Low-Cost, High-Performance Redox Flow Battery for Renewable Energy Storage

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ABSTRACT

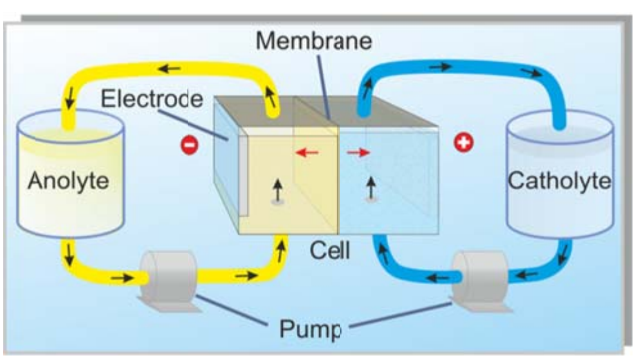
ITN's innovative Redox Flow Battery (RFB) combines advanced materials engineering with stack design breakthroughs to provide the high-power, low-cost energy storage solution that grid-based and off-grid power suppliers have been looking for. ITN's RFB provides higher power capability in a smaller space while using more economical materials to bring the marketplace an affordable and scalable battery to offset the fluctuations found in renewable energy generation (i.e., wind and solar). Combining this low-cost battery with renewable sources, grids, microgrids, and standalone power generators can deliver consistent and reliable power by using the battery to compensate for the intermittent nature of renewable energy production.

Keywords: redox flow battery, energy storage, grid storage, renewable energy, microgrid

1 REDOX FLOW BATTERIES

Redox flow batteries, due to their inherent safety, scalability, and long term durability, are the only technology that has the potential to satisfy all of the requirements for large-scale storage in applications where long discharge times are required. The power is governed by the stack area, while the total stored energy can be independently designed by simply adjusting the size of the tanks, i.e. the amount of electrolyte available to the system.

Figure 1—Redox Flow Battery Components



Cathode: $VO_2^+ + 2H^+ + e^- \xrightarrow{\text{Discharge}} VO^{2+} + H_2O$

Anode: $V^{2+} - e^- \xrightarrow{\text{Discharge}} V^{3+}$

Cell: $VO_2^+ + V^{2+} + 2H^+ \xrightarrow{\text{Discharge}} VO^{2+} + V^{3+} + H_2O \quad E_o=1.26V$

The primary advantages of RFB over other battery technologies include:

- **Safety:** No fire hazard
- **Long Life:** Greater than 10,000 charge/discharge cycles = low life cycle cost of energy
- **Low Maintenance:** Automated, sensor based battery maintenance
- **Scalability:** Supports systems from kWh to MWh and avoids complex cell level battery management systems required for li-ion, etc.

The inherent safety, durability, and scaling of RFB are derived from the simple mechanism that RFBs store energy via simple conversion of ion states in a liquid.[1] In contrast, lithium ion batteries store energy via intercalation of lithium ions into solid state crystalline matrix leading to mechanical strain and cracking of the intercalation materials that ultimately limit the lifetime of the batteries. Further, lithium-ion's use of liquid electrolytes introduces a flammability hazard, and leads to formation of interface materials that further limit battery life.

There are three main components of an RFB: (1) The Stack Power Assembly (SPA), with catalytically active electrodes to promote conversion of ion states and an ion exchange membrane to separate the anolyte and catholyte chemicals, (2) The Tank Electrolyte Assembly (TEA), and (3) The Power Conditioning Unit (PCU), which interfaces the battery to a grid/microgrid and monitors the health and state of charge. While RFBs have long been recognized as having superior potential to meet large scale storage challenges, their historical cost has been prohibitive. ITN has focused on a low cost SPA and TEA, introducing low cost materials and efficient designs to make an appealingly affordable RFB solution.

1.1 The Opportunity

Renewable energy generation is expanding rapidly throughout the world. Unfortunately, renewable sources (wind and solar) are intermittent and unpredictable.

- Wind turbines only produce electricity when the wind is blowing.
- Solar panels only produce electricity when the sun is shining.
- Electricity demand is based on human activity – which may not correlate to the schedule of the energy that is being generated.

Without storage, electricity must be used the moment it is generated. Thus, when a power source generates more energy than can be consumed:

- Utilities throttle down their coal, nuclear or hydro generation
- Solar systems offload excess energy to the grid putting more pressure on utilities' energy management
- Wind Turbines are turned off

Affordable RFBs solve the problems caused when energy generation doesn't precisely match user demand. Attaching batteries to power generation sources enables power providers to:

- Extend the life of conventional power generation assets
- Stabilize inconsistent power supplied by solar and wind energy sources
- Provide power for peak usage periods without needing to invest in excess capacity just to satisfy temporary demand, while having assets sit idle when demand is low

The integration of renewable energy generation and storage capability provides benefits of increased energy security, emergency preparedness, reliable energy pricing, etc. across commercial and military applications. Figure 2 shows a typical deployment where renewable solar and wind are the primary generators, the RFB provides storage, and a diesel generator and/or grid connection provide backup to meet localized energy demands with the lowest carbon footprint and cost. [2], [3]

Figure 2—ITN's RFB enables smart and economical networks for grid and microgrid applications.

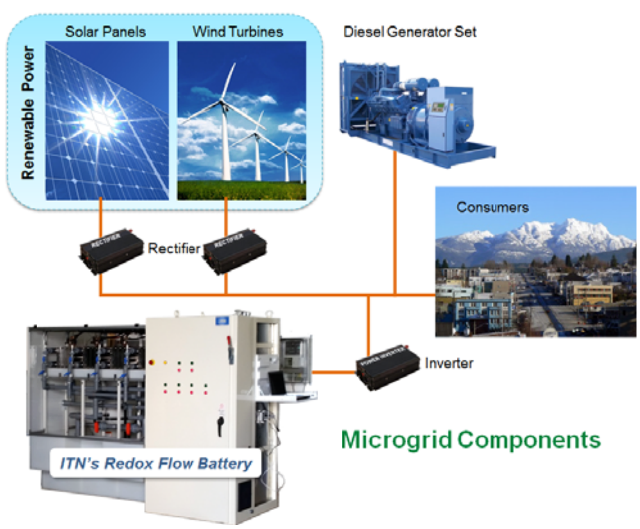
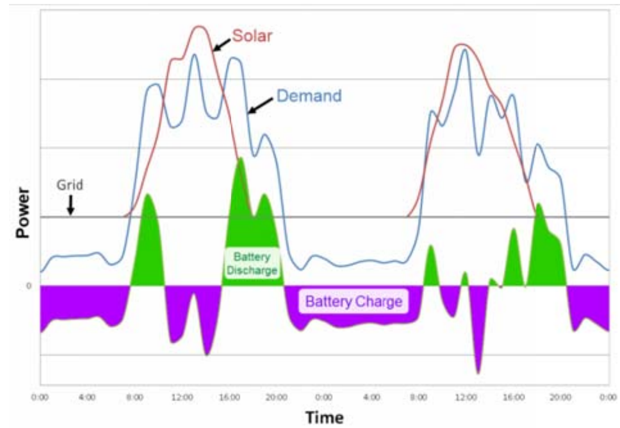


Figure 3 shows the impact of energy storage on the system operation. The RFB effectively buffers periods of excess demand and generation capacity to minimize the use of grid/genset assets to meet local energy supply. Periods of battery charge are shown in green, discharge in violet.

Figure 3—ITN's RFB helps match renewable power generation supply with customer electricity demand.



1.2 ITN's RFB Innovations

Building on its extensive membrane and fuel cell experience, ITN began to pursue RFB technology in 2010 leading to a Gen 1 RFB employing all vanadium chemistry, which incorporates a low-cost, high power density stack. Because the RFB's membrane and electrolyte constitute a large fraction of cost, ITN also pursued new designs to further reduce cost. In 2012, ITN won a $2.1M grant from the Advanced Research Projects Agency (ARPA-e) to investigate innovative membrane materials and electrolyte chemistries. With this funding, ITN is developing:

- Low Cost Membranes
- Low Cost Mn Electrolytes
- Lowest Cost Organic (Nonmetallic) Electrolytes

As a result of these efforts, ITN's team has developed materials and design breakthroughs that reduce the overall RFB costs by 50%, resulting in a Gen 2 battery that is significantly cheaper than current state of the art. Integrating these key differentiators, ITN has the lowest cost, highest performing redox flow battery for load shifting applications. These developments come from the company's long history of technical and process innovation.

Figure 4—ITN's Mn/V Electrolyte Offers Higher Voltage as Well as Lower Cost

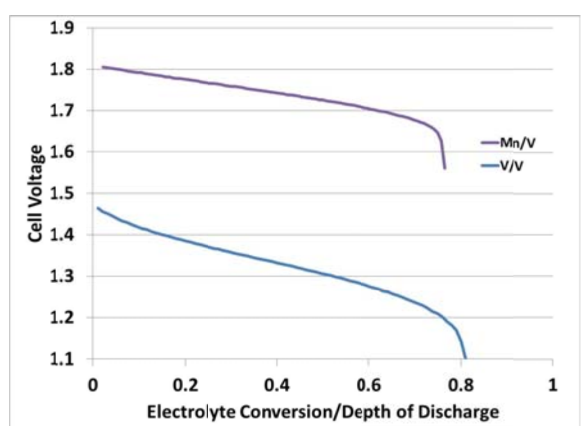


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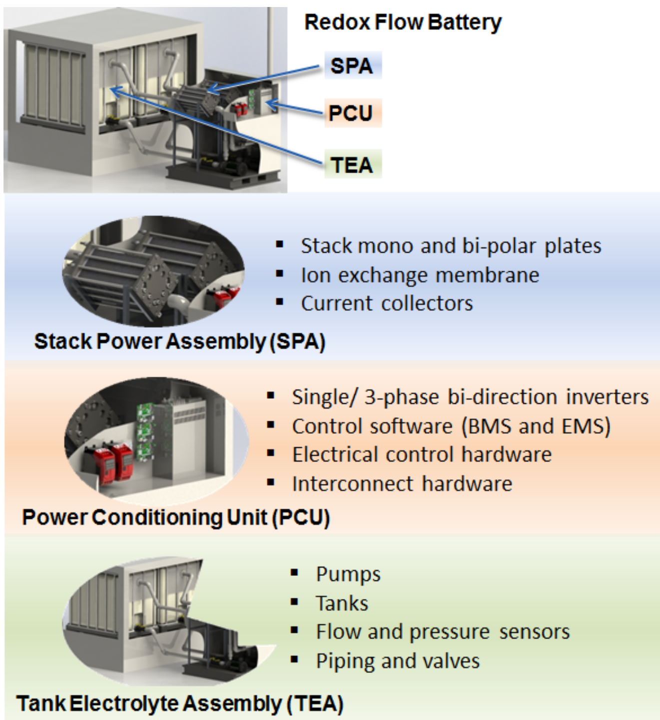
Figure 4 shows that, in addition to lower cost materials, ITN's next generation Mn/V electrolyte provides a higher cell/stack voltage to further improve the performance. In addition, ITN's membrane has shown strong cycling data and performance similar to Nafion®.

2 CONFIGURATION AND PERFORMANCE

2.1 ITN's Battery Configuration

ITN's advanced RFB consists of three main assemblies, the Stack Power Assembly, the Power Conditioning Unit, and the Tank Electrolyte Assembly (Figure 5).

Figure 5—ITN's RFB Design Concept



2.2 ITN's Battery Performance

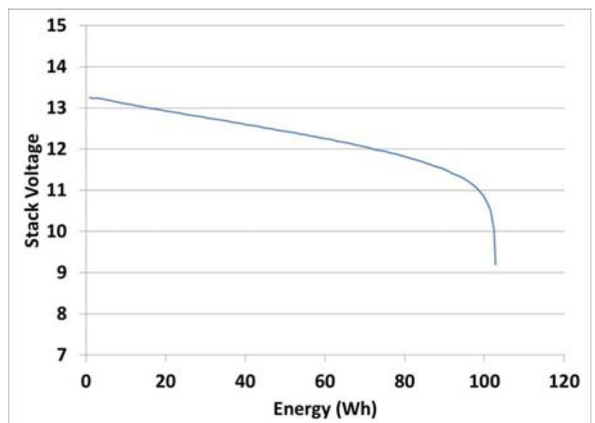
Figure 6 shows ITN's modular stack design that enables the SPA to be constructed from modules that can be connected in series/parallel combinations to provide the desired power and energy. Each stack shown can produce up to 5 kW of power. Figure 7 shows a typical discharge curve for ITN's subassembly stack design with coulombic efficiency ~98% and energy efficiency approaching 85%, even at high operating power density.

3 COMMERCIALIZATION

The world's industrial nations are expecting electricity storage needs to grow rapidly. To capture this emerging market, ITN has established strategic partnerships with two European partners to demonstrate and commercialize its RFB technology. With these partners, ITN has fielded two units (Figure 9). Figure 10 shows operation of one of these demonstration systems. Similar relationships are now being developed in the US and other regions of the world.

Figure 6—ITN's improved stack design provides high power and efficiency at low cost.

Figure 7—ITN's RFB achieves high power density and performs with industry leading efficiency.



The world's industrial nations are expecting electricity storage needs to grow rapidly and urgently need efficient and cost-effective large-scale energy storage systems (Figure 8). While the 2012 grid storage market of $200 million was substantial, market forecasters predict the market will grow exponentially to reach $19 billion by 2017. Advanced flow batteries are predicted to account for approximately 17% of this market.

To capture this emerging market, ITN has initially established strategic partnerships with two European partners to demonstrate and commercialize its RFB technology. With these partners, ITN has fielded two RFB units in 2014/2015 (Figure 9). Figure 10 shows operation of one of these demonstration systems during field testing. Similar relationships are now being developed in the US and other regions of the world.

Figure 8—Worldwide installed grid storage is predicted to exceed 14 GW in the next ten years. [4]

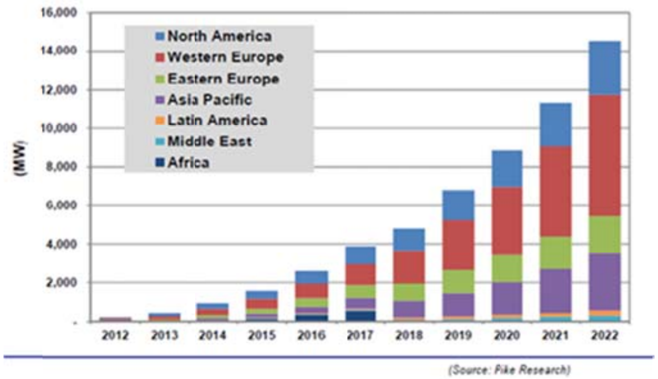


Figure 9—ITN's RFB Demonstration with a European Partner

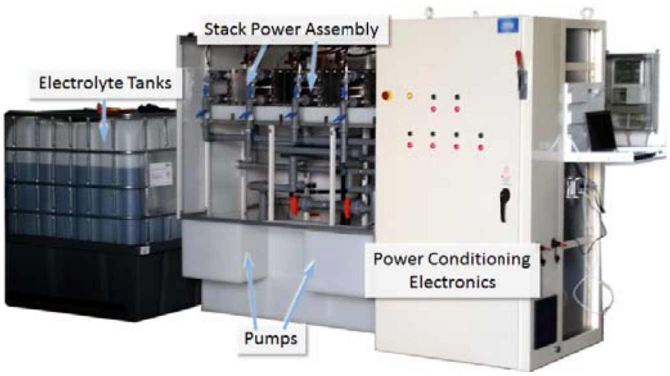
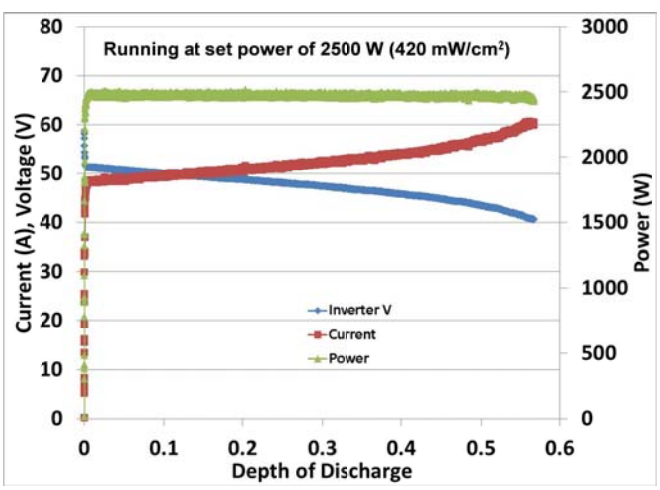


Figure 10—Field Testing of ITN RFB.

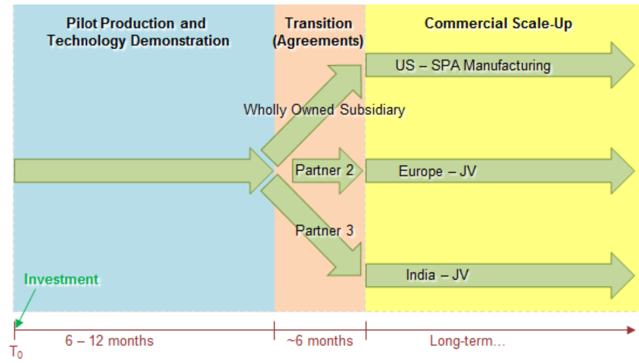


4 PRODUCTION TIMELINE

ITN will form additional strategic partnerships in different parts of the world via licensing agreements or joint ventures to leverage local expertise and established distribution channels and established business presence. The goal is to initially focus on 10 - 100 kWh systems (e.g., residential backup, telecom towers, military missions, etc.).

ITN will initially manufacture and supply the stack power assembly (SPA) and will provide specifications to our partners for the rest of the system.

Figure 11—ITN's Commercialization Timeline



Based on successful testing in Europe, ITN expects to secure a large purchase order and begin full commercial stack production in mid-2015. ITN is currently planning and procuring financing for the volume expansion to handle these orders as well as to handle expanded market demand based on these initial successes.

5 SUMMARY

With advances in stack design, membrane and electrolyte chemistry, and overall system efficiencies, ITN has advanced the state of low-cost RFBs for Distributed Power Systems, making redox flow batteries affordable for grid and off-grid storage solutions for the first time. ITN is beginning commercial production, based on existing relationships with initial customers and market efforts to establish new customers in commercial and defense markets.

REFERENCES

1. Ding, C. *et al.* (2013). Vanadium Flow Battery for Energy Storage: Prospects. *Journal of Physical Chemistry*, 1281-1283.
2. U.S. Department of Energy. (2013). *Grid Energy Storage*. Washington, DC: U.S. Dept. of Energy.
3. Weber, A. Z., *et al.* (2011). Redox flow batteries: a review. *J Appl Electrochem*, 1-5.
4. Dehama, A. & Adamson, K.-A. (2012). *Energy Storage on the Grid*. Boulder, CO: Pike Research.