

NanoElectroFuel Boosts Flow Batteries

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1. Introduction

I'm sure your first question is: what the heck is nanoelectrofuel (NEF). Since that is the main subject of this paper, we will get to that below, but first let's talk about the current state of the art for flow batteries. In case you don't really know much about these, I'm partially to blame, because I haven't written about them for a couple of years. The last post was in 2020, and is briefly described and linked below.

Long-Term Storage: This paper describes long-term storage technologies, some economic considerations, and recent developments.

<https://energycentral.com/c/cp/long-term-storage>

If you go through the above link to check out flow batteries, section 3 has a good description of these. The primary variant of these has the capabilities defined below:

Below are the basic metrics for the Vanadium Redox flow battery.

- *Charge/discharge roundtrip efficiency: 65% to 75%*
- *Typical charge/discharge cycle life: 10,000 cycles*
- *Present value of installed cost: \$5,800 to \$6,600 per kW*
- *Levelized cost of energy: \$260 to \$300 per MWh*

Although, given the right application, these have a place, their niche is very narrow. You can probably guess that a flow battery relies on the flow of a fluid to charge and discharge. The fluids in this case are aqueous solutions of the active salts for the two half cells (Anode and Cathode). The solutions are, respectively called Anolyte and Catholyte (each is an electrolyte). Like most solutions of compounds, these are highly diluted, and that explains the flow battery's very poor roundtrip efficiency, high energy cost, and most of all, its high price (big pumps and tanks). Thus, these batteries have a very narrow niche in grid storage. The good news is their scalability: they can quite happily cover applications, at least up to 100 MW.

So how do we fix the above-described weakness of flow batteries. Well, go to section 2.

2. NEF

The weakness of flow batteries is that they use an aqueous solution. Instead of a solution, what if we used an aqueous suspension of nano-particles.

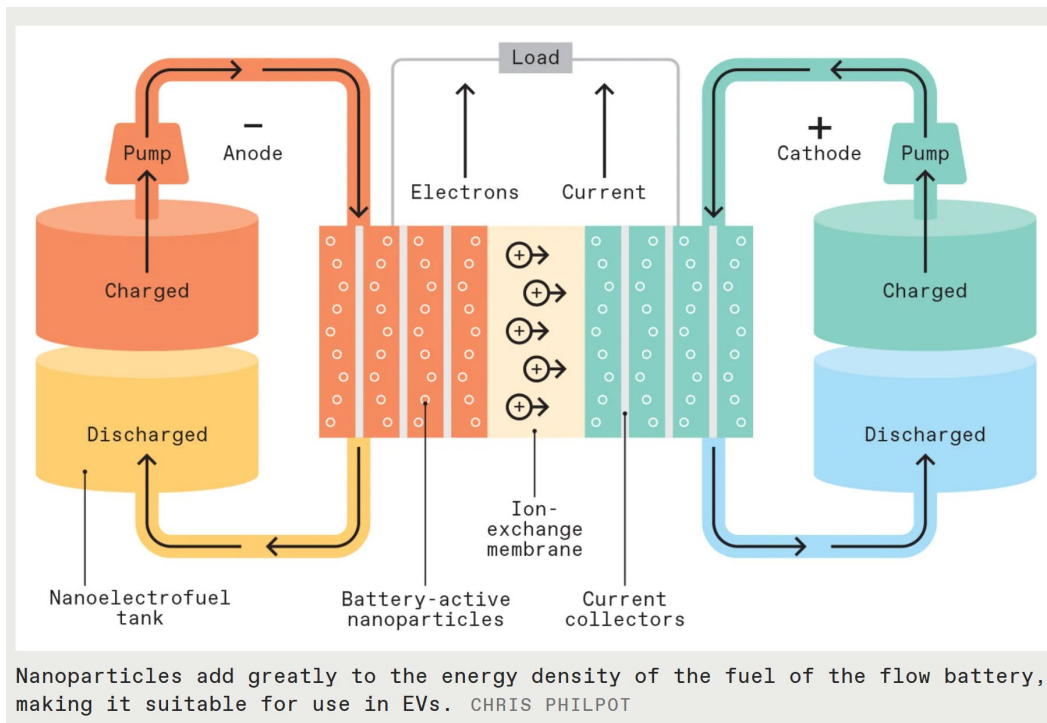
One good way to add capacity to a flow battery is with nanofluids, which hold nanoparticles in suspension. These particles undergo redox reactions at the electrode surface similar to how the dissolved ions react in conventional flow batteries, but the nanofluids are more energy dense. Importantly, the nanofluids are engineered to remain suspended indefinitely, unlike other suspensions—for instance, sand in water. That indefinite suspension helps the particles move through the system and make contact with the electrodes. The particles can compose up to 80 percent of the liquid's weight while leaving it no more viscous than motor oil.¹

¹ Robert N. Charette, IEEE Spectrum, "Can Flow Batteries Finally Beat Lithium?" Dec 24, 2023, <https://spectrum.ieee.org/flow-battery-2666672335>

Nanofluids suspended in water-based electrolytes were first investigated for this application in 2009 by researchers at Argonne National Laboratory and the Illinois Institute of Technology. The scientists found the nanofluids could be used in a system with an energy-storing potential approaching that of a lithium-ion battery and with the pumpable recharging of a flow battery. What's more, the nanoscale particles could be made from readily available, inexpensive minerals, such as ferric oxide and gamma manganese dioxide for the anode and cathode materials, respectively.

Additionally, because the nanoelectrofuel is an aqueous suspension, it did not catch fire or explode, nor would the material be hazardous if the battery were to leak. The battery possessed a wide operational range of between -40 °C and 80 °C.

In 2013, the team received a three-year, US \$3.44 million grant from the U.S. Department of Energy's Advanced Research Projects Agency–Energy (ARPA-E) to build a prototype 1 kilowatt-hour nanoelectrofuel battery. The prototype's success encouraged several of the principal investigators to spin off a company, called Influit Energy², to commercialize the technology. Through additional government contracts, the startup has continued to improve the components of the technology—the nanoelectrofuel itself, the battery architecture, and the recharging and delivery system.



2.1. Distribution of NanoElectricFuel

Assuming Influit Energy is successful in commercializing this technology, what applications might it address. Read on (from reference 1).

² <https://www.influitenergy.com/>

As she drives her electric vehicle to her mother's house, Monique's battery gauge indicates that it's time to reenergize. She stops at a charging station, taps her credit card at the pump, inserts a nozzle into the car, and in 5 minutes exchanges spent NanoElectricFuel for fresher stuff. As she waits, a tanker pulls up to refill the station itself by exchanging thousands of gallons of charged for spent NanoElectricFuel. Monique closes her EV's fueling port and heads onto the highway with enough stored energy to drive 400 miles.

This battery uses a completely new kind of fluid, called a nanoelectrofuel. Compared to a traditional flow battery of comparable size, it can store 15 to 25 times as much energy, allowing for a battery system small enough for use in an electric vehicle and energy-dense enough to provide the range and the speedy refill of a gasoline-powered vehicle. It's the hoped-for civilian spin-off of a project that the Strategic Technology Office of the U.S. Defense Advanced Research Projects Agency (DARPA) is pursuing as part of a drive to ease the military's deployment of all-electric supply vehicles by 2030 and of EV tactical vehicles by 2050.

The Department of Defense (DOD) uses a huge number of vehicles. Converting these from petroleum to electricity along with the logistics to keep them charged is pretty much impossible. Nanoelectrofuel is a dream come true, and thus DOD is pushing this technology hard. See the subsection below. and then the last section.

2.2. DOD's Problem and Solution

For the military, nanoelectrofuel batteries have obvious advantages over lithium-ion batteries as well as internal combustion engines, Kofford says. In military fighting vehicles, protecting a vehicle's fossil-fuel tank is critical, but that added protection weighs a lot and requires that the vehicle have a heavier suspension. That weight, in turn, reduces range and payload. Lithium-ion batteries, which are heavy in themselves and prone to fires, would also need to be heavily shielded against a shell hit.¹

By contrast, nanoelectrofuel batteries are fireproof, so the weight and safety issues are reduced tremendously...

"At the system level, if we can take a chemistry that is inherently safe, we don't need as much inner packaging in the battery itself," Kofford says. They also don't give off as much heat, so the vehicles are harder to spot from a distance, he adds. Civilian applications for nanoelectrofuel flow batteries beckon, notably in aviation. The reduced need for fire-safety systems in electric aircraft is a draw, observes Starr Ginn, NASA's advanced air-mobility lead strategist.

With nanoelectrofuels, Ginn says, "You don't [need] high-powered cables, you don't have electromagnetic interference problems." Nanoelectrofuel "just keeps checking these boxes off of all the things that are making it hard to build electric airplanes."

Similarly, the U.S. Air Force Research Laboratory's Transformational Capabilities Office is assessing how nanoelectrofuels could help in combat operations. Influit is also working with a commercial partner to pilot nanoelectrofuel flow batteries in their line of electric utility vehicles.

Considerably more work must be done to fulfill the potential of nanoelectrofuel technology. Influit and its government sponsors expect it will take two more years to put together all the pieces of a closed-loop system and to prove its value and scalability in a variety of applications. Katsoudas says that by 2025 or 2026, the world will be ready to give a serious look to nanoelectrofuel flow batteries for powering zero-emission vehicles, grid backup, electric utility vehicles, and the like.

2.3. The Competition

Two possible barriers block the technology's ascent: market forces and competing technologies.

Lithium-ion batteries are a mature technology and have a developed market. Hundreds of billions of dollars are being poured into the development and improvement of lithium batteries of all types, with governments underwriting much of the investment. For instance, DARPA, the Department of Energy, and the National Science Foundation are working with a host of companies to overcome the limitations of lithium batteries.

Government research organizations in the EU, South Korea, and elsewhere are funding similar research. To overtake lithium technology, Influit will have to convince someone with extremely deep pockets to help it scale up—perhaps from its own logistics supply chain or from EV manufacturers.

Then there is the technological competition. News arrives nearly daily of yet another lithium-ion advance. One report from researchers at the Chinese Academy of Sciences boasts of a 711 Wh/kg lithium-ion battery. A Chinese manufacturer claims that a new lithium manganese iron phosphate battery chemistry will power an EV for 1,000 km on a single charge and last 130 years.

Other announcements involve significant improvements in rapidly charging lithium-based batteries and making them safer for use in military vehicles.

Then there are the new battery chemistries that are not lithium based—for instance, sodium-ion and graphene-based batteries. And there have been advances in grid-scale batteries involving liquid metal technology, and improved traditional flow-battery technology using lithium sulfur.

Other direct competitors to Influit include e-fuels (synthetic carbon-based and carbon-neutral fuels produced from captured carbon dioxide and water using renewable electricity sources), as well as liquid organic hydrogen. Both fuels aim to directly displace fossil fuels. For Influit to gain market adoption, Volta's Rodby says, the company will need to articulate what the "market differentiator" for nanoelectrofuels is. Right now it seems the technology is a particularly good fit for the Department of Defense, which would likely be willing to pay a premium for it. As the largest user of fossil fuels in government, the DOD alone may enable Influit Energy to get to scale.

Of course, it may turn out that nanoelectrofuels find a home in other applications, such as boats, trains, or planes. For example, the largest cargo container ship carries some 15 million liters of fuel. If some portion of that were nanoelectrofuel that could be continually recharged, it might be possible to reduce the ship's carbon footprint.

There is a rich history of apparently superior technologies that came too late or too early to displace the incumbents. Nanoelectrofuel flow batteries appear to be superior to what we have today. Perhaps they will also be lucky.

3. Author's Opinion

In general, a new technology needs to find one or more young, growing niches to bootstrap the technology and allow it to mature. I see two potential niches. The first has been pointed out in reference 1— the U.S. Department of Defense (DOD) need to transition away from fossil-fuels by 2050. In the following two subsections, I will spin two DOD scenarios. The first is domestic (in-U.S.), and the second off-shore deployments.

3.1. Domestic Use-Case

In domestic military deployments DOD has several assets:

- A stable environment – any security threats are already managed.
- A green grid -- it is evolving to carry mostly greenhouse gas (GHG) free power in lock-step with the military's timeline.
- Lots of land on most military bases, especially in the west.

Thus, DOD can count on buying much of its GHG-free power through the grid, and also generating it using PV. All it needs is a place to store the energy. Nanoelectrofuel provides this storage, plus solves another problem, how to cure the other main GHG emissions source – vehicles.

Regarding a second solution, note that nanoelectrofuel has a high enough energy content such that it can probably also be used for most aerial vehicles. These vehicles will need to be redesigned to use electric motors, etc. for propulsion, so the additional modifications to support nanoelectrofuel (like four fuel tanks – see above block diagram) can be incorporated at the same time. The same modifications of small-to medium naval vessels will need to be made, but this will be easier. It is assumed that large naval vessels will use nuclear power (as most do today).

3.2. Off-Shore Use Case

The main concern for DOD forces deployed to foreign countries will be security where the potential for hostile-forces exists. I would guess DOD would use a standard design for a fortified facility that would use one or more small nuclear reactors to generate power, and use (most of) this power to recharge nanoelectrofuel. This would then be distributed to other facilities using tanker-trucks.

3.3. Back to the Beginning

One of the few applications that traditional flow batteries can currently address is grid-storage. Inluid Energy believes this also represents a good target for nanoelectrofuel batteries.

John Katsoudas, a founder and chief executive of Inluid, emphasizes the distinction between his company's design and a conventional flow battery. "Our novelty is in doing what others have already done [with flow batteries] but doing it with nanofluids," he says.¹

With the basic science problem resolved, Katsoudas adds... The company expects larger versions would also beat old-style flow batteries at backing up the grid because the nanoelectrofuel can be reused at least as many times as a flow battery—10,000 or more cycles—and it will probably be cheaper.

And use smaller pumps and tanks.