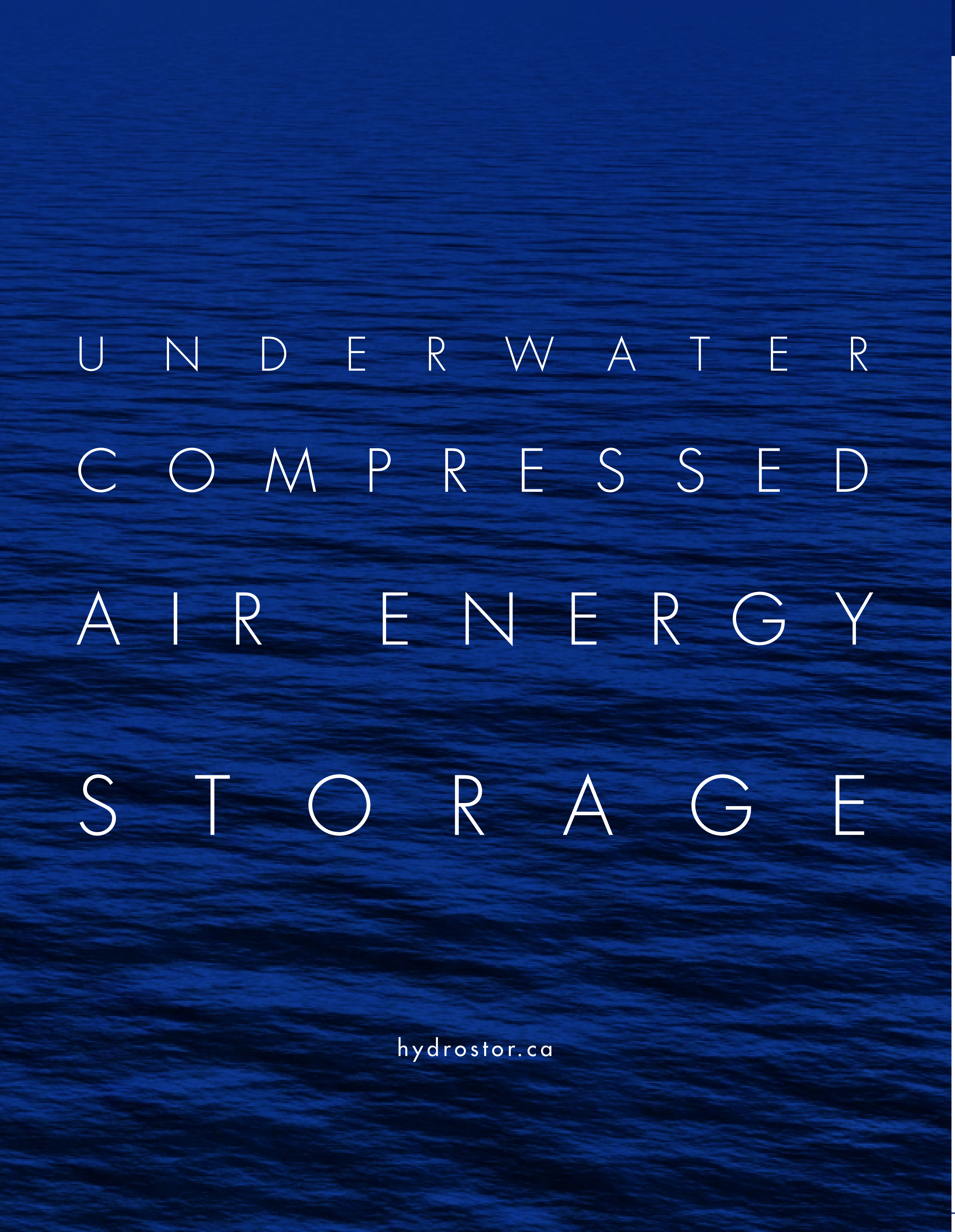
UNDERWATER COMPRESSED AIR ENERGY STORAGE

ISLANDS & MICRO-GRIDS

WHITE PAPER

hydrostor.ca



Hydrostor Inc - Underwater Compressed Air Energy Storage:

Enabling lower electricity rates and emissions for islands and micro-grids across the World

Hydrostor is a Canadian-based company commercializing a patented adiabatic underwater compressed air energy storage (UW-CAES) solution. This energy storage solution combined with renewable generation is a great fit for islands and micro-grids seeking to lower their electricity rates and emissions. This white paper provides an overview of the technology and how it can support these communities transition to a more sustainable energy system.

Table of Contents

SECTION I

Unique Situation of Remote Islands and Micro-grids

When most people think of the remote islands or micro-grids they imagine the beauty, independance and freedom that comes from living in low population density areas. However, for the electricity operators responible for producing and maintaining the electricity in remote communities, there are a number of unique features that can pose a challenge to being able to do so at a low cost. These challenges include:

- **Lack of domestic fossil fuel (natural gas, oil, coal) resource.** North America and Europe can produce power from locally sourced fossil fuels at low and stables costs, which is not available to most remote islands and micro-grids.
- **The high cost of imported diesel to fuel most electricity production.** Shipping in diesel or bunker fuel from the open market is a costly proposition with oil trading at ~$100/barrel (USD) and steadily rising. This results in a lack of control over electricity prices to being effectively held hostage by global oil markets.
- **Limited land availability.** This limits the ability of islands to grow local biofuels, develop inland pumped hydro facilities or centralized solar facilities.
- **Smaller "islanded" grids.** The scale of a typical remote island grid ranges from 1-100MW's and is typically "islanded" meaning it is not connected to adjacent island grids. This limit of scale prevents the adoption of some technologies that have minimum efficient scales in the 1000's of MW such as nuclear and liquefied natural gas terminals.
- **Remote from continental US, EU suppliers.** The costs of parts and expertise for complex systems can be prohibitive resulting in a bias toward proven, reliable, less complex systems.
- **Geological features.** Islands typically do not have large elevations or deep underground caverns, which limits the use of systems such as hydroelectric, pumped hydro, underground compressed air facilities that are prevalent North America and Europe.
- **Susceptibility to impacts from climate change.** Islands tend to have densely populated coastlines and are often referred to as being on the front line in the battle against climate change due to risks from increased ocean levels and extreme weather events.

However remote islands and micro-grids also have a number of unique features that can work to the advantage of electricity operators, including:

- **Strong renewable resources** (sun, wind, wave, tidal). In some island countries onshore wind turbines operate with +50% capacity factors versus North American and European averages of 20-25%.
- **Surrounded by deep waters** that can be used for deep lake cooling, ocean thermal energy conversion (OTEC), energy storage, tidal generation, etc.
- **Strong economic motivators and public support** for adopting non-fossil fuel alternatives for electricity generation.

These unique features mean that the renewable energy programs and technologies being adopted in North America and Europe are not necessarily the right solutions for remote islands. Hydrostor understands this, and has designed a solution tailor-made for this type of customer.

SECTION II

The 21st Century Island Electrical Grid

The traditional electrical grids deployed on remote islands or micro-grids includes a single centralized diesel generating station with distribution lines connected to the rest of the island. This configuration is proving to be expensive and unsustainable. Progressive utilities across the World (with support from organizations such as the World Bank, Carbon War Room, Inter-American Development Bank, and many others) are demonstrating that there is a more cost effective, sustainable and reliable configuration that is available today… the 21st Century Island Electrical Grid.

This new electrical grid uses a combination of:

- **Flexibility from demand response** (e.g. turning down water desalination plant production at times of short electricity supply, and ramping it up at times of excess supply), deep ocean cooling to reduce electrical demands, and thermal storage (e.g. making ice in times of excess electricity, and using it to reduce peak cooling demands the following day).
- **Distributed generation from a combination of renewables** such as wind, distributed solar, geothermal, and other renewable technologies once proven and cost effective (e.g. OTEC, tidal), but also has some decentralized biofuel and diesel fuel capacity to manage peaks and act as a back-up power resource.
- **Short duration energy storage** on the distribution network to maintain voltage and frequency regulation, and also to provide ramping support to transitioning from energy sources.
- **Bulk energy storage** to store renewable energy for use on-demand when renewable resources are not available, which is the application Hydrostor's system excels at and will form the focus for the remainder of this white paper.

Bulk energy storage is generally defined as technologies capable of storing enough electricity to discharge at its rated capacity (say 10 MW) for at least 4 hours and in many cases 8-12 hours. These bulk energy storage assets are very different from rapid responding, short duration storage (e.g. flywheel, lead-acid batteries, or capacitors), which focus on smoothing out second by second fluctuations and may provide up to 15 minutes of discharge in ramping applications. Instead, bulk energy storage is more comparable to a generating facility although its "fuel" is often surplus renewable energy. These systems need to replace lost generation for many hours at a time.

SECTION III

Business Case for Bulk Storage

The business case for bulk energy storage for remote islands and micro-grids is very compelling. With the introduction of low cost and scalable energy storage solutions like Hydrostor's, the day has come where renewables plus storage is lower cost than diesel generation for most island nations.

The storage applications (i.e. uses) and benefits differ for each project, but in generally there are five main benefits to bulk storage including:

- **Allows increased renewable penetration, and thereby reducing reliance on higher cost diesel.** In many islands the all-in diesel generation costs is $0.30-$0.60/kWh (USD) and renewable generation is $0.10-$0.20/kWh (USD). So it is clearly more cost effective to use wind instead of diesel, however wind does not produce consistently for 24 hours every day as diesel can which is why many utilities express concerns with having more than ~30% of their generation from wind without any bulk storage. With bulk energy storage wind can produce consistently throughout every day with the same reliability as diesel allowing the percentage from wind to move from 30% to over 70% resulting in a lower cost of electricity. Cost effective bulk energy storage enables the cost of renewables plus storage to be less than diesel, without sacrificing the dispatchability or reliability.

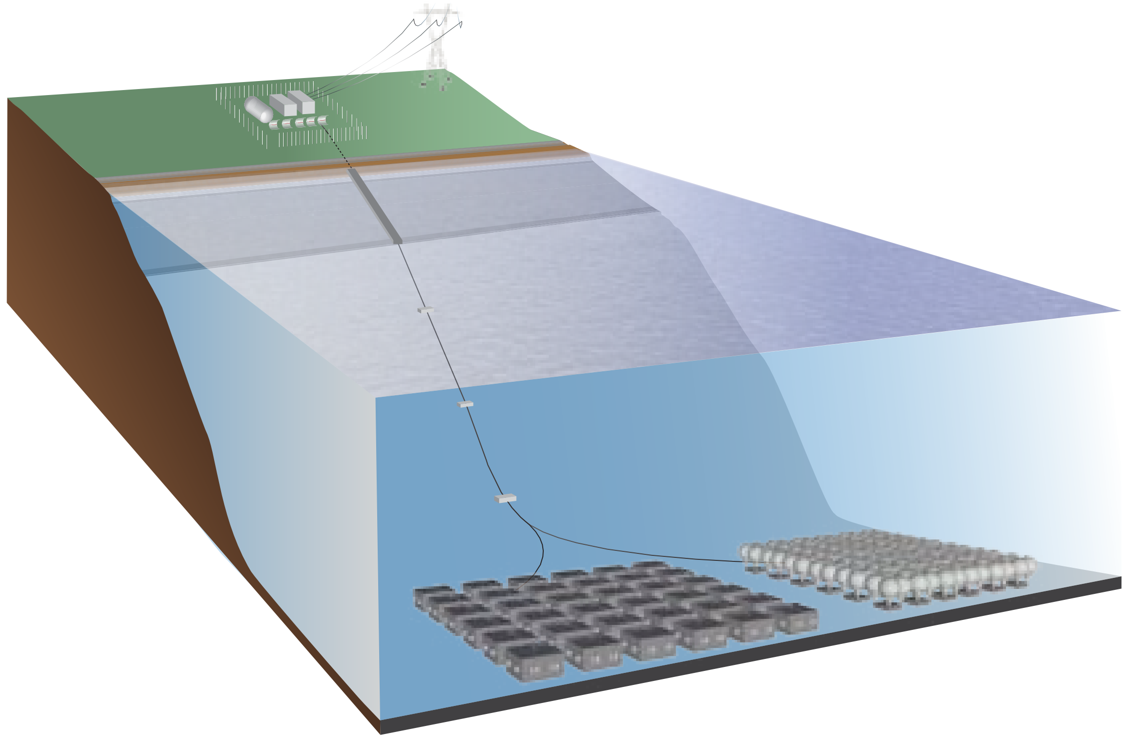
- **Reduced curtailment of renewable energy.** Most wind contracts (or Power Purchase Agreements) include a clause stating that any customer driven curtailment (i.e. turning wind blades to reduce production in times of surplus electricity) is considered "deemed generation" and the utility must pay for the lost production. In these cases, the utility is paying for electricity that it didn't need because it was produced at the wrong time. With bulk energy storage this wind would have been stored and used at a later time to offset costly peak diesel generation.
- **Increases fuel efficiency and reduces wear and tear on thermal (i.e. diesel) assets caused by turning up/down in order to balance grid.** In the absence of bulk energy storage, the diesel generators need to be turned up/down and on/off frequently to respond to both electricity demand and available supply from the renewable facilities. Given it is windiest at night (when demand is lowest), there are large swings in the amount of electricity required from diesel generation. The turning up/down of the diesel facilities can have a significant negative impact on the life of those assets (analogous to highway versus city driving), as well as their fuel efficiency. With bulk energy storage, the storage plant does the majority of this responding leaving the diesel facilities free to produce at their most fuel efficient levels and prevents the wear and tear from constant fluctuations.
- **Increased utility control and flexibility.** Bulk energy storage provides 2x the power rating in flexibility (e.g. a 10MW storage plant can charge at 10MW or discharge at 10MW providing 20MW of flexibility for the grid operator). This flexibility is a premium for electrical utilities seeking to integrate intermittent renewable generation especially when it is decentralized such as residential solar.
- **Minimize the size of the transmission line infrastructure** connecting wind sites. A large cost of a new wind farm is the transmission line connecting it (often located in rural parts of the island or far offshore) to where the electricity is used (city centres). Given that a productive wind farm has a capacity factor of 50%, that means the transmission line is only 50% utilized. By including bulk storage on the wind farm side of the transmission line, the transmission cable can be reduced by ~1/3. At times when the wind farm is producing to full capacity and the smaller transmission line is fully utilized, then the storage facility charges itself with the remaining electricity for use when the transmission line is not fully utilized.

SECTION IV

Hydrostor's Underwater-CAES Technology

Hydrostor's patented storage solution uses semi-adiabatic underwater compressed air energy storage (CAES) to store bulk electricity for long durations (4-48 hours), at scales of 1 to 50MW and at the lowest costs in their target markets. The system is safe, environmentally friendly and offers the ability to supply truly green energy 24/7.

The storage system works by using electricity to run an air compressor. The compressor takes air from the surrounding environment, compresses it and captures the heat created during compression. This heat is stored for later use, increasing the efficiency of the system. Concentrated solar can be used to add additional heat to the system, which further increases roundtrip efficiencies. (Note: Some companies are developing an isothermal compressed air system which removes large thermal differential and has the potential to increase roundtrip efficiencies ~5%; however these mechanical systems have yet to be fully developed and tested).



The air is then directed to an air cavity located 100+ meters below the surface of the water where the energy is stored at the same pressure as the water around it. The deeper the water is and closer to shore, the higher the pressures and more cost effective the storage solution becomes.

When the stored energy is required, the flow of the system is reversed and the weight of the water forces the air to the surface where it collects the stored heat, and turns a generator that reproduces approximately 60-70 per cent of the input electricity before returning only air to the environment.

The primary advantages of this design include:

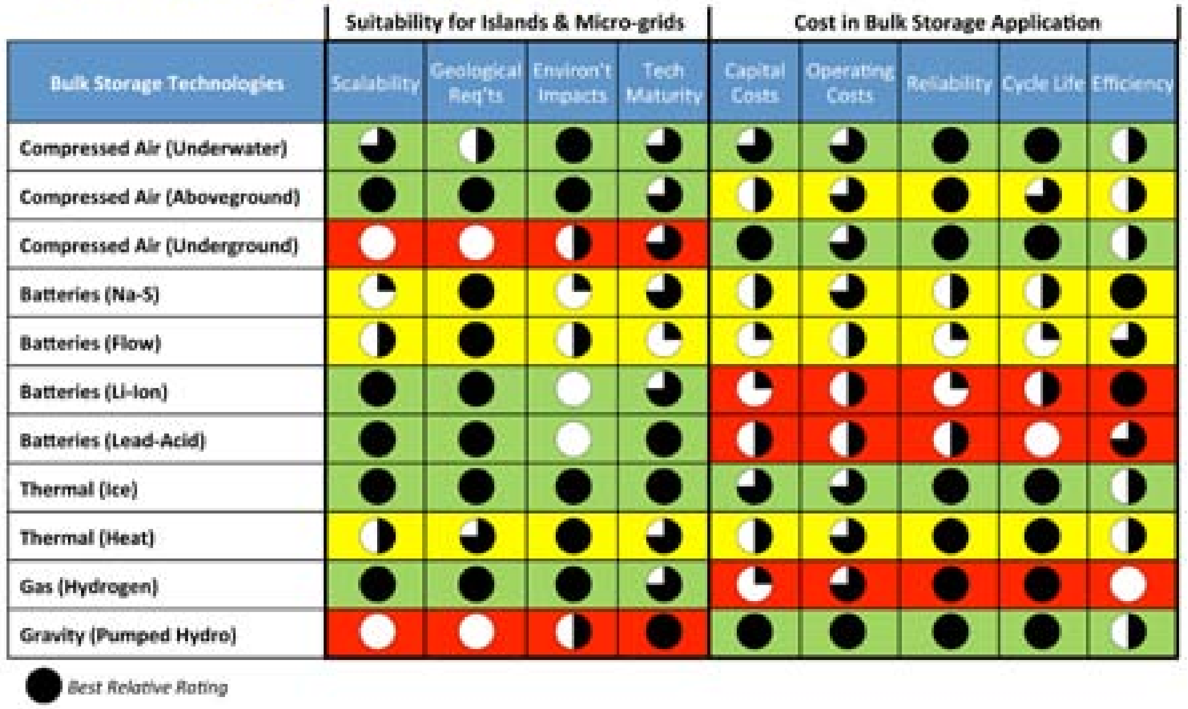
- Proven off-the-shelf mechanical components that utilities are familiar operating and maintaining (e.g. compressors, turbines, heat exchangers)
- Low-cost system as a result of using (a) "free" air and (b) use of ocean as pressure vessel
- Long-life due to proven components
- Safe with no toxic chemicals
- Small onshore land footprint required
- Environmentally friendly by creating an artificial reef that is a net positive on marine habitat
- Does not use any fossil fuels

SECTION V

Competitive Positioning of Hydrostor UW-CAES Solution

There is a range of bulk energy storage systems commercially available on the market today, as well as others in various stages of development. When comparing each of the technologies there are a number of factors that must be considered including capital cost, operating cost, scalability, cycle life, efficiency, reliability, geological requirements, environmental impacts, and the stage of technological maturity. Below is a summary table that rates the more prominent bulk storage technologies along each of these dimensions.

Technology Comparison



Not all technologies are a good fit for remote islands and micro-grids, as highlighted using the first four rating criteria, specifically:

- **Underground CAES** and **pumped** hydro not a strong fit because most islands do not have empty salt caverns / natural gas wells or two lakes with the suitable height differential, combined with the fact that the minimum efficient scale is +50MW which is larger than the storage needs of most islands.
- **Na-S batteries** have minimum scale requirements that make them a little large for most Caribbean applications, in addition to challenges with the environmental impacts of the chemicals used.
- **Flow batteries** are promising, but have yet to reach a level of technological maturity for grid integration.
- **Heating** is not a great fit for islands due to the land footprint required, as well as the minimum scale requirements.

However, being a technical fit for the remote island micro-grid market is not enough. A solution must also be economic compelling. The various technologies differ considerably as highlighted in the second group of five rating, specifically:

- **Lead-acid** and **li-Ion** batteries can be efficient and a good fit for short duration applications, but the capital costs, declining efficiencies and limited cycle life limit the economic feasibility of these solutions for bulk storage applications.
- **Aboveground-CAES** has higher costs than underwater-CAES due to costs of pressure cavity and in some cases use of custom / high-pressure machinery (e.g. for isothermal designs), as well as a larger onshore footprint.
- **Hydrogen** can be an appealing solution for seasonal storage when integrated with a natural gas network, however the cost and efficiency (primary in the process to make the hydrogen) make it not competitive in markets without existing natural gas networks.

Overall, there are two storage solutions that are both (a) an excellent fit for remote islands and micro-grids, and (b) are economically compelling today; **ice storage** (for cooling loads) and **underwater-CAES** (for electricity to electricity storage). Hydrostor is the low-cost bulk storage solution that is the best fit for remote communities seeking to make renewable generation on-demand for the majority of their electricity needs.

SECTION VI

Case Studies

The sizing and economics behind energy storage facilities is dependent on the application for which it is being used. Below are four illustrative case studies that outline specific applications and the associated benefits. The case studies are:

1) Wind Fueled Peaking Plant
2) Flexibility to Accommodate Distributed Solar
3) Offshore Wind Farm
4) Storage to Enable More Efficient Diesel Generation
5) End Consumer Self-Generation

Case Study #1: Wind Fueled Peaking Plant

Situation	A Caribbean island has an average cost of generation of $0.30/kWh from diesel generation. Due to cost considerations and concern for the environment, they recently commissioned a 20MW wind park under a PPA at $0.11/kWh. The cost savings from this lower cost electricity source has island residents and business owners encouraging the utility to install a second 20MW wind farm to further reduce electricity rates.
Challenge	However, the utility sees certain challenges that the average consumer does not. Namely, the utility is curtailing wind generation 3 nights / week due to: • Period of low demand for electricity • Period of highest wind production • Operational decision to limit the maneuvering of the thermal generating assets due to impacts on life expectancy, maintenance costs, and fuel efficiency The contract for the wind park requires the utility to pay for lost production due to curtailment that cuts into some of the cost savings versus diesel, but the wind farm still has a very compelling business case. The utility is concerned that further increasing the amount of electricity from wind on the island may result in higher levels of curtailment to the point where the business case for wind is no longer compelling, therefore limiting the amount of low cost wind the utility can reasonably implement. The other option was to secure low cost energy storage. The search proved challenging as the island does not have the geological features for pumped hydro or underground-CAES, and the various battery technologies analyzed resulted in costs of energy from storage higher than the cost of diesel.
Situation	Hydrostor's system provides the utility with the flexibility they sought to reduce curtailment losses and provide peak power at a cost well below the cost of diesel. The utility is seeking to install a 6-8 hour energy storage solution to store 5MW of wind generation overnight that can be used as lower-cost peaking capacity during the high demand times the following day. The blended cost of the 20MW wind farm with 5MW of bulk energy storage was $0.15/kWh enabling further reductions in electricity rates.

Case Study #2: Flexibility to Accommodate Distributed Solar

Solution	Solar costs continue to decline, and in some cases can produce power for less than $0.10/kWh. In jurisdictions with residential net metering, distributed solar is being installed by consumers for both self-consumption and to sell back into the grid.
Challenge	The utility does not have insights into the production levels of distributed solar systems, have contractual agreements with these consumers to produce, and at nighttime and periods of cloud cover there is no output from these systems. In order to ensure the grid has sufficient capacity in the face of this uncertainty, the grid operator requires additional capacity to provide additional flexibility. The traditional way of adding capacity is to install more diesel generation. This extra capacity is costly with peaking capacity at $0.40/kWh and up.
Solution	Energy storage provides twice the amount of flexibility as fossil fuel generating capacity, as it can swing between charge mode to discharge mode (whereas generating capacity can only produce). By constructing a centralized energy storage system, the utility has the flexibility needed to continue connecting distributed solar panels without impacting grid reliability.

Case Study #3: Offshore Wind Farm

Solution	A small island is seeking renewable energy to reduce power costs on the island, but have public concerns over locating wind farms on the island due to limited land availability and potential impacts to tourism. They are therefore seeking to construct an offshore wind farm over the horizon (approximately 10km offshore). The size of this wind farm (25MW) will represent approximately 25% of the islands generating capacity.
Challenge	The utility has fears that large swings in production from the offshore wind farm will cause operational challenges to keep the grid balanced, and although short duration batteries (10-15 minutes) will help; they are only a partial solution.
Solution	By co-locating a 5MW Hydrostor underwater CAES system with the offshore wind farm, the grid operator receives a number of benefits, including: • Reduced capacity (and therefore costs) of transmission line connecting wind farm from a 25MW line down to a 20MW line saving ~10% of the capital costs associated with the transmission line • Eliminates forecasted curtailment due to high wind production at times of low demand • Provides a minimum level of production of 5MW from the facility during all peak hours reducing the amount of reserve capacity the utility requires • Provides a maximum of 20MW level of production during off-peak hours • Provides 5MW peak capacity on-demand on all days except where (a) wind is not producing at all as storage is used to fulfil minimum production level, (b) wind is producing at full capacity as therefore storage is charging to ensure transmission line capacity is not exceeded This system configuration dramatically reduces the grid operators concerns by narrowing the production band from the wind farm. The costs of the storage facility (adding ~$0.02/kWh to the offshore wind farm PPA rate) can be easily justified by direct savings from transmission line cost avoidance, less diesel back-up due to minimum/maximum production levels, elimination of curtailment penalties, and from the ability to continue replacing diesel with lower cost renewables with storage.

Case Study #4: Storage to Enable More Efficient Diesel Generation

Situation	A small island generates 100% of their electricity from diesel. Due to the size of the diesel generators and the large swing in peak/off-peak electricity demand, half of the diesel generators are constantly being turned up/down and on/off.
Challenge	As a result of this sub-optimal operating schedule; the diesel generators consume 30% more diesel than they do when running at optimal level, have higher maintenance levels and are expected to reach end of life years sooner.
Situation	Hydrostor's underwater-CAES solution could be used to balance electricity demand/supply, which would allow the diesel generators to operate at more optimal levels and ultimately reduce electricity rates and emissions even through 100% of the power is still produced from diesel. Adding storage results in more electricity generated from each barrel of diesel consumed (as increased diesel generator efficiency is greater than energy storage losses), as well as benefits of longer diesel generator life, less maintenance, and having the energy storage facility provide a source of reserve capacity when "charged".

Case Study #5: End Consumer Self-Generation

Situation	A group 4 resorts in a remote part of an island are frustrated with their high costs of electricity, unreliable grid connection, and costs for local back-up diesel generators. They experience a power outage 2-3 times/week, pay over $0.40/kWh, and still have to have their own back-up power supply to ensure their guests do not have a poor experience.
Challenge	The resort owners are fearing that the costs associated with securing a stable electricity supply is making them less competitive in the regional tourism market.
Situation	The resorts decided to develop a dedicated solar and storage facility in partnership with the objectives of: • Self-generating over 80% of their electricity needs • Reducing the overall cost of electricity • Generate marketing from eco-tourism • Increasing reliability by having two forms of back-up power (a) grid, (b) existing local generators The local government has incentives where 33% of investment into green energy systems is eligible to be recuperated by the private sector through tax credits. Hydrostor and a solar project developer offered to construct 10MW solar array on the

Situation	rooftops and shaded parking areas of the 4 resorts, as well as 3MW underwater-CAES energy storage system. This packaged was financed by Hydrostor and the project developer, and the resorts paid less than $0.25/kWh for electricity consumed.

SECTION VII

Contracting Options

Hydrostor offers a variety of contracting options to accommodate customer preferences. The five most commonly discussed are listed below, which is followed by a description.

a) Direct Sale
b) Storage Capacity Contract
c) Storage Tolling Contract
d) Adder to Existing Renewable Generation
e) "Baseload" Renewable Generation & Storage Facility

A) Direct Sale: A customer purchases a storage facility and is the facility owner. Facility financing, maintenance support and warranty period are offered as part of the sale. This option is good for utilities that must own electrical assets by regulation, or where end consumers are eligible for incentives if they buy and install clean energy systems.

B) Storage Capacity Contract: A customer contracts for a storage facility independent of any renewable generation facility contract. The storage facility is compensated on a flat monthly amount based on system capacity (power rating, duration of storage, efficiency, uptime), and the operator can use the facility as often as desired. This option is good when cost certainty for the capability is desired.

C) Storage Tolling Contract: A customer contracts for a storage facility independent of any renewable generation facility contract. The storage facility is compensated for a tolling PPA rate for every kWh that is used to charge (or discharged) from the facility. This tolling PPA includes a minimum usage levels, and often a laddered rate structure depending on usage (more usage results in lower rate). This option is good for customers who are focused on pay-per-use.

D) Adder to Existing Renewable Generation: A customer contracts for storage as an "adder" to an existing renewable PPA. The storage capacity transforms the renewable generation from an intermittent production facility, to a facility that (a) eliminates curtailed generation, (b) has minimum production levels during peak hours, (c) maximum production levels during off-peak levels. Therefore, the flexibility provided by storage makes the entire renewable facility more valuable to the utility. The contract is an "adder" to the existing renewable PPA that is payable on every kWh produced by the renewable facility (net of compensation due to storage efficiency losses). This option is good for utilities that have an existing wind farm, but are having challenges with intermittency that storage can solve.

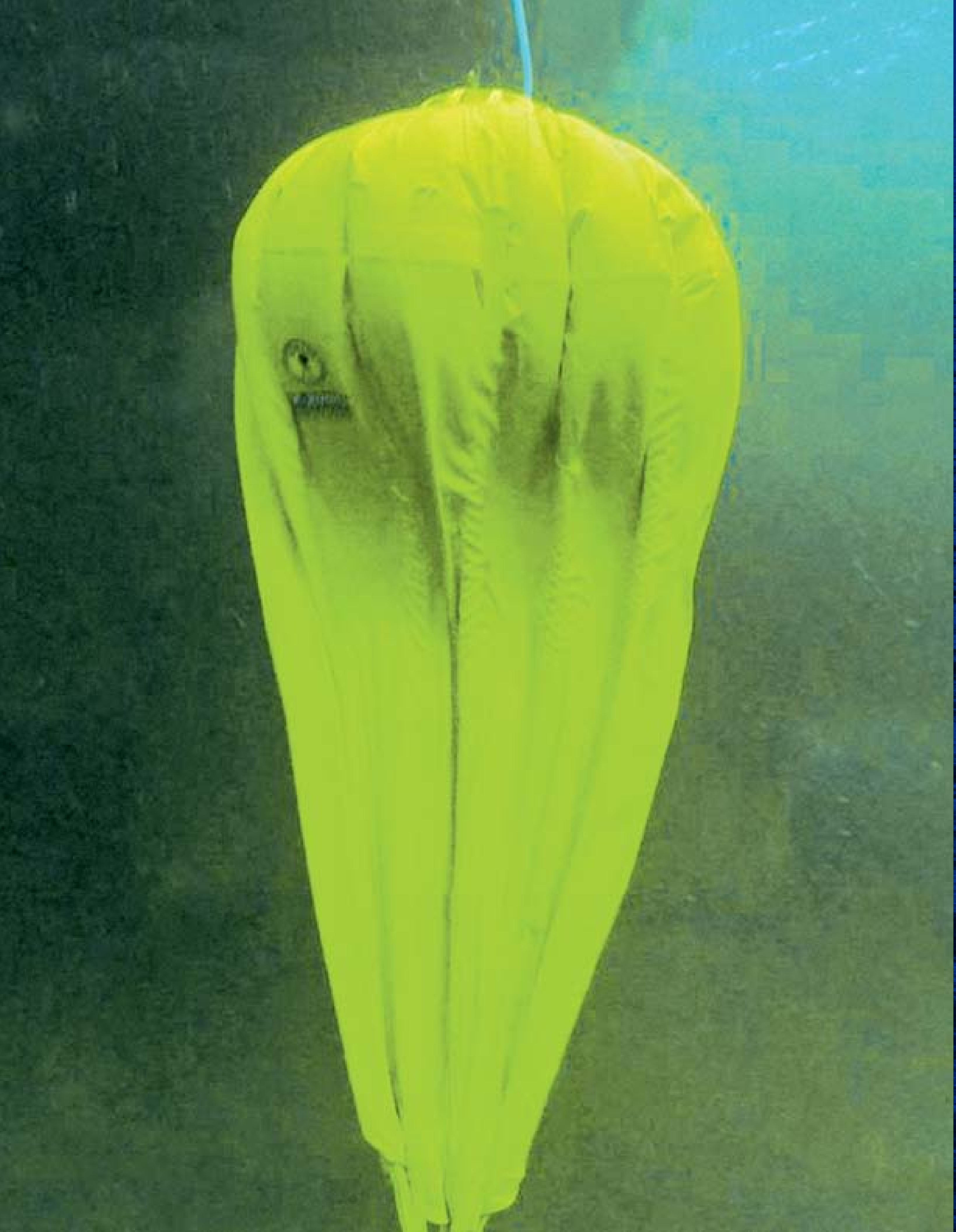
E) "Baseload" Renewable Generation & Storage Facility: A customer contracts for renewable generation and storage under a single contract. The contract will outline the minimum production levels that are to be met at least 85% of the hours of the year to qualify as a baseload facility. The size of the renewable generating facility and the storage system are sized accordingly. The total capital and operating costs for the facility are combined to determine an overall Power Purchase Agreement (PPA) rate for the integrated facility. This option is good for utilities seeking to add new wind capacity, but want the project developer to offer a more stable output from the facility.

SECTION VIII

Next Steps for Interested Utilities and/or Project Developers

Utilities, micro-grids operators and/or project developers should start getting experience with bulk storage today. This experience will allow for a better understanding on the potential for renewable energy, how to address the challenges posed by intermittency, a clearer picture on the true business cases and an opportunity to adjust renewable energy plans accordingly.

Hydrostor offers low-risk demonstration systems for utilities to begin gaining valuable experience operating energy storage facilities. Interested utilities and/or project developers are encouraged to contact a Hydrostor representative today.




hydrostor.ca

UNLEASH THE **POWER BELOW**

HYDROSTOR

1 Yonge St, Suite 906
Toronto, ON
M5E 1E5
Canada

T_ 416 - 548-7880
F_ 416 - 345-9044
W_ www.hydrostor.ca
E_ info@hydrostor.ca