

Study Finds DOE-funded Research in Energy Storage Provides a Vital Foundation for Success of Today's Hybrid & Electric Vehicles

- Hybrid and electric vehicles are showing great developmental and commercial market progress.
- Innovations in nickel metal hydride and lithium-ion batteries are critical to these developments.
- DOE's research emphasis on each type of battery technology has preceded the market introduction of vehicles using them.
- Three decades of DOE-funded research on vehicle energy storage and related areas has resulted in 222 patents, cited 482 times by leading organizations active in battery technology for hybrid and electric vehicles.
- DOE's role in bringing together multiple organizations in the research and supplier communities helps establish successes with advanced batteries for hybrid and electric vehicle applications.

Current innovations in battery and ultracapacitor technologies found in today's hybrid and electric vehicles are traced back to foundational research in energy storage, funded by the Department of Energy (DOE) during the period spanning 1976 to 2007 -- according to an independent evaluation study.

Hybrid Electric Vehicles (HEVs) sales increased by 360,000 units in the U.S. from 1999 to 2007, with noticeably accelerated growth rates in 2004 and 2006 (Figure 1). Plug-in Hybrid Electric Vehicles (PHEVs) are also gaining public awareness and attention, while the development of next-generation Electric Vehicles (EVs) is underway.

DOE's 30 years of research in vehicle energy storage, including industry and university partner research funded by DOE, has contributed to these developments. The key pathways of DOE influence are: energy storage research for Nickel Metal Hydride (NiMH) batteries, currently used in HEVs, and advances in Lithium-ion (Li-ion) batteries, considered the battery of choice for PHEVs.

DOE research ranks near the top in patents for advanced battery & ultracapacitor technologies for hybrid & electric vehicles

Citations of DOE-funded patents by other organizations are an indicator of DOE's technology research impacts. Over the period 1976 to 2007, some 222 DOE-funded patents were awarded in battery, ultracapacitor, and supporting component technologies linked to patents covering the batteries used in today's HEVs, PHEVs, and EVs.

DOE-funded patents were cited by more battery/ultracapacitor patents than any other organization, except Matsushita (Figure 2). DOE's patent citation ranking is a conservative estimate because some of Matsushita's NiMH-related patents are linked to DOE-

Figure 1. Hybrid Electric Vehicle Sales in the U.S., by Model Year, 1999-2007*

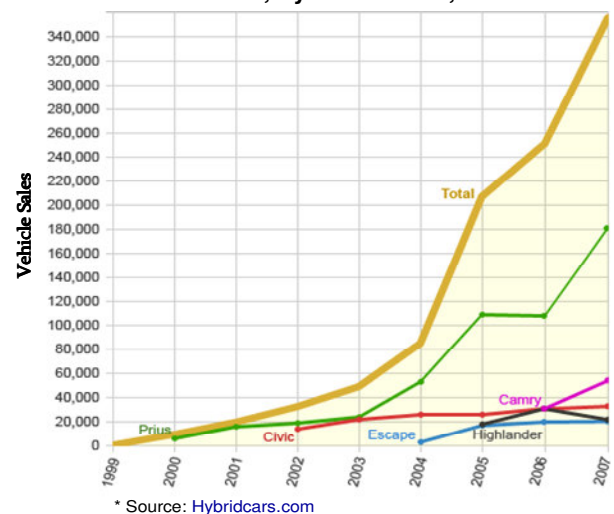
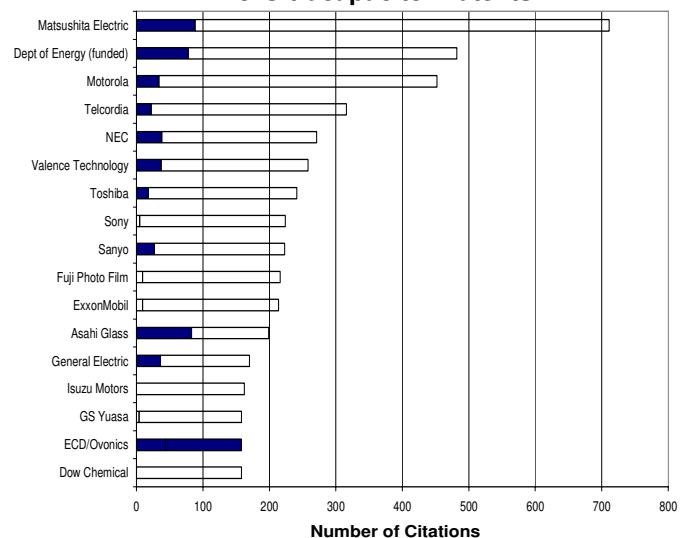


Figure 2. Organizations Whose Patents are Cited Most Frequently by HEV/PHEV/EV Battery & Ultracapacitor Patents



funded patents, as explained in the study. The 222 patents received a total of 482 citations, an average citation rate of 2.17 - among the highest citation rate of all leading organizations active in battery technology for hybrid and electric vehicles. The comparatively large number of cited DOE-funded patents, suggests DOE research forms a broad foundation for the advances in battery and ultracapacitor technologies for HEVs, PHEVs, and EVs - a foundation upon which specific industries for these technologies are built.

An average of 18 percent of all HEV, PHEV, and EV battery and ultracapacitor patents issued since 1994 cite at least one DOE-funded patent. In comparison, other organizations have the following averages: Matsushita Electric (26%), Motorola (15%), Sanyo (11%), NEC Corporation (10%), Honda (5%), and Toyota (3%).

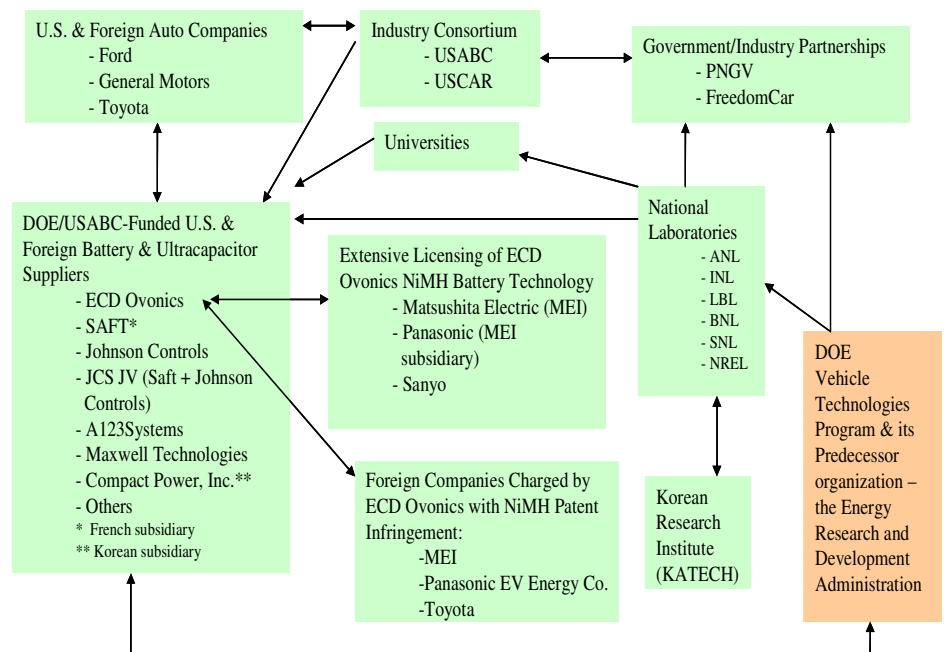
By working with multiple organizations in the vehicle energy storage community, DOE helped establish a far-reaching, integrative network of vehicle energy storage researchers and suppliers

DOE's vanguard efforts include establishing partnerships with, and providing research funding to, multiple organizations, notably the U.S. Advanced Battery Consortium (USABC) and the U.S. Council for Automotive Research (USCAR). During the period 1976 to 2007, DOE helped establish a broad network of national laboratories, universities, auto manufacturers, and battery suppliers. DOE's influence through this network is summarized in Figure 3 and described in more detail in the study.

Some notable examples of DOE's network of influence, documented in the study, are:

- ✚ General Motors (GM) and Daimler Chrysler powered their early all-electric demonstration fleets with DOE-funded NiMH batteries (early 1990's).
- ✚ NiMH batteries with higher power and extended life were successfully demonstrated with DOE funding prior to auto makers using the batteries to demonstrate HEVs (early 1990's).
- ✚ DOE influence on the international HEV battery market is indicated by the extensive licensing of Ovonic Battery Company (Ovonic) NiMH batteries, funded in part by DOE, to major battery suppliers around the world (2004).
- ✚ Royalty payments to DOE have arisen from licensing and incorporation of Energy Conversion Devices (ECD)/ Ovonic technology in the NiMH battery provided by Sanyo for the Ford Hybrid Escape and Honda Accord Hybrid.
- ✚ GM included NiMH batteries from Cobasys (part of the DOE-funded ECD/Ovonic group) in several of its HEVs (2006).
- ✚ Argonne National Laboratory, a DOE national laboratory, licensed its advanced rechargeable lithium battery technologies to NanoeXa to develop and transfer into commercial use for next-generation HEVs and PHEVs (2006).
- ✚ GM issued contracts to two DOE-funded companies to compete for supplying Li-ion batteries in a prototype sports utility PHEV (2007).

Figure 3. Network Linkages Identified by Experts



Source: *Linkages of DOE's Energy Storage R&D to Batteries and Ultracapacitors for Hybrid, Plug-In Hybrid, and Electric Vehicles*, prepared by Rosalie Ruegg, TIA Consulting, Inc., and Patrick Thomas, 1790 Analytics, LLC., February 2008. http://www.eere.energy.gov/ba/pba/pdfs/vehicle_energy_storage_r_and_d_linkages.pdf

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