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# ELECTRICITY STORAGE

## SCOPING THE TECHNOLOGY AND POLICY FRONTIERS

ENERGY CENTER
UNC KENAN-FLAGLER BUSINESS SCHOOL

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# Electricity Storage – A Conference Report

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# Electricity Storage Event – Key Take-Aways Summarized

The UNC Kenan-Flagler Energy Center, in conjunction with the UNC Institute for the Environment, hosted a one day, invitation-only event on electricity storage. The main purposes of the event were 1) to determine how major utilities are valuing and deploying battery storage today and 2) scope the prospects for new storage technologies which could be game-changing over the next decade. To that end, five major utilities and five technology developers presented their assessments and prospects. Key take-aways from the session are summarized below:

## ***Summary Comment***

Cost effective, long duration electricity storage remains a daunting challenge, and no 'silver bullet' solution is yet visible. Significant incremental progress has been made and likely will continue. Battery costs continue to decline while cost-effective utilization is now approaching 4 hour discharge. Utilities are now finding battery storage projects to be economic in specific locations, especially when justified by deferring/avoiding significant transmission or substation investments. Emerging technologies hope to extend battery storage cost-effectiveness towards 10 hour discharge. Technology details about how these manufacturing cost and discharge targets will be achieved remain limited. This argues for caution as regards assuming that breakthroughs in long duration storage will materialize in the next decade.

The progress in battery storage is making hybrid projects combining wind/solar generation and storage increasingly competitive with existing peaker plants. This should accelerate the retirement of older peaker plants, especially in regulated power markets. While much of the focus has been on batteries, long term energy storage encompasses a broader set of technologies. Pump storage hydro (PSH) and compressed air storage (CAES) are proven, cost-effective forms of long duration storage. Their fast response capability and flexibility make them excellent complements to increasing amounts of intermittent generation. However, both PSH and CAES are limited by formidable siting and licensing challenges requiring many years to navigate; they also require large capital sums. Some utilities are 'de-bottlenecking' their existing PSH capacity by adding new generators; such projects may constitute the lowest cost source of incremental long duration electricity storage.

***How Utilities value and deploy Storage Today***

- Battery Storage has a multi-dimensional value proposition providing economic credits to justify the investment (Attachment 1 & 2). The list of primary value streams includes:
  1. Deferral/avoidance of transmission/distribution upgrades
  2. Electricity arbitrage: i.e. storing low value electricity for discharge at higher value times
  3. Capacity backup, clipping energy from wind/solar when available to discharge when renewables are offline
  4. Smoothing/ramping support, enabling full generation mix to ramp up/down more efficiently with minimal curtailment/dumping and/or costly starts/stops of peakers
  5. Optimize design of wind/solar projects in light of load curve and PPA terms
  6. Ancillary services including frequency response

  Storage's ability to provide backup power is often labeled 'capacity value' and generally is deemed 3-10x more valuable than its ability to 'arbitrage' power prices, i.e. capture very low value electricity generated off-peak and save it for discharge at higher value moments on the load curve.

- Some skepticism was expressed in the ability to dynamically optimize across all of these potential values. The ability to achieve "value stacking" in practice seemed most likely in a case where there was a primary use during defined time frames freeing up the asset in other times for another use.

- There was a general consensus that battery storage today is cost effective within a 2-4 hour discharge window. The consensus extends to the fact that lithium-ion (LIB) costs will continue to decline, especially as electric vehicle demand ramps up (Attachment 3). Considerable doubts were expressed however as to whether the pace of battery cost declines projected in some quarters will be realized. More will be said on this below when we list the major take-aways from the technology developer presentations.

- The major utilities generally agree that deferral/avoidance of transmission/distribution upgrades is currently the most important justification for current battery storage projects. They gave multiple examples of difficult to serve locations where storage represents a more cost-effective solution relative to new power lines or sub-station upgrades.

- Several utilities gave examples of current storage projects where remote customers are to be served by newly installed storage or solar + storage with the benefits being improved reliability on otherwise vulnerable distribution links and the deferral of costlier distribution upgrades.

- Storage vendors see integrated projects combining wind/solar power with battery storage as increasingly cost competitive with existing fossil fuel peaker plants (Attachment 4). They see a large market for phasing out peaker plants in favor of integrated renewables/battery storage solutions. While it may seem counter-intuitive to use a high fixed cost solution for peaking, the ability to use renewables plus storage at "zero" marginal cost in non-peak times can help beat the natural gas option. The major utilities were more reticent on this topic, perhaps viewing the case for these integrated renewables/storage projects as more market and site specific.

- Some technology developers project a large global storage market created on the backs of large increases in renewable, intermittent power generation (Attachment 5). In this scenario, intermittent power is mandated with storage following to address growing grid stability concerns. Such scenarios tend not to discuss cost impacts or the technical specifics of how needed longer duration storage is to be achieved.

- One company has created a firm energy product by combining wind, solar and storage. The combination of wind and solar requires less storage to balance the desired output.

- One looming concern with lithium ion storage is with new fire protection requirements being considered. As energy density of storage increases, the fire risk and cost of providing required fire protection may impact economics of projects.

- Two utilities confirmed the dramatic cost-effectiveness of pump storage hydro (PSH) as a means of electricity storage. Pump storage hydro is proven, mature technology with very large capacity, up to 4,000 MW. It provides cost effective storage (capacity factors of 75-85%) with up to 22 hours of discharge. However, suitable sites and permitting processes are major constraints. Most PSH was built in conjunction with nuclear plants during the 1970s. Today the challenges of siting and licensing confront potential projects with a 10+ year timeline from conception to possible startup. Capital costs are also in the multi-billion dollar range. Even with these challenges, PSH's long life (40+ years) and ultra-large capacity offer the prospect of economic returns. The problem for most utilities now resides in finding suitable sites and taking the risk of spending large amounts of early project capital, only to find the project never obtains final environmental and regulatory approval.

- That said, PSH's ability to offer cost-effective long duration storage would make for attractive paring with increasing amounts of intermittent wind and solar generation, a fact causing utilities to reexamine its possibilities. One utility is currently considering a new PSH site as a response to a state mandating a massive expansion of wind/solar generation by 2030 and legislative indications finding PSH to be in the Public Interest. This utility believes PSH to be possibly the best response to the needs created by a large increase in intermittent generation, i.e. those needs being for fast reacting, high volume energy injection with the capacity for flexible and resilient reaction to subsequent supply/demand changes. Attachments 6 & 7 provides two utilities views of the PSH value proposition.

- This utility's project provides an idea of what's involved in developing new PSH. Siting and construction licensing take 3-4 years while construction will take 5-7. Construction involves building a reservoir, underground tunnels for water flow and a power station located ~200 ft. underground. Attachment 8 provides more details of the PSH project development process.

- Another is 'debottlenecking' its existing PSH capacity by adding more efficient generators. This latter strategy, which can increase storage capacity by up to 30%, may offer the single most cost effective form of new electricity storage.

- Compressed air electricity storage (CAES) is another form of proven, long duration storage. Existing projects use off-peak or cheap renewable power to compress air into some form of cavern, usually underground (e.g. mined out salt dome). When power is needed, the compressed air is released and heated by fossil fuel combustion before blowing through a turbine. Existing projects show efficiency factors in the 40-55% range and can cost effectively store power for discharges of 2-14 hours (Attachment 9). As with PSH, siting, licensing and capital cost are factors limiting the number of CAES facilities; as an example, one southern state facility took two years of salt dome mining to create the storage cavern. However, the growing presence of intermittent generation sources is reviving utility interest in new CAES projects.

- Advanced forms of CAES are now in development. These seek either to eliminate the need for combusting the released compressed air or to store heat efficiently from the original compression stage for use later when the compressed air is released. Some projects using these concepts are now under construction with startup envisioned in the next several years.

***Scoping the Electricity Storage Technology Frontier***

- Storage technology developers and venders presented their outlooks, some focused on different battery technologies, others on advanced forms of hydro or air-based storage. All forecast a large need and growing market for long-duration storage driven by the twin trends towards 1) greater penetration of wind/solar into the global generation mix and 2) the increasing penetration of electric vehicles into transportation with a concomitant need to extend driving range and reduce recharging time. Another objective is to extend the 'cycle life' of batteries such that their effective life comes closer to matching the underlying life spans of wind/solar assets or electric vehicles.

- The 'long duration' horizon being targeted would extend the current 2-4 hour, cost-effective discharge window of Lithium Ion batteries out to 8-10 hours. Success in this effort would allow battery-based storage to meet most if not all 'intra-day' grid storage requirements. Vendors also argued that 8-10 hour storage, in conjunction with planning and some de-carbonized natural gas power, could meet intra-day and possibly intra-week requirements. Longer duration, e.g. seasonal storage, still remains over the horizon.

- One developer outlined the challenge of long duration storage by describing the capabilities to be targeted if storage is to replace high capacity factor natural gas. The developer noted that today's LIBs cost ~$300 kWh of installed capacity, have a discharge duration of less than 10 hours, and a system life less than 12 years. To replace natural gas, storage costs would need to decline well below $100 kWh while extending discharge duration to 100s of hours (Attachment 10). These are the outcomes being sought by this developer on the basis of proprietary technologies that allow lowest cost materials to combine with function IP, custom design and specialty chemical additives. This developer, however, declined to provide any more details as to the technology that would achieve its ambitious targets – advising that the firm intended to patent and disclose much of its intellectual property in the coming months.

- Other developers were noticeable reticent to discuss costs, delivery dates or demonstration events for their advanced technologies. One developer showcased their varieties of 'zinc-air' batteries which in the most advanced form promised up to 20 hour discharge capacity. This developer also gave examples of multiple projects already deployed around the globe Attachment 11). However, almost all of these projects were small scale and located in remote communities in developing countries; this suggested that the technology's cost competitiveness was such that it could only be justified by the physical unavailability or very high cost of conventional alternatives.

- Another presentation offered a schematic of a 'solid state' LIB (Attachment 12) without any discussion of costs, target capabilities or timeline. Given that the audience included the executives responsible for storage at 5 leading U.S. utilities, the developers' reticence on these subjects could not fail to be noticed, and encouraged a perception that a 'breakthrough' battery is still a laboratory project.

- Presentations on advanced forms of PSH, hydrogen or 'liquid' air storage were no more informative. Technical schematics were presented, suggesting that the concepts were physically feasible; once again the absence of any cost or economic data raised commerciality concerns. The liquid air storage presentation did suggest some demonstration applications had occurred, moving the technology beyond mere 'proof of concept' in the lab.

- A final presentation focused on the production of synthetic, renewable natural gas. This concept involved using low cost renewable power to produce hydrogen via electrolysis. The hydrogen is then reacted with $CO_2$ captured from combustion waste gas, with new natural gas resulting. The process is seen to be carbon neutral or better, as the C02 produced by eventually burning the new natural gas is equal to or less than the C02 captured and fed into the methanation process.

- Once again, no cost data or scale-up timelines were presented. Examples of small scale demo plants were presented without economics. The process is one of multi-step capture and conversion, i.e. $CO_2$ must be captured separately from the hydrogen manufacturing process and then a separate methanation step must be completed (Attachment 13). Scale economics will be impeded by the dependence on low cost but intermittent power. In sum, this intriguing concept of synthetic, renewable natural gas looks cost uncompetitive with LNG and would likely require subsidies and /or carbon credits to be commercial.

***<u>Conclusion:</u>***

The outlook at present is for progress on battery manufacturing costs and incremental technical improvements eventually to render battery storage cost effective in a 4-10 hour discharge window. Assuming aggressive wind/solar mandates are maintained, this will afford utilities the opportunity to improve grid resiliency, defer transmission/distribution investments and replace some fossil fuel peaking capacity with hybrid wind/solar + storage. Selected opportunities to optimize existing PSH and CAES and perhaps develop some new sites may also be captured.

While there are instances in which storage is being successfully deployed, it is at present in targeted situations and use cases and not yet an economic winner throughout the U.S. None of the presented advanced technologies appear to offer any near term breakthrough prospects. Most appear to be laboratory or early stage demonstration projects; the absence of any convincing data suggesting a given technology has capability to reach cost competitive targets is noteworthy.

The intensity and breadth of technology development efforts is hard to miss. One leaves this discussion with a strong impression of few stones being left unturned – breakthrough chemistries, manufacturing, software, analytics and reconfigurations of existing designs are all 'on the table.' However, the physics, chemistry and economics of electricity storage are challenging. Many of its value streams are hard to model and capture in pricing. Contract markets, well developed for wind/solar, hardly exist for storage.

These barriers and obstacles argue for caution as regards what electricity storage can deliver over the next decade.  Regulators mandating aggressive wind/solar penetration should pay attention to the costs associated with assuming that battery storage will provide the solution to growing intermittency and grid instability.  Regulators and environmental groups may also want to re-examine the case for PSH and CAES as more cost-effective ways to support the growing presence of wind/solar on the grid.

# Electricity Storage

# Appendix

1. ***Common battery + (Solar and/or Wind) Optimization***
2. ***Integrating Energy Storage into the Business – Value Streams***
3. ***Battery Costs and Declining***
4. ***Battery configuration will vary based on the customer's characteristics***
5. ***Long duration energy storage is a $20 billion market***
6. ***Pump Storage Hydro: Proven Long Duration Storage***
7. ***PSH Value Proposition***
8. ***Stages of PSH Development***
9. ***CAES Advantages***
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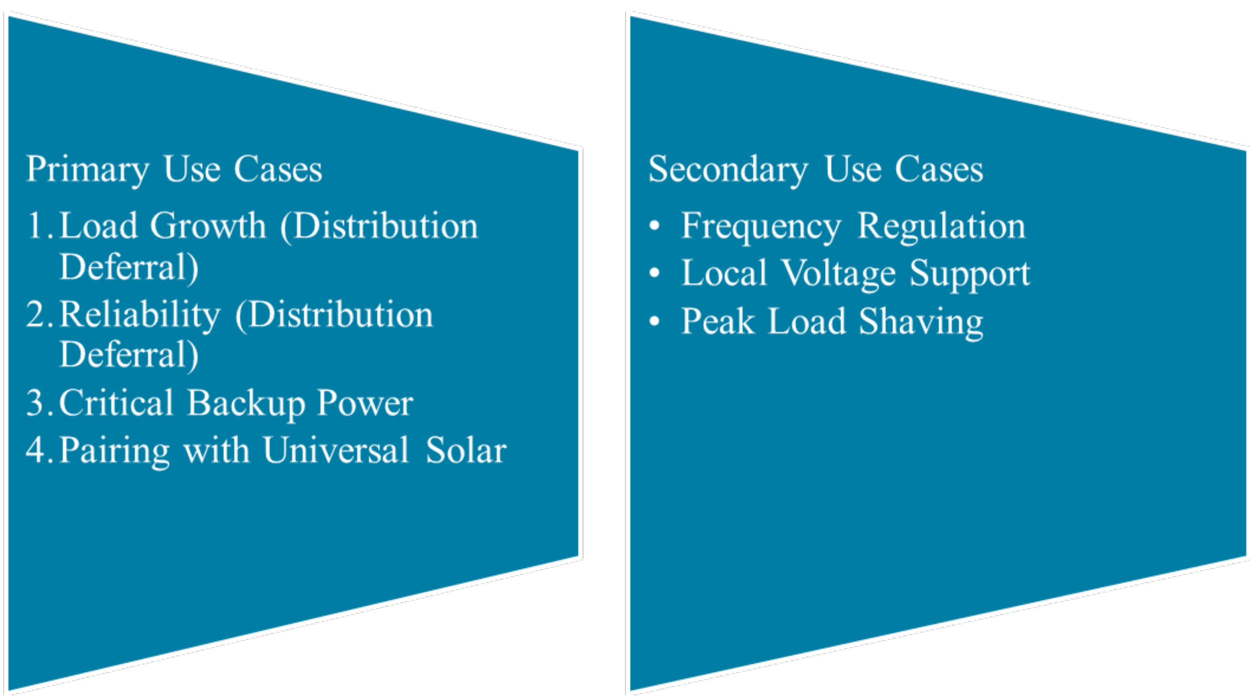
11. ***Advanced Technology Storage: Installed Base Worldwide***
12. ***Li-Ion / What's next? All solid state battery.***
13. ***Power to gas technology and possible application***

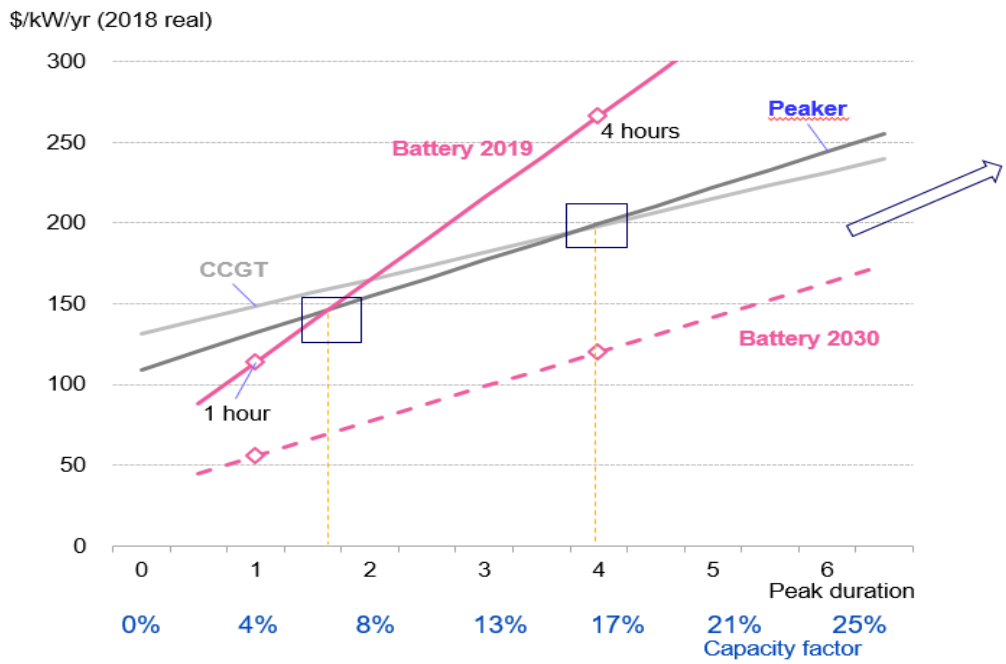
**Appendix 1: Common Battery + (Solar and/or Wind) Optimization**

| Use Case | Description |
| --- | --- |
| Peak Capacity Firming / Shifting | • Shift capacity of generation for more certainty in desired hours (e.g. SPP resource adequacy rules)<br>• Depending on battery can deliver very high certainty during peak hours (peaker replacement) |
| Clipping Capture | • Capture clipped energy with battery to discharge when available<br>• Solar DC, Solar Interconnect, Wind Interconnect |
| Smoothing | • Overcome the renewable generation variability via battery cycling and deliver a smoother generation profile |
| Hybrid Renewable | • Optimize the design of a hybrid wind, solar, and/or battery site for desired profile, capacity hours, and system benefit |
| Integrated Portfolio Optimization | • Charge battery during low (or negative) price periods to discharge during higher priced hours<br>• Either grid-connected or resource-connected |
| Post PPA Optimization | • Incorporate details of PPA price and constraints and re-optimize integrated solution<br>• PPA price, energy GEP and limits, interconnect MW, Battery MW and duration, DC:AC ratio, etc. |

**Appendix 2: Integrating Energy Storage into the Business - Value Streams**



**Appendix 3: Battery Costs are Declining**



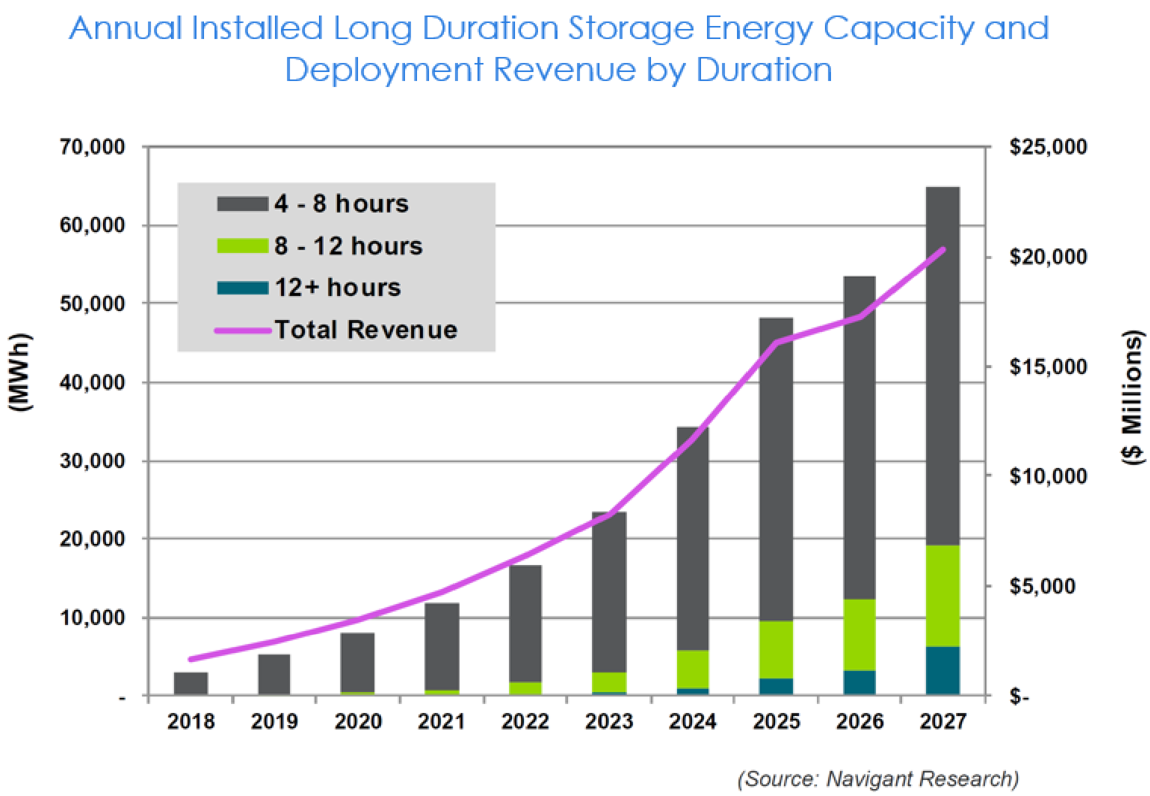

**Appendix 4: Battery configuration will vary based on the customer's characteristics**

## Peaking Capacity

- **As the battery industry scales up, the first peaking capacity batteries we will see deployed are the shorter duration batteries (1-4 hour range)**
- **Peaking capacity and duration is very dependent on the customer buying the battery**
  - The utility has a transmission constraint or local capacity issue
  - The utility has plans to retire old generation (may or may not be publically announced)
  - Utility is growing organically and trying to meet peak demand with new generation

**Utility has a team dedicated to sizing batteries that match customer's profile**

**Appendix 5: Long duration energy storage is a $20 billion market**




Interest in long duration storage is rising around the world as the rapid growth of variable output renewables continues and issues with grid stability and efficiency become more tangible for grid operators.

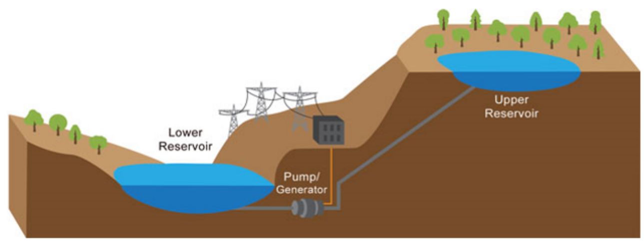
**Appendix 6: Pump Storage Hydro: Proven Long Duration Storage**

***Advantages:***

- Very high capacities - up to 4,000 MW
- 76-85% efficiencies
- Long life - up to 50 years & low operating costs
- Mature technology -40 installations in US
- No air emissions

***Challenges:***

- Permitting
- Available land




**Appendix 7: PSH Value Proposition**

With renewables and retirements, a greater *need* for fast and accurate response, high-volume ramping of energy injection and absorption, resiliency and flexibility

PSH resources

- Reach full generating capacity in minutes from offline state (grid is the limiting factor in many cases)
- Are beneficial in the event of a loss of a traditional resources
- Are fuel secure and fuel diverse, supporting the system when fossil fuel generators experience a disruption due to delayed gas and oil deliveries, or frozen coal piles
- Can act as load allowing renewable and other resources to stay online

Utility supports development of new PSH resources to meet the needs of the ***evolving electric grid***.

**Appendix 8: Stages of PSH Development**

1. Feasibility Studies
   - Site selection
   - Preliminary specs
   - Geotechnical studies
2. Licensing and Permitting
   - Preliminary Permit Application (PPA)
     - Takes a few months
     - Locks in the footprint for PSH
   - Preliminary Application Document (PAD)
     - ~1 year
     - More details such as drawing but specs are still in draft stage
     - FERC orders environmental studies (DEQ, Army Corp, DGIF)
   - Final Application
     - 2-3 years
3. Construction
   - 5-7 years
   - Large diameter tunnels
   - Underground power house (~200ft)
   - Reservoirs

**Appendix 9: CAES Advantages**

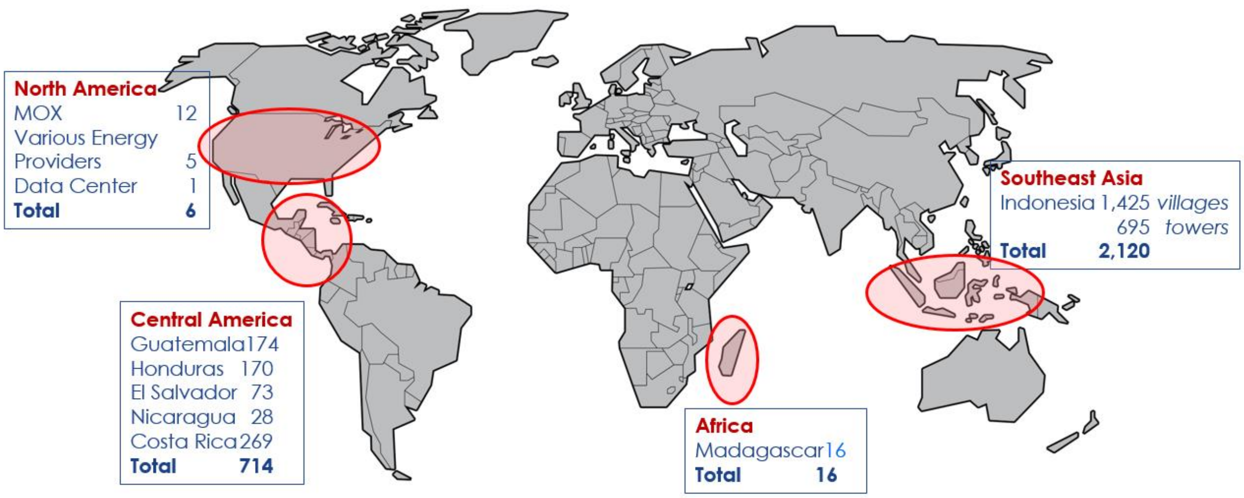
- Small footprint – 2 acre/100MQ
- Excellent part load efficiency
- Fast ramp rate, 20%/minutes
- Cold start – full load in <10 minutes

**Appendix 10: Replacing High Capacity Factor Natural Gas with Storage**

# CCGT vs. Short- & Long-Duration Storage

| Specification | CCGT | Short-Duration Storage | Long-Duration Storage |
|---|---|---|---|
| Power Output (MW) | 200 - 1000 | 1 - 1000 | 1 - 1000 |
| Discharge Duration (hrs) | 100s | <10 | 100s |
| Startup Time (sec) | 300 | <1 | <1 |
| Ramp Rate (MW / min) | 50 | 3000 | >1000 |
| System Life | 25 | <12 | 25 |
| Power CapEx ($/kW) | 1300 | <$1500 | <$1500 |
| Energy CapEx ($/kWh) | N/A | 100s | 10s |

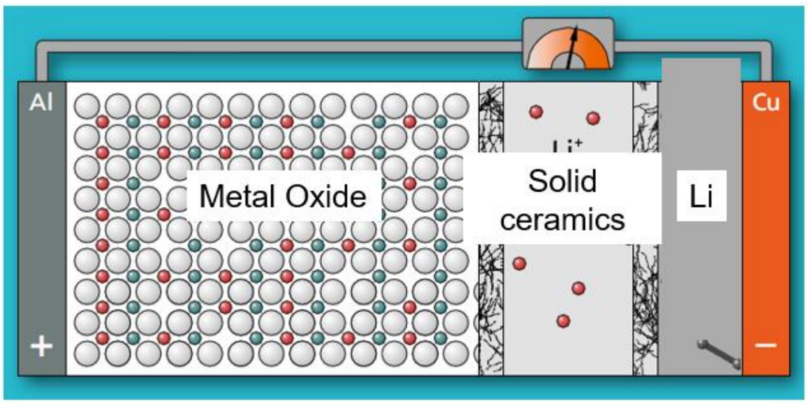
**Appendix 11: Advanced Technology Storage: Installed Base Worldwide**



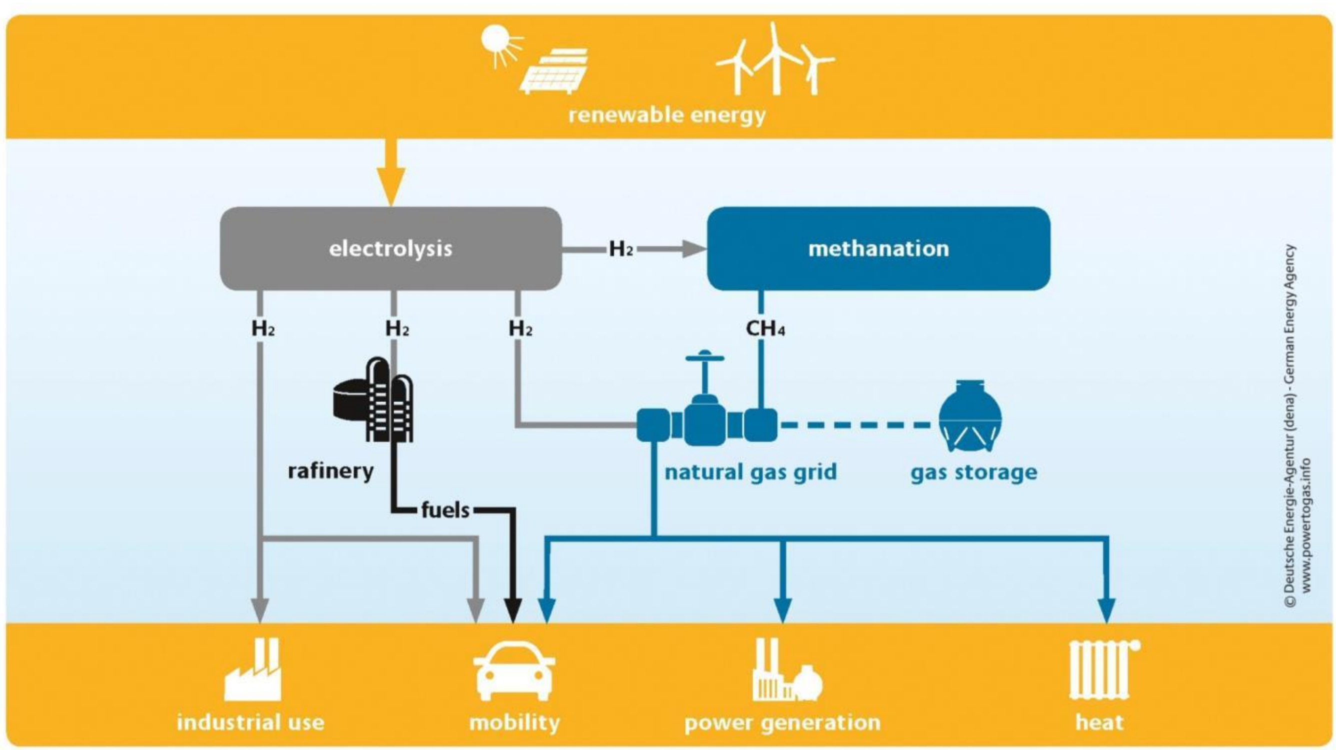

**Worldwide**
**Total Units 2,856**
**MWh 48.0**

**Appendix 12: Li-Ion / What's next? All solid state battery.**

- higher energy density than Li-Ion battery
- Higher safety due to missing liquid electrolyte
- Higher temperature stability
- R&D for stable interface construction and commercialization necessary




**Appendix 13: Power to gas technology and possible applications**



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