Publisher’s Note: The problem of global warming is directly tied to the issue of moving off fossil fuels and onto alternative energies. This move, in turn, requires a redesign of power grids around the world – a game-changer in which developed countries can either play the lead or, as has happened occasionally with new wireless installations, the follower, vs. emerging nations.

On this issue, however, there are no winners and losers: we all share the planet, and we all lose if we don’t move quickly enough.

Redesigning the grid requires a number of technical and infrastructure changes, but none are more important than removing the supply volatility characteristic of solar and wind installations, the two leading energy supply sources (beyond hydro) being deployed in this battle. The grid needs a new battery system, and the question of what kind, how much, and how fast, if answered properly, will now be key to saving the planet.

[Please open the attached .pdf for best viewing.]

by Simon Hackett
Simon Hackett, a longtime SNS member, FiRe speaker, and now a FiReStarter company investor and advisor, is probably the best-known entrepreneur in Australia. As the first owner of a Tesla vehicle (he now has three) in Oz, and as holder of the world’s longest single-charge electric car run, he is well aware of batteries and their limits, and of Tesla’s achievements. In this issue, Simon shares with us his research on how to solve the grid battery challenge, and why flow batteries are the best solution. – mra.

**Takeaway Points:**

- Burning fossil fuels presents a substantial medium-term threat to human habitation of the planet.
- Unless the impacts of the “duck curve” are addressed, renewable-energy sources will start to do more harm than good to the existing energy grid.
- An “energy” battery is required for grid time-shifting applications.
- Tesla Motors has reframed the storage battery as an object of desire.
- “We need to be able to build this thing using simple manufacturing techniques and factories that don’t cost a fortune.” – Donald Sadoway
- Flow batteries are ideally suited to grid-scale “energy” applications, arguably more so than lithium chemistry.

**THE NEW POWER GAME**

_Energy storage is at the tipping point for reframing renewable energy as a genuine zero-carbon replacement for today’s fossil-fueled energy grid_

**By Simon Hackett**

Anyone who has been paying attention knows that burning coal (and other fossil fuels) to generate electricity has the substantial disadvantage of contributing in a major way to atmospheric carbon dioxide and particulate pollution. This specific human activity is driving changes that present a substantial medium-term threat to human habitation of the planet.
In addition to rooftop solar installations, high-density, generator-scale wind, solar, and concentrated solar power (CSP) facilities are becoming so widespread that their advent is causing increasing challenges in the management and operation of the world’s utility energy grids.

A 29 megawatt concentrated solar power plant at the Chevron Oil Field in Coalinga, California. (Taken by the author in May 2015)

In some countries, we are now seeing periods in which the levels of renewable-energy generation are exceeding total grid energy demand during solar or wind strength peaks. The duration and frequency of these “crossover” periods is increasing as renewable-energy deployments accelerate.

Not only are these crossover periods a management challenge to the grid during times of high renewable-energy generation, but they also create additional challenges for the opposite reason. When clouds occlude solar-panel or CSP arrays, their energy output can fall away so fast that baseload power generators may not be able to be spun up fast enough to fill the gap. This leads to pathological outcomes, such as the need to burn more coal in parallel to operating renewables, just in case clouds move rapidly across the sun.

The impact of this large influx of solar-derived energy during daytime solar peak times creates an energy supply and consumption pattern known as a “duck curve,” due to its shape, described further here.
Baseload fossil-fuel–based electricity generators can’t (yet) be taken away because power demand exists 24/7. However, unless the impacts of the duck curve are addressed, renewable-energy sources will start to do more harm than good to the existing energy grid.

Turning Renewable-Energy Generation into a Baseload Power Source

To get rid of the fossil-fuel–burning baseload power generators, we must find a way to time-shift the flow of renewable-energy generation at the same global scale that we are deploying renewable-generation capacity. Only then can we stop burning petrified forests for our daily convenience.

The presence of grid-scale energy storage will allow us to efficiently match the shape of the electrical-energy supply curve from renewable sources to the shape of the demand curve on a 24/7 basis.
Today the highest proportion of time-shifted renewable-energy generation in the world is sourced from “pumped hydro.” For a combination of fairly obvious reasons (including the need for specialized geography and large quantities of water), this is a niche solution not capable of general application. The general solution (and opportunity) seems best addressed by the manufacture and deployment of grid-scale batteries.

To make financial sense, the production of batteries at grid and global scale has to run down the same curve of increasing production and decreasing unit cost that has so positively affected the price and availability of solar panels over this past decade.

It seems clear that the world can do this. We have done things this big before.

That is not to underplay the major challenges here. The business case has to be on a trajectory that makes long-term sense. The batteries have to be up to the task, in terms of longevity and reliability. We also need to have enough efficiently obtainable raw materials in the world to make enough of them so that their production can be scaled-up massively.

Ahead of these engineering and economic challenges, however, perhaps the largest single barrier has simply been one of perception. The problem needs to be reframed as solvable and tractable problem – and then it can, and will, be solved.

**Power vs. Energy in Batteries**

To help understand the distinction between “power” and “energy” in the context of batteries, let’s start with a look at the use of batteries in a Tesla Motors electric car.

The Tesla Model S P85D uses a lithium-based (“power”) battery pack which stores a nominal 85 kilowatt-hours (kWh) of energy. While 85 kWh is the equivalent of drawing one kilowatt for 85 hours, the outcome is quite different when a driver mashes his foot to the floor.

During maximum 0-60 mph acceleration, the twin motors of this vehicle draw over 500 kW out of that battery pack, launching this big luxury sedan like a rail-gun. However, this huge power draw lasts only a few seconds, after which nominal power draw returns to more “pedestrian” levels (10-15 kW at typical metropolitan speeds).

If the power-draw rate from the battery pack were maintained at that huge level, two things would happen: the battery would be exhausted in several minutes and – despite
the liquid cooling system built into it – it would get very hot, perhaps even dangerously so, and would therefore need to be shut down for safety.

The other key characteristics of the automotive power application are a very light duty cycle (with a high proportion of time spent at complete rest vs. time spent charging / discharging) and very small average depth of discharge (the percentage of the battery capacity used in a typical daily driving cycle is very small).

These characteristics require a “power” battery. They place a very low average stress level on the battery pack, aside from short periods of high demand.

A power battery application requires a sprinter, not a marathon runner. Lithium based-chemistries are really well suited to power battery applications.

**For grid time-shifting applications, however, we need an “energy” battery.** In this case the emphasis is on the capability for a battery system to combine with renewables to emulate the long-term, relatively constant power draw that comes out of a baseload power generator plant.

To meet this demand, grid-scale batteries have to be capable of working almost all of the time (close to a 100% duty cycle). They should also be capable of being deep cycled in order to maximize energy density at grid scale (close to 100% depth-of-discharge per cycle).

They have to do this every day of their working lives, potentially delivering multiple full operating cycles each day as they time-shift energy continuously, matching renewable supply to human demand. This workload requires an “energy” battery – a marathon runner, not a sprinter. The choice of appropriate battery technology combined with excellent battery management is critical to the success of batteries in this punishing role.

There is already evidence that poor battery system choice combined with these punishing grid-scale workloads can lead to premature battery failure. One example would be the recent failure of a lead-carbon grid-based system on Kauai, described here:


Hawaii, due to particularly high per-capita deployment of solar generation, is a special case in point. But the mounting stresses on the grid there serve as a signpost for similar issues elsewhere.
Making It Happen

Keen early adopters have been installing battery storage alongside their home solar arrays for years. I put one of these in my own home back in 2010.

But the generator-scale renewable-energy intermittency challenge won’t be solved with small batteries inside suburban homes – though that will be of some assistance: our homes (and our offices) are where the belief in the solution gets created.

The CEOs of energy-generation companies – who all live in houses of their own – need to see and believe in this change. They can then carry this belief and confidence into their boardrooms.

Supply follows demand. Until recently, the one thing we lacked was a lightning rod to reframe energy storage as an attractive proposition to the general population.

The Tesla Energy “Powerwall”

Tesla, maker of the world’s best and most important electric car, the Model S, has recently re-factored its lithium-based vehicle (“power”) battery packs and redeployed them into an “energy” role.

Leveraging extremely strong social media mojo for both the Tesla brand and its CEO, Elon Musk, the release of Powerwall in late April 2015 has made a global splash. For perhaps the first time ever, the concept of energy storage as an affordable, easily installed home product has made news all over the world.

Despite being based on existing lithium-derived battery chemistry, and arguably constituting nothing new in a technical sense compared with what already exists in the floor of the Model S, Powerwall has nonetheless done something unique: it has made the concept of electrical energy storage sexy, in a realm where batteries have previously been viewed by consumers as being about as interesting as a bag of rocks. The design decisions to adopt the same form factor as a wall-mounted work of art, to make the product curved, and to make it available in a variety of colors to suit the decor of one’s garage, are all very important indeed – more so than what is inside the box. Tesla has reframed the storage battery as an object of desire.

This is not something any previous battery manufacturer has managed to achieve… perhaps because others have simply failed to realize that it matters!

Consequently, interest in Powerwall right now has very little to do with its life cycle economics. Rather, Powerwall is capturing a slice of consumer desire to do something, on a personal level, about getting ourselves on a path to renewable-energy self-
sufficiency within our lifetimes.

There are parallels with the Toyota Prius. The Prius wasn’t an especially good technical solution for fuel-efficient driving (a good small diesel car does better in terms of mpg), but it was a focus point for consumers who wanted to do something to help offset at least some of the huge waste of fossil fuels inherent in driving internal combustion engine vehicles. Powerwall has the potential to have a similar impact in the energy storage realm. Battery vendors must now consider a previously irrelevant issue: industrial design (in the Apple sense of making things beautiful, not merely functional).

The parallel development of a viable, electrically based transport sector (led, of course, by Tesla) offers the potential to apply renewable-sourced, time-shifted power toward transport applications. Not only can we de-carbonize our electricity grid, but we can also do so in parallel to moving large parts of our transport infrastructure toward using renewable energy as well.

**Lithium Batteries at Grid Scale**

The continuous conversion of intermittent energy sources into baseload power at grid scale is a punishing application for batteries. There are significant challenges inherent in the use of lithium and other “rare-earth”–based battery chemistries in this role.

A rare-earth–based battery is using, as its name describes, a rare commodity in terms of ease of availability as a source material to mine and refine for use in energy storage applications. There is a good argument for expending the finite supply of rare-earth materials, by preference, into applications (such as transport) that require their use.

**Alternative Battery Approaches**

Requirements for batteries suitable for grid-scale deployment at global scale include:

- 100% depth-of-discharge capability without battery degradation or damage
- Support for continuous duty-cycle operation (not requiring rest between energy cycles, capable of multiple aggregate cycles per day)
- Made from commonly available materials to ensure cost-effective source material supply to global scale
- Wide operating temperature range without active thermal control
- Not at risk of thermal runaway or fire if physically damaged or shorted out
Driven by the huge scale of the resulting opportunity, several companies are now working on new forms of batteries that have most or all of these attributes. Let’s take a look at a few of the leading contenders.

**Ambri** ([www.ambri.com](http://www.ambri.com) – formerly Liquid Metal Battery), led by Professor Donald Sadoway, was a key influence in the understanding that alternatives to rare-earth–based batteries are worthy of study and development. He delivered a popular and worthwhile TED talk in 2012 on this topic, “[The Missing Link in Renewable Energy](http://www.youtube.com/watch?v=V9VAdpd7j9w).”

That talk gave me an appreciation of the merits of developing non–rare-earth–based batteries, and it led to my own decisions to look at investment and involvement opportunities in this sector.

Here is the “ah-ha” moment in Sadoway’s talk:

> This battery needs to be made out of earth-abundant elements. I say, if you want to make something dirt cheap, make it out of dirt – preferably dirt that's locally sourced. And we need to be able to build this thing using simple manufacturing techniques and factories that don’t cost us a fortune.

The Ambri Liquid Metal battery continues to be developed. At reasonable-energy storage levels, these are very big, very heavy batteries that (by design) run at high temperatures. They are very much intended to address the grid-scale energy storage and delivery goal.

Ambri is well resourced and is presently moving from the prototype to the early field-trial stage, with commercialization and volume commercial production slated to commence in the next few years.

**Aquion Energy** ([www.aquionenergy.com](http://www.aquionenergy.com)) is another fascinating battery maker. It has chosen to deploy batteries using an absolute winner in the material abundance stakes: seawater!

One challenge this creates is very low energy density. A cubic shipping-pallet–sized Aquion module delivering a nominal 29 kWh weighs in at 1,440kg (3,175 lbs.), which is substantially heavier and larger for a given energy capacity than even lead-acid batteries.

Aquion is also well resourced and focused upon the delivery of its batteries to the market.
Redflow (www.redflow.com) makes a different type of battery, called a *flow battery*:

Here’s what makes a flow battery special:

- Being based on a distinctly different approach to energy storage, in which liquids are held in two tanks that are external to the battery electrode. The two tanks have separate pumps to move the liquids through an electrode stack where ion exchange occurs across a membrane. The two liquids do not themselves pass across the membrane, and they remain separate throughout the ion exchange process for both charge and discharge cycles.

- Meeting all of the criteria noted earlier, with some additional special properties that are a consequence of the active fluids being held separately, and outside of the electrode, rather than contained within it.

- Having the ability to be fully charged and then shut down and left ready for operation for an arbitrary period of time (months or even years), with practically all of the battery energy available when it is restarted. Conventional batteries left in storage without being float-charged will ultimately self-discharge and may suffer damage in the process.

- Having the ability to be completely discharged (to zero volts) without suffering damage; they can also remain in that fully discharged state for arbitrary periods.
• Being extremely hardy, capable of operating in tough environmental conditions and at very high duty cycle rates.

• Supporting (by design) regular and repeated 100% charge / discharge cycles. Indeed, the only internal self-maintenance performed by a flow battery involves a periodic full discharge cycle to “reset” the electrode stack. Accordingly, the harder one works a flow battery in the discharge cycle, the better!

This form of technology is not new. Like many other battery developments, the challenge hasn’t been about demonstrating the underlying chemical reaction and solution approach. Rather, it has been about “everything else” – e.g., getting a reliable, mass-produced battery out of the lab and into the market.

There has been a long path involved in moving from a lab-demonstrated good idea to making a cost-effective, reliable battery that can achieve an extended, maintenance-free commercial operating life. It has also been difficult to make a flow battery that works at a size and scale appropriate to smaller site requirements while also being scalable to grid scale in a cost-effective manner.

I discovered Redflow a few years ago while searching for innovative companies in the energy storage space. Redflow makes a battery that has emerged successfully from more than a decade of research and commercialization development. *(Disclaimer: I was so impressed with its technology that I invested in the company and later joined its board of directors.)*

The core Redflow product line is the zinc bromine module (ZBM). The latest version – ZBM3 – is an 11 kWh storage device weighing about 240 kg.

![The Redflow ZBM battery module.](source: Redflow Limited)
The grid-scale Redflow Large Scale Battery (LSB) integrates 60 ZBM3 modules into a 20-foot shipping container form factor to deliver a nominal 660 kWh of storage. It has high internal redundancy and automatically works around the failure of any internal ZBM3 modules.

![A Redflow grid-scale battery system, with doors removed. (Source: Redflow Limited)](image)

One of the challenges with new battery companies is figuring out whether they are really making batteries that work, that can be purchased for real applications – or whether they’re still “vaporware,” in commercial terms.

The Redflow ZBM product line commenced commercial production earlier this year at Flextronics in Mexico, with batteries now being delivered into integration projects in key customer sites around the world. The first production Redflow LSB is being built now for installation at my multi-tenanted office structure in South Australia ([www.base64.com.au](http://www.base64.com.au)).
My intention is to integrate the LSB with our existing rooftop solar deployment and to time-shift our consumption of grid-sourced energy (recharging the battery overnight and delivering energy into the office during the day). Once a planned expansion of our existing solar deployment is completed, we aim to take the whole office complex “off the grid,” with our existing grid supply becoming the backup energy path rather than the primary one.

Field demonstrations of LSB units with grid-energy companies in grid-leveling applications are in negotiation now and are expected to commence later this year.

I believe that flow batteries are ideally suited to grid-scale “energy” applications, arguably more so than lithium chemistry, because of their distinctive (and unique) technical characteristics, as already mentioned.

Where to Go from Here

To underscore a point Elon Musk made at the Powerwall release event: converting the world energy grid to becoming majority renewable-sourced is now entirely achievable.

But it will take more than just Tesla to do it.

I look forward to seeing many other companies contributing to the global-scale task of transforming our electricity supply systems into using renewable energy as the primary generation source. This is a task that will keep a lot of companies busy for a long time, as they literally change the world.
I believe that 2015 will be seen, in future years, as the year that the renewable-energy storage sector hit its inflection point. I can’t wait to see the results of that inflection point taking hold in the world around us.

(Editor’s Note: In recognition of its success in moving to commercial battery production, Redflow has been selected as a FiReStarter company at FiRe 2015.)

About Simon Hackett

As a successful Australian technology entrepreneur, Simon is invested in a variety of Australian and US startups in fields he is passionate about.

Simon is also on the board of the Australian National Broadband Network Company (www.nbnco.com.au).

Simon is a keen supporter of electric vehicles. Meeting Elon Musk at FiRe in 2008 led to him being the first Australian customer of Tesla in 2009. His family now owns several Tesla vehicles (and no gas powered ones), with more on order!

In the energy sustainability field, he has invested in startups in Australia and the US. His largest single investment today is in Redflow (ASX:RFX), where he is now a significant shareholder and a member of the board. He considers this to be a case of putting his money where his beliefs are.

Simon is a serial delegate at the SNS FiRe conference, having participated in almost all FiRe events since their inception. He first attended FiRe to find inspiration (and he did). He keeps coming back for conversations with friends (current and future).

I would like to thank Simon Hackett not only for taking the time to share his insights on grid re-design and battery requirements, but also for his longtime personal contributions to advancing Australia, and now the world, through the application of appropriate technologies in communications, energy, and other critical industries.
I also want to thank Editor-in-Chief Sally Anderson for putting all of these thoughts into perfect shape. – mra.

Your comments are always welcome.

Sincerely,

Mark R. Anderson

CEO
Strategic News Service LLC
P.O. Box 1969
Friday Harbor, WA 98250 USA

Tel.: 360-378-3431
Fax: 360-378-7041
Email: mark@stratnews.com

To arrange for a speech or consultation by Mark Anderson on subjects in technology and economics, or to schedule a strategic review of your company, email mark@stratnews.com.

We also welcome your thoughts about topics you would like to suggest for future coverage in the SNS Global Report.

For inquiries about Partnership or Sponsorship Opportunities and/or SNS Events, please contact Sharon Anderson Morris, SNS Programs Director, at sam@stratnews.com or 435-649-3645.

If SNS is a competitive weapon, shouldn’t all of your employees have it? Email David Morris at david@stratnews.com for details on SNS Site Licenses.

Please visit www.stratnews.com/insideSNS for:

- “In Case You Missed It”: Recent headlines relating to SNS members
- FiRe videos
- SNS event photo galleries
• SNS iNews®
• The SNS blog, “A Bright Fire”
• The SNS Media page
• SNS FiReFilms
• Subscription rates and permissions
• About SNS and About the Publisher

UPCOMING SNS EVENTS

Register now for FiRe 2015, our 13th annual Future in Review conference:

October 6-9, 2015 / Stein Eriksen Lodge Deer Valley
Park City, Utah
www.futureinreview.com

With great appreciation for our SNS Global Platinum Partner

ZIONS BANK®
Our SNS Global Gold Partner

And our SNS Computing and Communications Channel Partners, Nuance and Telstra

... for their Partnership and Support of SNS Events.

Thank you to our FiRe Bronze Partner, Deloitte

SCI, our FiRe Academic Partner

and The Rodel Foundations, our returning FiRe/Thunderbird Internship Sponsor