using lead acid batteries. However, the lead acid batteries had limited capacity and had to be exchanged once a day. In order to be able to operate the full day without changing/charging the battery and without compromising the air quality, the conclusion was to build a series hybrid bus with a lead acid battery and a Capstone microturbine using compressed natural gas. The first series hybrid bus started to operate successfully in 1997.

Chattanooga 1997.
CARTA 714.
Series hybrid bus.

There are two fundamental design concepts for hybrid electric vehicles. A parallel hybrid electric has the reciprocating engine as the primary power source and uses a mechanical transmission. The battery is a supplement. A series hybrid electric vehicle uses the battery as the primary source and has an electrical powertrain. The engine is basically an on-board battery charger**. Series hybrid electric vehicles are also called plug-in hybrid electric vehicles (PHEV).**

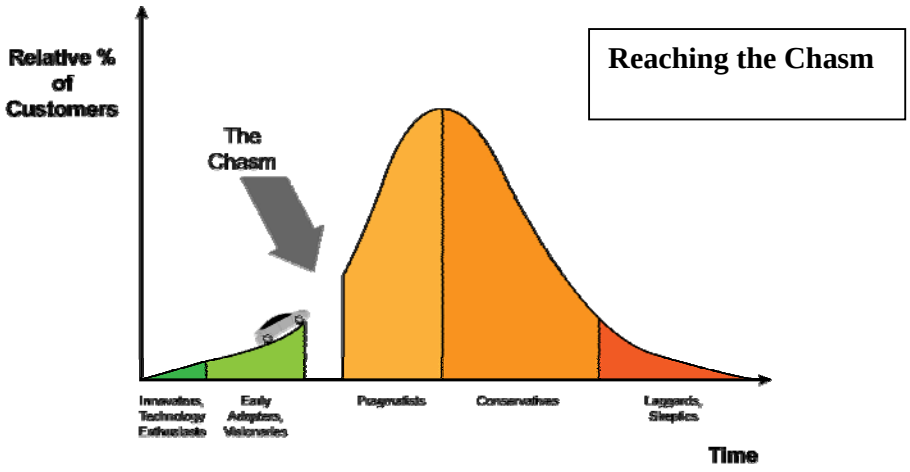
In fact the Capstone microturbine was originally developed with hybrid vehicles in mind. It was designed for extremely low emissions, less than 9 ppm of NOx, SOx and CO. It is one of the very few engines that can meet California's super ultra low emissions standards (SULEV), which are the most demanding air quality standards in the world, without any exhaust gas cleaning. The maintenance requirement is minimal thanks to features such as air bearings and thus no oil.

Capstone C30 (30 kW)

Several hundreds of microturbines have been delivered to buses around the world. Overall the performance of the vehicles has been quite good illustrated by success stories like at Christchurch, New Zealand. Three buses, designed and manufactured by Designline International, entered revenue service in March 2000. During the following 18 months they accumulated 189 000 miles with a 96 % availability.

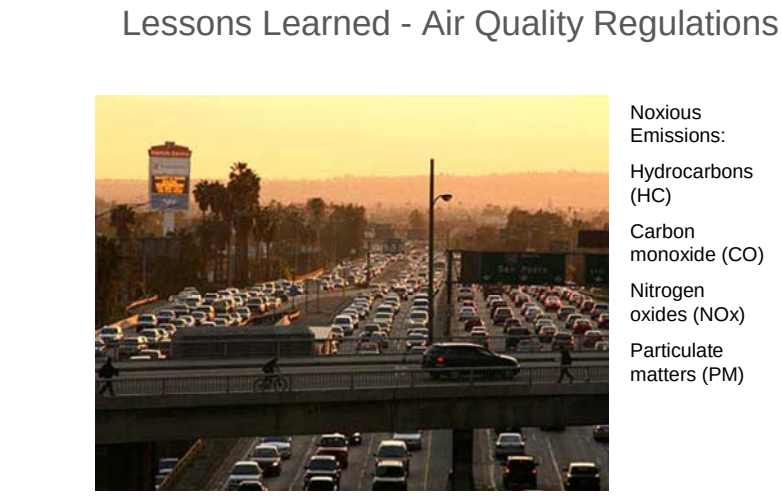
Designline International. MK Series Hybrid Electric Buses.

Nevertheless, series hybrid vehicles have not yet taken off as a mainstream commercial product. The chasm has been reached, but has not been crossed.



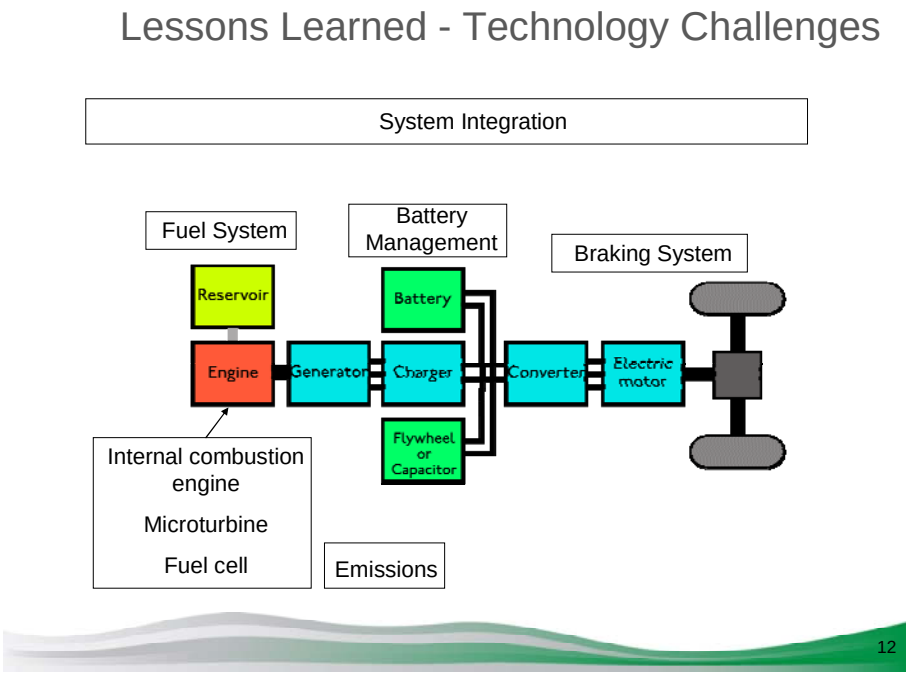
Which are the lessons learnt from these early developments?

Tougher air quality requirements, especially in California, helped stimulate the early development of plug-in vehicles. California Air resource Board (CARB) has frequently been the first in the world in setting higher standards for air quality. Generally after a while other states and countries have followed. Plug-in vehicles are not the only solution to achieve CARB's SULEV, but it is probably fair to say that without these standards we would have seen substantially less development of plug-in vehicles.



There were many technical lessons learnt. The developments of the inverters and the control systems were challenging. System integration and fuel systems, e g propane and diesel in addition to compressed natural gas (CNG) have also been anything but trivial. The single biggest issue was the battery. The lead acid battery has a low first

cost, but it has low energy density and cannot be deep cycled. Consequently, the battery had to be oversized and the whole system had more or less to be designed to optimize the battery performance and life.



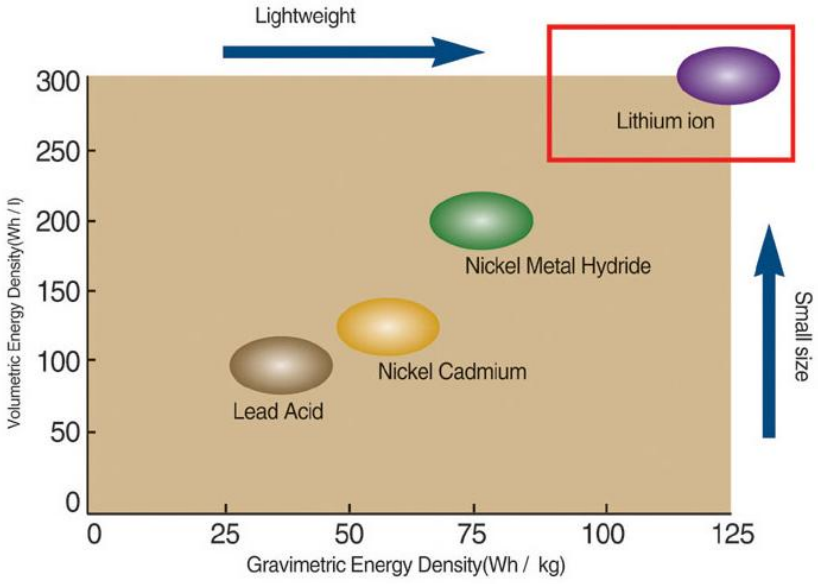
Neither the large automotive companies nor the major specialty vehicle companies pioneered the plug-in hybrids. It was generally small start-up companies, who were the pioneers. In spite of being innovative, fast and lean, it has been difficult to reach the cost levels necessary for a broader market acceptance. The pioneers had to go after narrow niche markets, where the benefits of the plug-in hybrid solution could justify the higher costs.

Clockwise:
Twin engine series hybrid bus. China.
Hybrid tractor trailer. Prototype. USA.
Tunnel hybrid locomotive. Japan.

A decade later many things have changed, not just a little but fundamentally. Battery technology has progressed significantly. Greenhouse gases have become part of the equation and there is now a strong public awareness about hybrid vehicles.

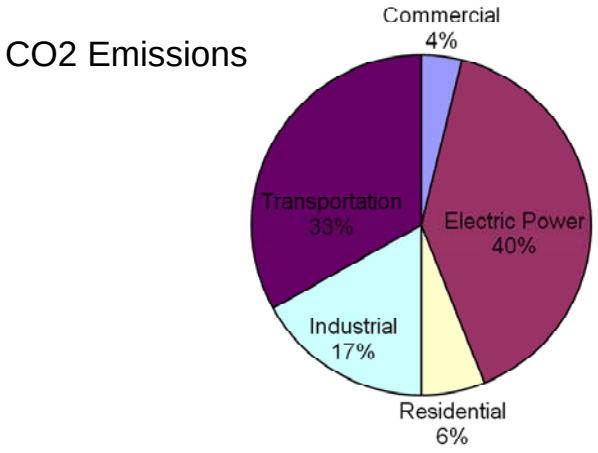
Thanks to Toyota with its Prius, let be a parallel hybrid, the hybrid concept has got great public awareness. Production started in 1997. US sales commenced in 2001. By 2008 over a million Pries have been sold. Prius success has resulted in the acceptance by the mainstream automotive companies. Most of them now offer hybrid vehicles and the first plug-in (series) hybrid cars are expected to enter the market in 2009/10.

In terms of technology the battery remains the single biggest challenge, but now there are many more options than the lead acid batteries, e g nickel metal hydride batteries, which are the ones used in the Prius. Most expectations are now set on the lithium batteries, which have four times the energy density of the lead acid batteries.



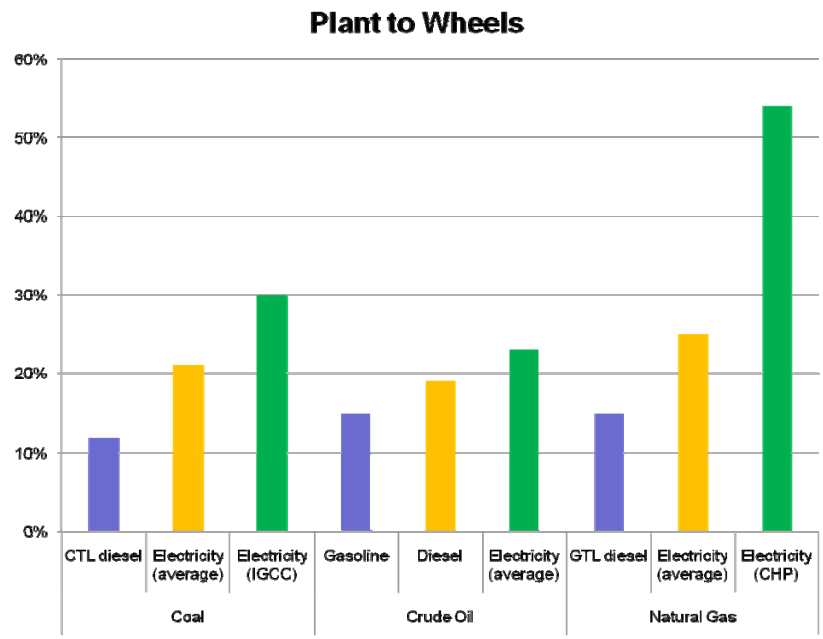
However, there are still many challenges in perfecting the lithium battery for automotive use, e g calendar life, cycle life, temperature range, safety and, not least, cost.

Fuel economy and air quality are still two main drivers for plug-in vehicles, but the greenhouse gases have become an additional and increasingly heavy factor. The transportation sector in USA produces over 30 % of all greenhouse gases. Consequently, it is difficult for the Government to ignore this sector when developing regulations and incentives for a reduction of carbon dioxide (CO2).



Source: Energy Information Administration. October 2008.

Since there are no practical means to capture the CO2 at the tailpipe, the only way to reduce the CO2 is by increasing the energy efficiency from well to wheels. Plug-in vehicles will have a lower carbon footprint. The biggest reduction would happen if the plug-in vehicles could be charged with electricity from renewable energy sources. Even with power from the fossil power plants the plug-in vehicles will be better. Several studies have concluded that it is more efficient to use fossil fuels to produce electric power and charge plug-in vehicles than to convert the energy to a liquid fuel for traditional vehicles with reciprocating engines. The electric powertrain of the plug-in vehicle has superior efficiency over the thermo-mechanical powertrain of the traditional vehicle.



Coal-To-Liquid: CTL, Integrated Gasification Combined Cycle: IGCC, Gas-To-Liquid: GTL, Combined Heat and Power: CHP.
Source: World Wildlife Foundation report: "Plugged In". 2008.

It is reasonable to believe that the Government will support plug-in vehicles both directly through tax credits and/or other incentives for purchases of plug-in vehicles, as well as indirectly by higher efficiency standards or through a mechanism for greenhouse gases cap and trade that includes vehicles.

Contrary to 10 years ago the Electric Industry now is not only accepting plug-in vehicles but actively in favor of them. Plug-in vehicles represent a new revenue stream. In fact it may be the single best opportunity for revenue growth. Since most plug-in vehicles will be charged during the night it can be done from using excess capacity at already existing power plants. Further with substantially more intermittent power generation sources, especially wind, having the plug-in vehicles will help the load leveling as well using the batteries for power regulation.

In conclusion: Public awareness, technology progress, Government support and the buy-in from the Automotive and Electric industries will help the plug-in vehicles cross the chasm, to where consumer driven demand will take over and make it a truly commercial success.