Technology report

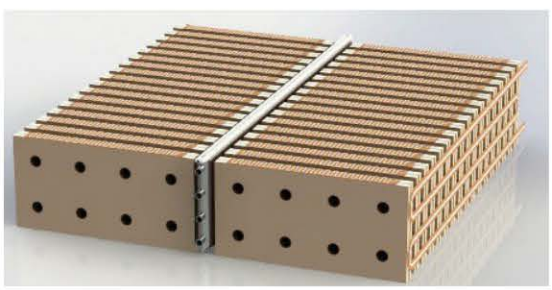
INTERIORS | MATERIALS

Adsorption-based thermal batteries could help boost EV range by 40%

Today's electric vehicle (EV) batteries can provide only enough power to propel them 100 mi (160 km) or so on a single charge, a shortcoming that often leaves little left over for cooling or warming the passengers. Climate-control systems can reduce an EV's range by as much as 30%, especially in the summer. And while "range anxiety" continues to put off many potential EV buyers, the prospect of being forced at times to minimize the use of the HVAC system certainly doesn't help either.

Several research and development projects funded by the **Advanced Research Projects Agency for Energy** (ARPA-e) are under way to create novel heating and cooling technologies that could lessen the power drain of HVAC systems on already overtaxed EV battery packs. Some of these efforts aim to create "hot-cold systems" based on "thermal batteries" that exploit enhanced thermo-adsorptive effects to replace electromechanical vapor-compression refrigeration technology.

One of these systems takes advantage of new high-capacity adsorbents that can store great quantities of refrigerant in a small space. The coolant is then used for either heating or cooling as required as it cycles through the system. This project is being conducted by a university/industry team of researchers at **MIT**, the **University of California, Berkeley**, the **University of Texas at Austin**, and engineers at **Ford**. The group received $2.7 million in support a year-and-a-half ago to demonstrate a thermal adsorption-based climate control system capable of delivering both heating and cooling for EVs with minimal use of the electrochemical battery bank.



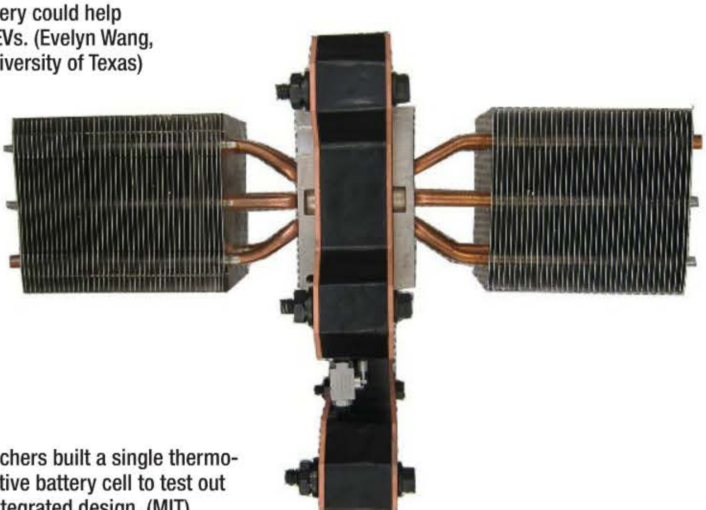
This prototype thermal battery could help provide HVAC services for EVs. (Evelyn Wang, MIT, and Carlos Hidrovo, University of Texas)

Thermal battery

"A thermal battery charges and discharges much like an electrical battery, except that it provides a temperature difference instead of a voltage difference," said Evelyn Wang, a professor of mechanical engineering at MIT, who is leading the work. "Our focus is developing a thermal battery with enough energy density to run the HVAC systems in EVs and so help overcome existing range limitations."

In addition to storing enough energy, the new system must be compact and lightweight enough to fit in EVs, she said, noting that her team "was working closely with Ford on meeting the EV packaging constraints." The plan is to test the technology in a Ford Focus EV after the first prototype hot-cold device is completed, which is expected in six to nine months.

"So far, we've finalized the design and have



Researchers built a single thermo-adsorptive battery cell to test out their integrated design. (MIT)

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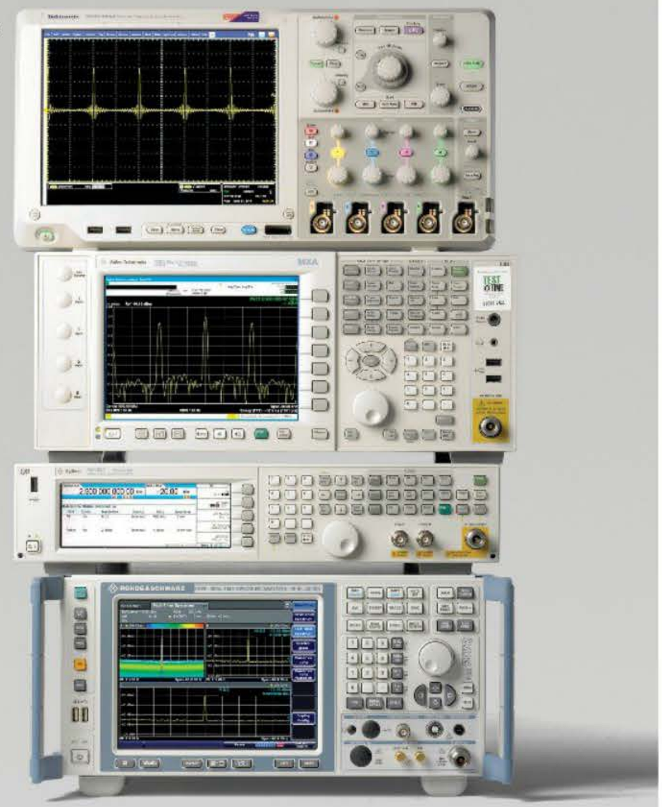

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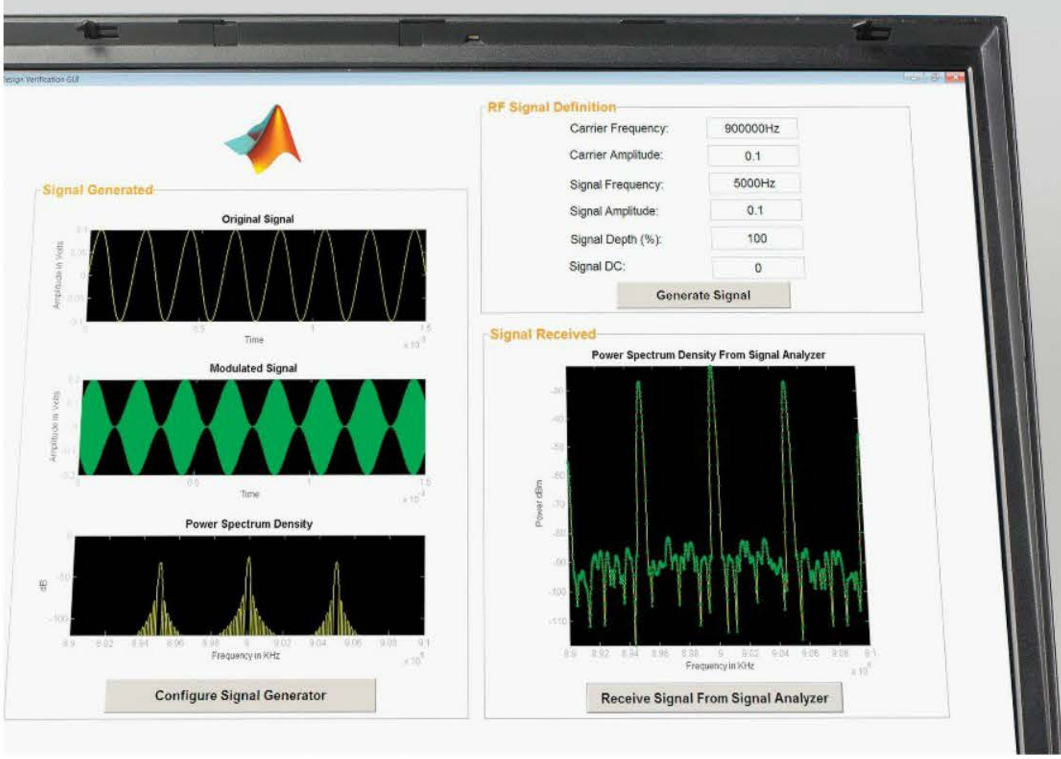

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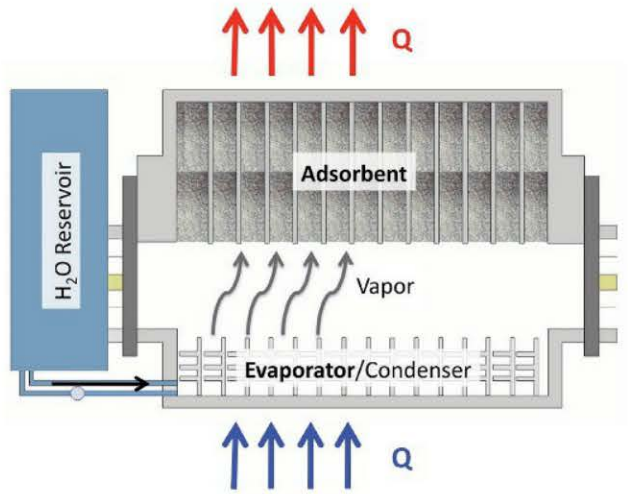
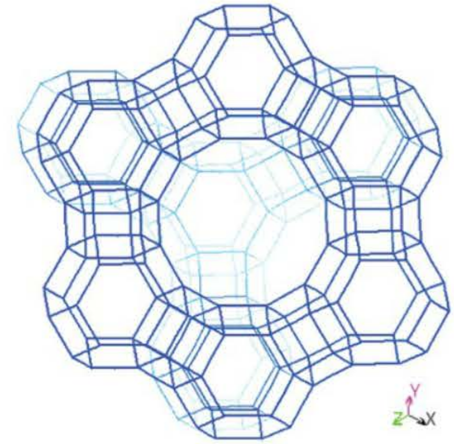
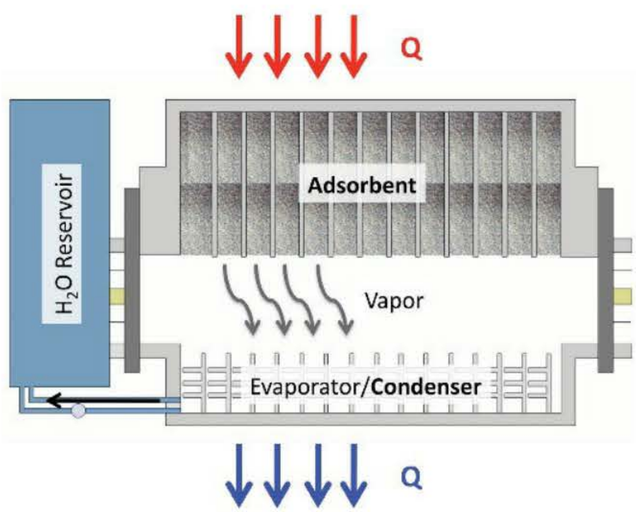


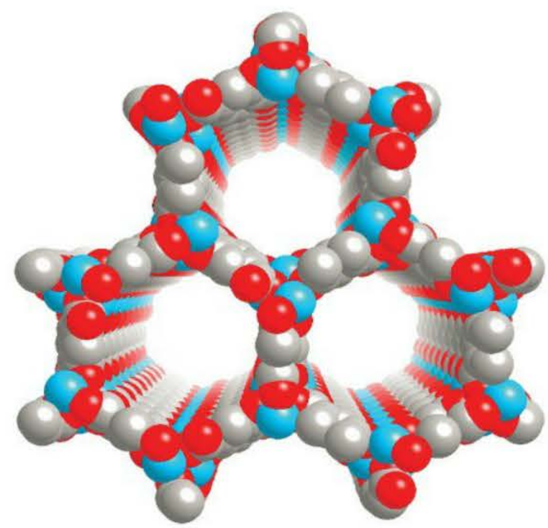
Adsorbent bonds to water vapor, providing heating; incoming water evaporates, providing cooling. (MIT)



A representation of the structure of the zeolite molecule, which has been modified to boost its adsorbency. (MIT)



The adsorbent is regenerated with heat; water vapor condenses and flows into the reservoir. (MIT)



Designer molecules called metal-organic frameworks could have even greater adsorptive capacity. (Omar Yaghi's group, University of California, Berkeley)

The prototype thermal battery will be tested in a Ford Focus battery-electric vehicle.

started building a prototype that demonstrates the energy density we need," Wang said. "Next we'll need to scale up materials production."

The program is targeting a 2.5-kW device with 2.5 kW·h of cooling capacity and 4.5 kW·h of heating capacity. The unit should weigh about 35 kg (77 lb) and occupy a volume of 30 L (1.1 ft^3). If successful, the technology could potentially extend EV driving range by 30-40%. Such a system—if sufficiently effective—could also work in hybrids and conventional internal-combustion-engine powered cars, not to mention buildings.

Passive heat pump

In the thermal battery system, said Shankar Narayanan, an MIT postdoctoral associate, water from a reservoir "is pumped across a valve into a low-pressure vessel, during which it evaporates and absorbs heat." This evaporative cooling can be used to lower the temperature of air that is sent into the passenger cabin.

The water vapor is then exposed to a special adsorbent—a high-surface-area material that is entirely shot through with many tiny pores. Each pore has been engineered to have an extremely strong "hydrophilicity," or affinity for bonding to water molecules, he said. The high-capacity material pulls the vapor out of the container while keeping the pressure low so more water can be pumped in and evaporated.

Heat is released as the material adsorbs the water molecules, Narayanan continued. This heat can then either be used to warm the passenger compartment or, if not needed, extracted by a heat exchanger and dumped into the atmosphere using a radiator.

Unlike a conventional vapor condensation system, the new device should use little electricity because it transports the vaporized refrigerant water from the evaporator to the adsorbent bed place passively—that is, without needing external means of vapor transport or compression, he said. The bed would operate at about 80°C (176°F), while the evaporator would run at 0 or -5°C (32 or 23°F).

At some point, the adsorbent will become saturated with water, so the thermal battery system would need to be recharged when the electrochemical battery is charged. Regenerating the adsorbent means heating it to above 200°C (392°F) for several hours, which forces it to release the water. The vapor, desorbed from the bed, then moves on to the condenser, where gas turns to liquid and the water is collected in the reservoir for subsequent cycles.

New adsorbent materials

"The basic concept of the adsorption cycle has been used in large industrial systems, but ours works in a different manner," Wang said. Existing systems have low energy-conversion efficiencies and are bulky and heavy. New, much better-performing materials are needed to make for a thermal battery that is sufficiently powerful, compact, and lightweight.

Another obstacle to packaging is that most processes require separate contain-

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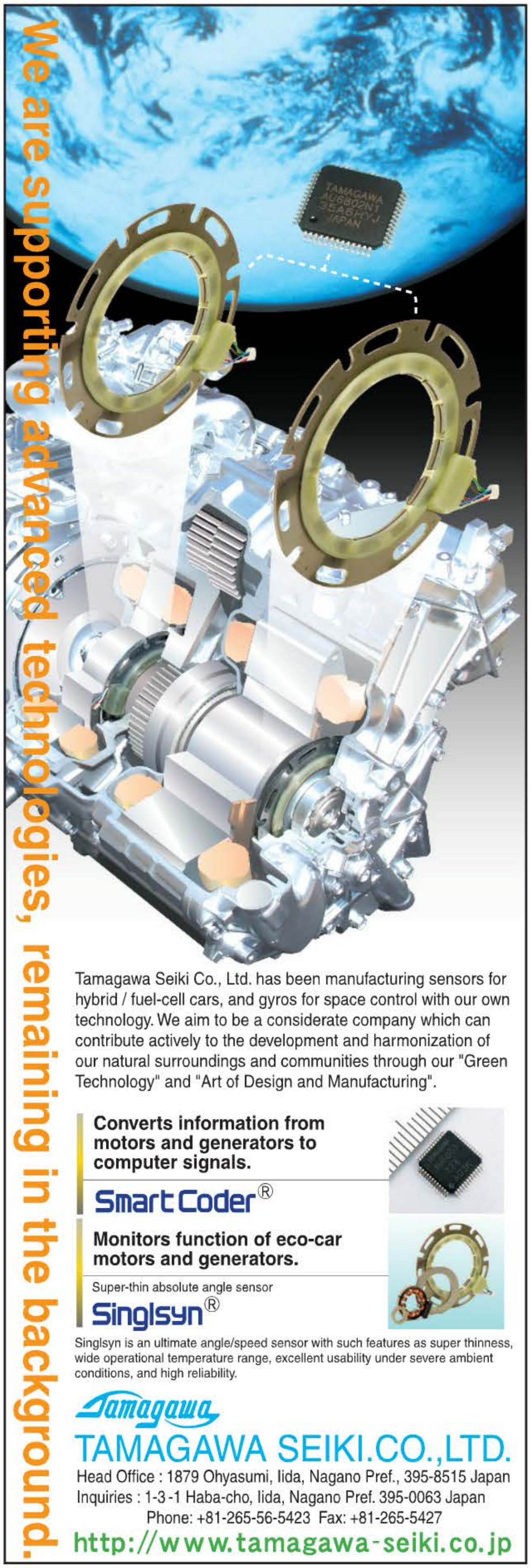


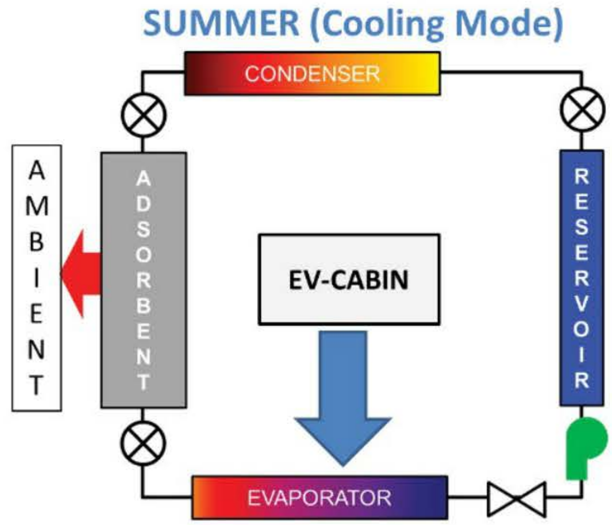


Diagram shows how the thermal battery system works in summer. Arrows show heat transfer direction. (MIT)

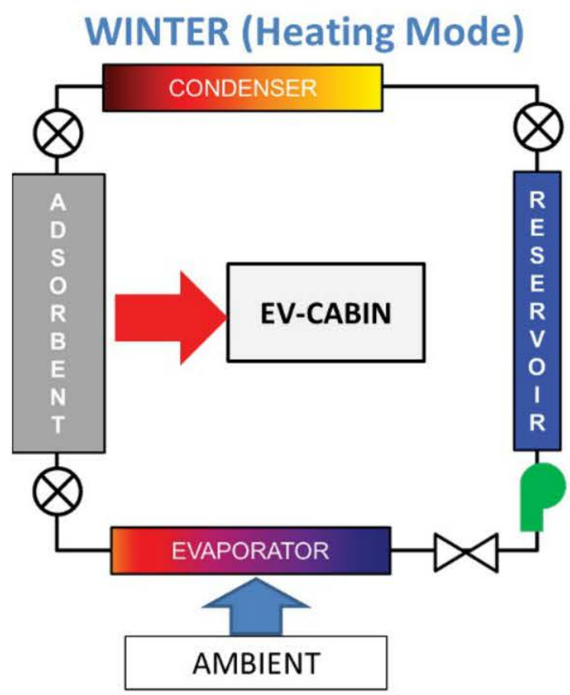


Diagram shows how the thermal battery system works in winter. Arrows show heat transfer direction. (MIT)

ers for evaporating and condensing the coolant, but the team's streamlined design employs a single container for both purposes. Its monolithic, one-piece condenser/evaporator saves space and brings the vapor flow close to the condensing surface. To provide maximum packing and water storage, layers of adsorbent are mounted on concentric fin tubes that fit around the evaporator/condenser unit.

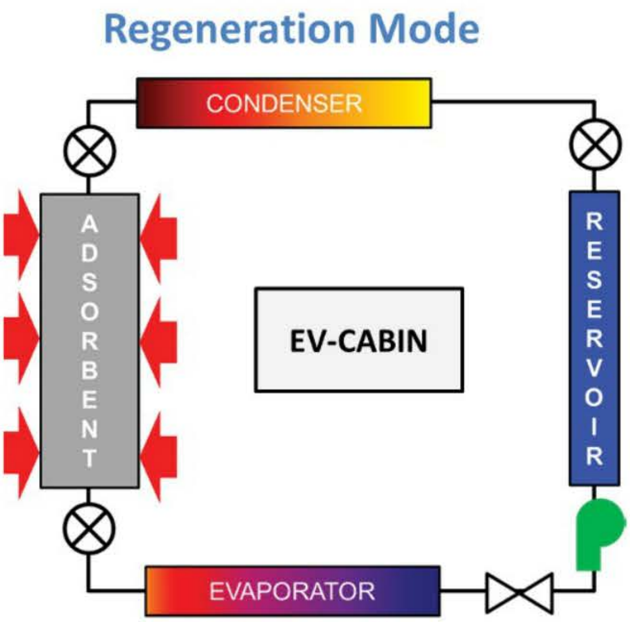


Diagram shows how the thermal battery system is regenerated during charging. Arrows show heat transfer direction. (MIT)

The MIT researchers have developed a new material that features "really high adsorption capacities" by modifying zeolite, a stable, readily available aluminosilicate material that is microporous. By chemically removing part of the framework of silicon atoms in the zeolite, they have tailored its pore size and boosted its affinity for water, creating a material with strong hybrid physi/chemisorption capabilities. On the down side, it requires 200°C heat to release the water during regeneration.

Because the highly porous mineral does not conduct heat well, the researchers have added thermally conductive carbon-based binder materials to provide highways for heat to escape the bed more rapidly.

Designer molecules

The ARPA-e-supported project is also studying so-called designer molecules that could have extremely strong adsorption capacities. Chemistry professor Omar M. Yaghi and his colleagues at UC Berkeley specialize in metal organic framework (MOF) molecules, whose physical and chemical properties can be systematically altered by varying the composition.

"The nice thing about MOFs is that you have a lot of ability to use different linkers to connect up metal clusters," Narayanan said. Their Tinkertoy-like arrangement "provides lots of flexibility so you can easily change pore size."

MOFs also could have lower regeneration temperatures, which could enhance cycling efficiency.

But the designer molecules pose their own challenges. Making stable MOFs that resist reacting with water is an issue, and production scalability and costs are less than clear. With further progress in both areas, MOF adsorbents could enable even higher-density thermal energy storage than the modified zeolites.

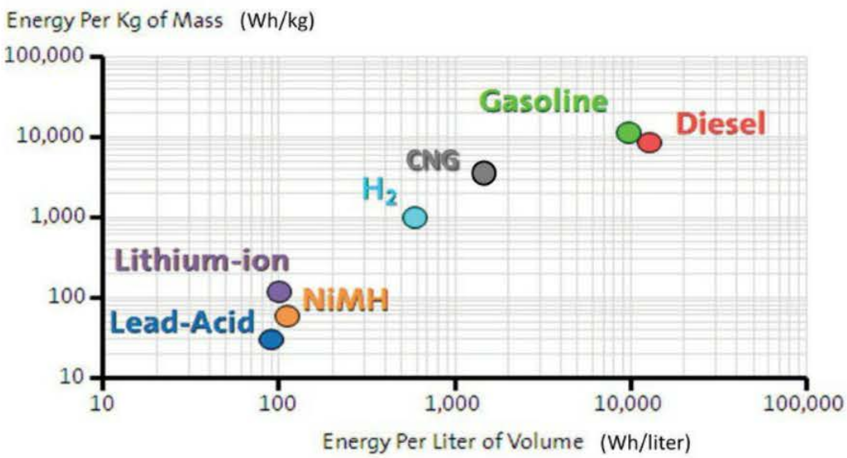
Steven Ashley

ENERGY

The case for alternative fuels

There would have to be compelling reasons to justify switching from petroleum for transport. Why? For one, as liquids, gasoline and diesel are easy to distribute. They are also energy-dense. A gasoline or diesel tank can be filled in a few minutes and carry the vehicle hundreds of miles more conveniently than any other fuel type.

Another stark fact stands out: the petroleum infrastructure is well established. There are 7000 oil rigs worldwide. There are 150 refineries in the U.S. alone, each processing between 5000 and 500,000 bbl per day. Worldwide there are more than 700 refineries pumping out about 80 to 85 million bbl per day of refined products, mostly gasoline and diesel. Oil refineries and rigs cost billions of dollars, representing a vast sunken cost. There is understandable inertia to keep producing and using gasoline and diesel.



At present, storing electrons on board vehicles is less practical and consumes more space and weight than either gasoline, diesel, hydrogen, or compressed natural gas. (General Motors)

One good reason to switch would be if we were running out of petroleum. At least for the near future, that seems unlikely as proved oil reserves continue to grow. Oil industry professionals continue to innovate, finding ways to extract oil profitably from miles under the sea floor or coax it from once recalcitrant tight and heavy oil formations with enhanced oil-recovery techniques such as hydraulic fracturing.

So, is there any reason to expect a rise in alternative fuels? Natural gas is growing in North America, especially in commercial vehicles, largely driven by the price difference compared to gasoline. Big automotive companies continue to invest in electric and hydrogen fuel cell vehicles. They must have their reasons.

Here are a few likely scenarios that might drive adoption before 2035.

Demand outstrips supply

The **International Energy Administration** (IEA) in 2012 projected worldwide demand for petroleum rising to almost 100 million bbl per day by 2035, from its current level of about 85 million

bbl per day. The agency also predicted a doubling in worldwide growth in passenger cars to 1.7 billion. Countries such as China, Brazil, and India could rapidly increase their car fleets beyond the IEA projections. If the oil industry could not invest rapidly enough, the resulting high gasoline prices might impel a switch to alternatives, although this might be economical only for a short time.

Urbanization and local air quality

Controlling pollution on a local basis within congested cities may spur local uses of alternative energies. Many countries are researching low emission zones (LEZ), where polluting vehicles are restricted. As an example, London's LEZ primarily targets diesel vehicles with gross vehicle weight (GVW) over 7000 lb. Besides outfitting either cleaner engines or filters, the London authorities also encourage a change to alternative fuels such as natural gas (though biodiesel does not meet the cleanliness standard). LEZs seem like a natural fit for either electric or hydrogen fuel cell vehicles.

Massive disruptions in the oil market

The oil market of 2013 is a global affair, with oil shipped far and wide to refineries that re-export refined products. There are a few choke-points in this distribution system. Supply problems could arise from earthquakes, hurricanes, wars, or civil disturbances in key critical areas. If this happens, the price of gasoline and diesel could rise to the point where alternatives become economical.

In some ways, the anxiety over supply is seen in countries that import more oil than others. The European Union countries, Japan, India, and South Korea all import 70-90% of their oil. Not surprisingly, some of them are investing in a number of alternative-fuels programs. India is the world's fifth and Italy is the world's sixth largest users of natural gas for transport. In 2012, 11% of Italy's new cars were natural-gas-powered vehicles. If supply anxieties were to bleed into other countries, expect alternative fuels programs to increase.

Technological breakthrough in electric batteries

On an energy basis, in many areas of the world, driving on electrons is cheaper than driving on oil. One estimate by **General Motors** in 2008 showed that at 10 cents/kW·h, it would cost a **Chevrolet** Volt owner only about 2 cent/mi, compared to about 12 cent/mi for gasoline at its price in 2008. While improving fuel efficiency will certainly change that ratio, the fact remains that electricity is usually cheaper. Building the initial infrastructure to deliver that electricity is also relatively cheap, easing the transition to electron mobility. If batteries could hold more, cost less, and charge faster...who knows? The economics of the fuel itself is compelling.

(The facts, pictures, and conclusions for this article were drawn from the new **SAE International** book, "Future Automotive Fuels and Energy Technology Profile" by Bruce Morey, published in August 2013, ISBN 978-0-7680-7502-1, SAE Order Number T-128, http://books.sae.org/t-128.)

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