EXPANSION ENERGY

The Patented "VPS™ Cycle"

Utility-Scale & Commercial-Scale Power Storage
+
Next-Generation Combined-Cycle Power Production
Utilizing Liquid Air

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www.expansion-energy.com

Overview of Expansion Energy LLC

Business Model

- » Energy & Environmental technology development
  - US & International patents and patents-pending
- » Technology licensing
  - License to OEMs; Project Developers; Energy Companies/Utilities; Other

Technology Areas (mostly based on cryogenic gas processing)

- » "Bulk" Power Storage & Next-Generation, Waterless Combined-Cycle Power Production
- » Conversion of Low-Grade Heat to Power
- » Small-Scale/Mid-Scale Liquefaction of Natural Gas (LNG)
- » Waterless Fracturing for Oil & Gas Extraction
- » Carbon Capture & Sequestration
- » Mineral Resource Recovery from Industrial Waste Streams

Company Headquarters

- » Metro New York City

Major Goals of "Bulk" (multi-MW) Power Storage

» Transfer off-peak, low-value **baseload** power to peak demand, high-value period

» Transfer off-peak, low-value **renewable energy** (e.g., wind, solar, LFG, ADG) to peak period

» Convert **intermittent renewable energy** (e.g., wind, solar) to **"firm" dispatchable power**

» **Reduce grid congestion** by placing storage near high-demand end-users

» **Grid capacity upgrade deferral** for utilities & generators

» **Grid stabilization** + protection from multi-hour disruptions

» **Reduce peak demand + energy charges** for commercial/industrial/military sites

» **Power reliability for end-users**

» **Eliminate** the need for **"peaker" power plants**

Additional Applications & Market Needs

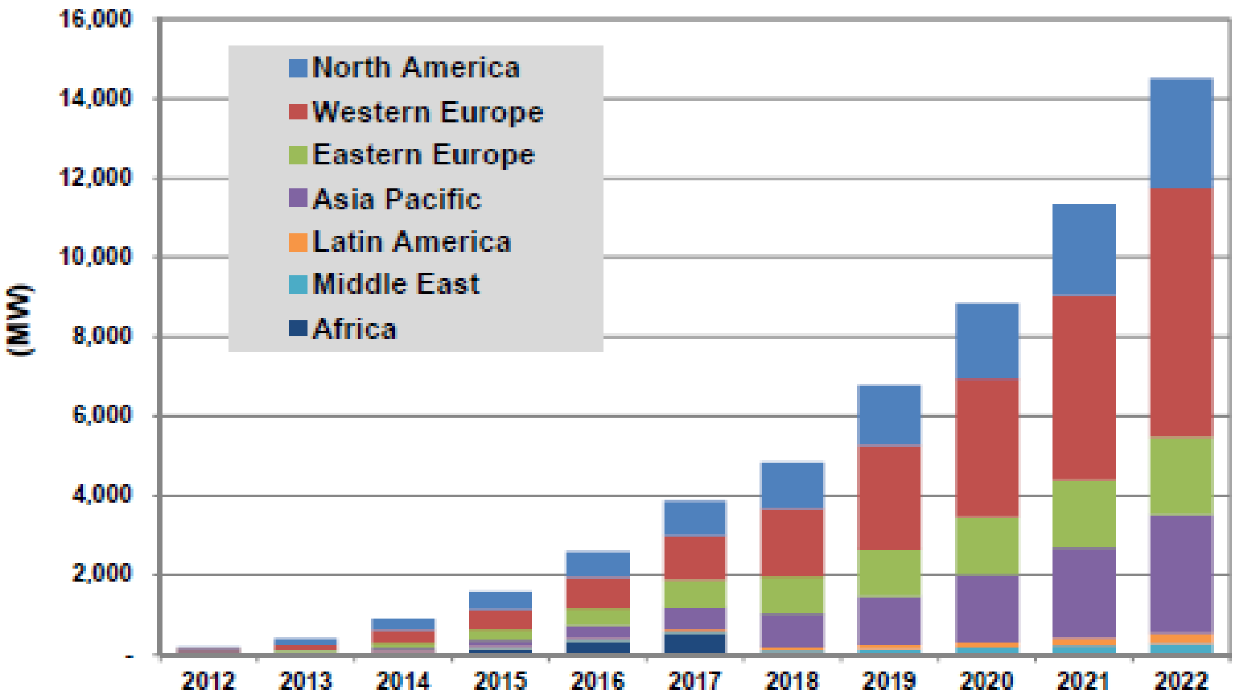
» **Infrastructure resiliency** – recovery from natural disasters; grid outages; etc.

» **Micr癖rids**

» *Advanced,* ***waterless****, ultra-high efficiency* ***combined-cycle power generation & CHP***

Market for "Bulk" Power Storage on the Grid

Total Global Installed Energy Storage Capacity: 2012-2020



Source: Navigant Research

Annual market size of nearly $20 Billion by 2020

(Expansion Energy estimate based on MW projections from Navigant Research)

Applications/Value Categories for Bulk Power Storage

Adapted in part from NY State Energy Research & Development Authority (NYSERDA) published reports

1	Electric Energy: Buy Low (off-peak), Sell High (peak)
2	Electric Supply Capacity
3	Eliminates the Need for "Peaker" Power Plants
4	Reduce Transmission Capacity Requirements
5	Reduce Transmission Congestion
6	Transmission & Distribution Upgrade Deferral/Displacement
7	Operating Reserve
8	Regulation and Frequency Response (Regulation)
9	Transmission Support
10	Electric Service Reliability
11	Electric Service Power Quality
12	Electric Service Bill Reduction: Demand Charges
13	Electric Service Bill Reduction: Time-of-use Energy Prices
14	Renewable Electricity Production Time-shift
15	Renewables Capacity Firming
16	Energy Storage Tax Credits (as available)
17	Carbon Credits (as available)
18	Transmission & Distribution Line Losses: Energy
19	Transmission & Distribution Line Losses: Capacity
20	Goodwill / Public Relations

The "VPS Cycle" addresses nearly all of these.

The Solution: Expansion Energy's Patented "VPS™ Cycle"

» Cost-effective, scalable, multi-megawatt (5 MW to 500+ MW) power storage & combined-cycle power generation utilizing Liquefied Air as the storage medium

- ***VPS is a highly efficient "distributed generation" power plant with storage built in***
- ***A new paradigm for power generation & storage ⇒ replaces large centralized power plants***
- ***Lowest capital cost per kWh (of daily capacity) of any bulk storage technology: $150-$300/kWh***

» **Heat rate** for VPS = **1,700 - 4,500** BTU/kWH (vs. 6,600 - 7,700 for combined cycle plants)

» Fast start – less than 20 minutes to reach full outflow capacity (+ partial outflow faster)

» Has some similarities to Compressed Air Energy Storage (CAES), but with 10 X greater storage density, no reliance on special geologic conditions, and much higher efficiency

» **VPS is 100% man-made** (vs. CAES) ⇒ reliable, predictable, replicable

» VPS components are 100% commercially available ("off-the-shelf")

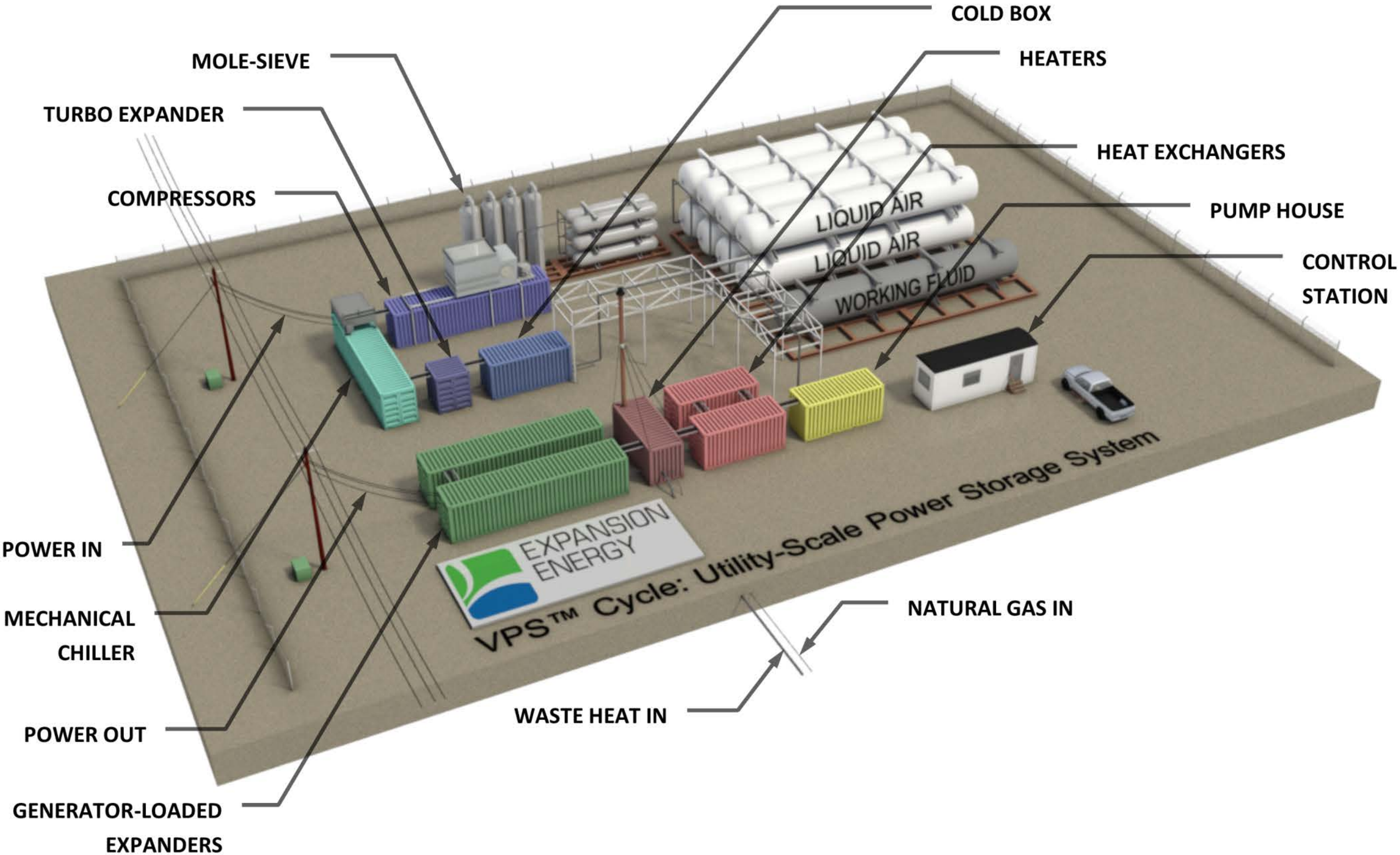
» "Round-trip efficiency" (RTE) can exceed 90%

» **4 to 10+ hours of power release capacity** ⇒ daily cycling, at a constant release rate

» **Can be deployed virtually *anywhere*** above-ground (or below-ground)

» Substantially reduces grid congestion if sited near high-demand end-users/load centers

"VPS™ Cycle" Plant Rendering



"VPS™ Cycle" Issued Patents & Pending Patents

» 6 Issued USA patents

» 2 Issued Australian patents

» 1 Issued Japanese patent

» 1 issued South Korean patent

» 1 issued Canadian patent

» Additional patents pending in:

- USA
- Europe
- Japan
- China
- India
- Brazil
- South Korea
- Canada
- Australia

VPS Cycle Dramatically Reduces CO_2 Emissions

» A NG-fueled VPS Cycle plant's CO_2 emissions = **0.15 to 0.26 Tons/MWH**

» A typical NG-fired Combined Cycle power plant CO_2 emissions = ~ **0.57 Tons/MWH**

- Therefore, VPS plants reduce CO_2 emissions by **50% to 70%** vs. Combined Cycle plants

» A typical NG-fired Simple Cycle Peaker plant CO_2 emissions = ~ **0.90 Tons/MWH**

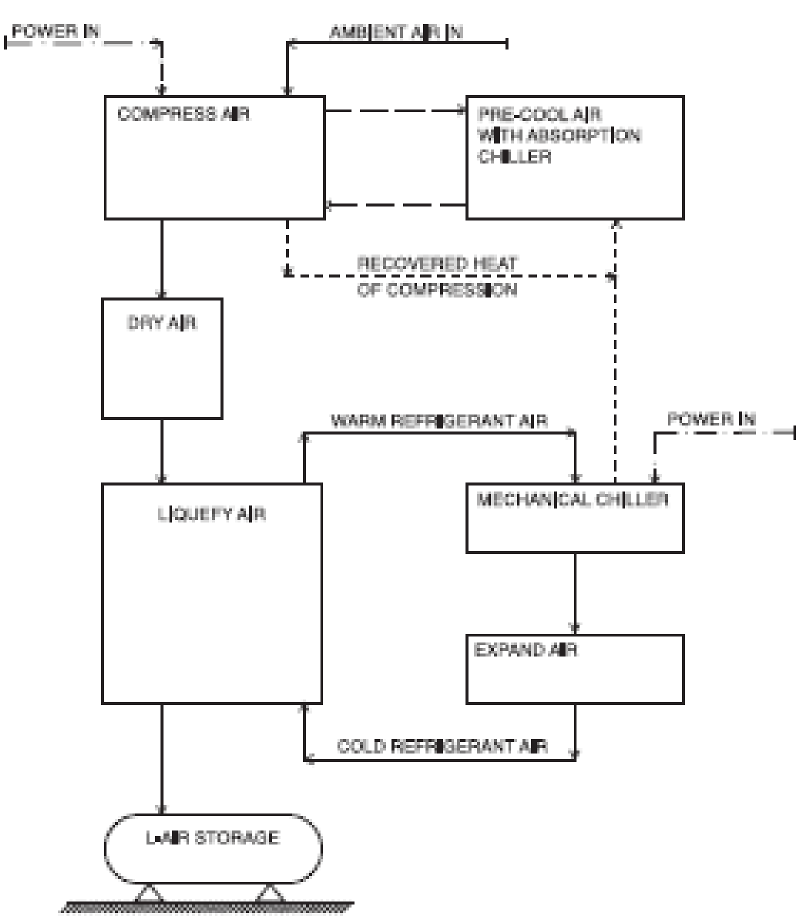
- Therefore, VPS plants reduce CO_2 emissions by **72% to 85%** vs. Peaker plants

» **If high-temp. waste heat is used instead of NG, VPS's CO_2 emissions can be reduced to 0**

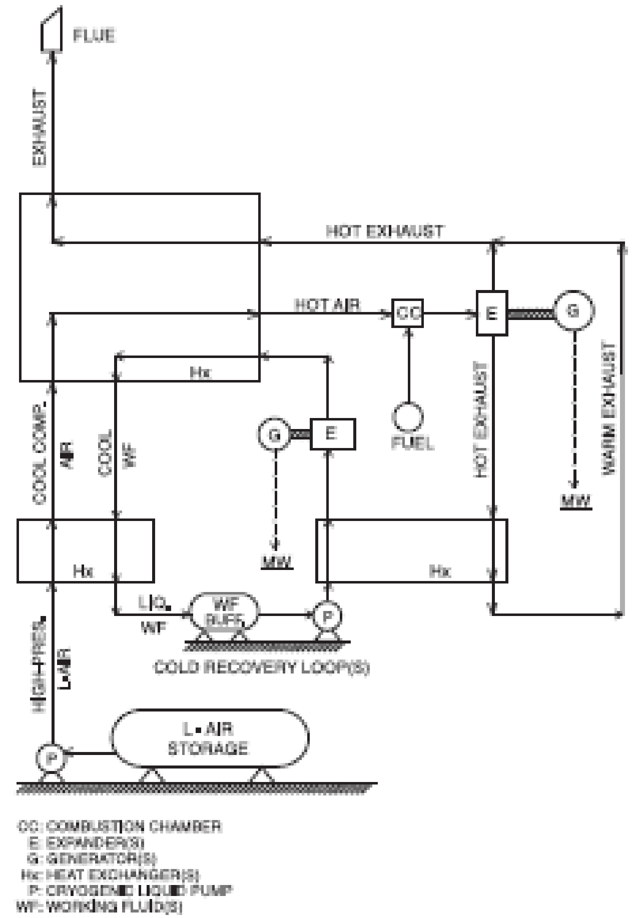
VPS Cycle Dramatically Reduces Water Consumption

» VPS Cycle plants **do not consume water** (unlike standard combined-cycle plants)

Basic Schematic of the "VPS™ Cycle" System



Stage 1: POWER INFLOW TO STORAGE



Stage 2: POWER OUTFLOW FROM STORAGE

U.S PATENTS: #7,870,746, #7,821,158 B2, #8,020,404, #8,063,511

VPS Cycle's Main "Off-the-Shelf" Components

Main Power Inflow Components

- Multi-stage air compressor
- Molecular sieve
- Absorption Chiller
- Cryogenic refrigeration array
  - Mechanical chiller and compressor-loaded cryogenic turbo-expander
- Main heat exchanger and smaller heat recovery exchangers
- Cryogenic (L-Air) storage tank(s) – shop-fabricated tanks may be used
- Instrumentation & program logic (automated)

Main Power Outflow Components

- Cryogenic liquid pumps
- Cold recovery "loops"
  - CO_2 and secondary refrigerants are condensed after vaporization and expansion by waste heat
- Main heat exchanger and smaller heat recovery exchangers
- Fuel gas compressor
- Combustion chamber
- Generator-loaded, multi-stage hot gas expander
- Instrumentation & program logic (automated)

Liquid Air Storage Tanks in Gallons

- 20,000 G = 6 MW
- 40,000 G = 12 MW
- 75,000 G (largest shop-fabricated tank) = 22 MW
- 150,000 G (2 shop-fabricated tanks) = 45 MW
- 225,000 G (3 shop-fabricated tanks) = 70 MW
- 1,000,000 G (1 field-erected tank) = 300 MW

VPS Cycle Inflow-to-Storage Mode (Stage 1 of the Cycle)

- Occurs during off-peak power periods (e.g., overnight)
- Water and CO_2 are removed from moderately compressed stream of inlet ambient air
- The dry inlet air is mixed with recycled "refrigerant air" and are jointly compressed to about 500 psia
- Recovered heat of compression drives an absorption chiller
- The absorption chiller acts as an inter- and after-cooler to the compressor
- Additional cooling of refrigerant air is achieved by a mechanical chiller whose waste heat also drives the absorption chiller
- Deep refrigeration of the refrigerant air is achieved by a compressor-loaded turbo-expander(s)
- The cooled, dry inlet air is liquefied by heat exchange with the deeply chilled refrigerant air, achieving **air-to-air liquefaction**
- Liquid air is stored at optimal pressure and temperature in an L-Air tank(s)

VPS Cycle Outflow-from-Storage Mode (Stage 2 of the Cycle)

- Occurs during peak power demand periods (e.g., daytime)
- Liquid air (L-Air) stored at optimal pressure and temperature is pumped to a high-pressure with cryogenic liquid pumps
  - Pumping requires relatively little energy versus compressing
- Refrigeration content of pumped L-Air is used to condense two counter-flowing working fluids, which in turn vaporize the outbound air
- Vaporized, high-pressure air is combusted with natural gas, producing hot combustion gases
- Hot combustion gases help heat the outbound air and heat the pumped-to-pressure working fluids
- The open-loop (air) portion of the Outflow mode yields about **70%** of the total net power output
- The closed-loop (refrigerant working fluid) portion of the Outflow mode yields about **30%** of the total net power output

Why Use Liquid Air as a Power Storage Medium?

» Air is free, abundant, non-toxic and non-explosive

» Liquid air is orders-of-magnitude more dense than atmospheric or compressed air, allowing it to "hold" many times more energy in an above-ground, man-made container

- Compressed air requires ~ 10 X more storage space (volume) than liquid air does

» Compressed air energy storage (CAES) requires large underground caverns & geologic expertise. Liquid air (VPS) is stored in entirely man-made, above-ground facilities

» VPS can achieve > 90% RTE. CAES only achieves ~ 45-65% RTE

» VPS releases power at a steady rate throughout its outflow stage

- In contrast, CAES's power release rate diminishes throughout its outflow stage

» ~ 97% of the inlet stream to a standard turbine's combustion chamber is air

- VPS sends hot, "pre-compressed" air to the turbine, saving ~ 60% of the turbine's work

» "Waste cold" and "waste heat" can be recovered in multiple areas of the system to provide additional "work"

- In contrast, CAES has less potential to utilize waste heat, and has no waste cold to utilize

Levelized Cost of Energy (LCOE) Comparison

VPS Cycle LCOE versus Other Storage & Generation Technologies

Technology	CAPEX/kWh of Daily Discharge Capacity	Off-Peak Charging $/MWh (assumption) *	LCOE ($/MWh)
VPS Cycle LAES	$150 – $300	$50	**$125 – $135**
CAES	$200 – $500	$50	**$190 – $400**
Pumped Hydro	$240 – $360	$50	**$185 – $275**
Lithium Ion Battery	$500 – $1,300	$50	**$350 – $750**
Flow Battery	$375 – $1,100	$50	**$300 – $900**
GT Peaker	N/A	N/A	**$220 – $300**

LCOE values in the above table assume 8 hours per day of discharge capacity

*** $50/MWh is high for Off-Peak pricing in most of the US. However, it is more typical for other global regions.**

Comparison of "VPS™ Cycle" vs. Other Bulk Power Storage Systems

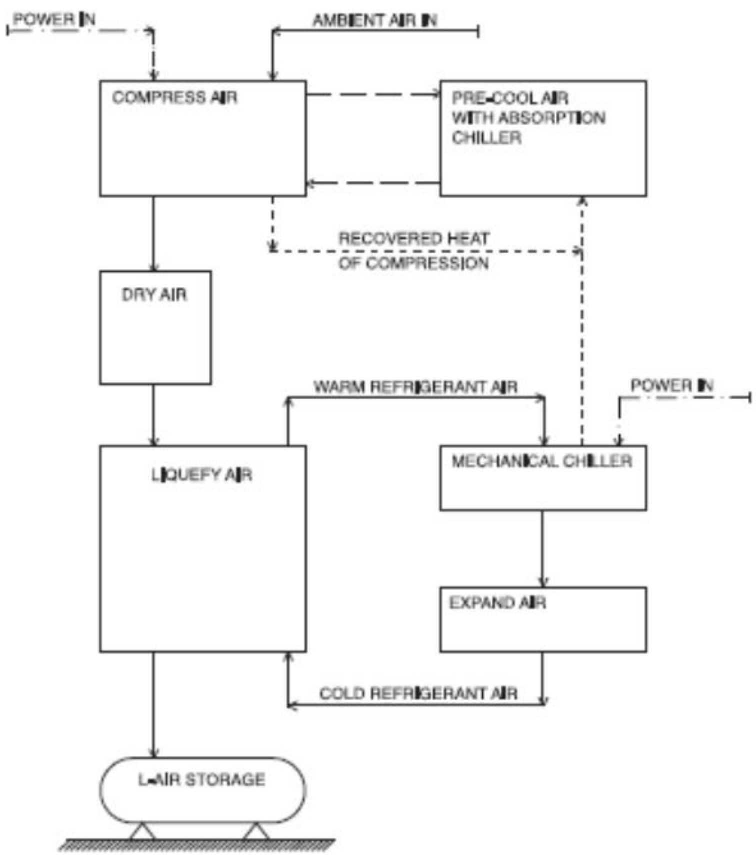
	CAES (Compressed Air)	Pumped Hydro (Water)	Battery	"VPS Cycle" (Liquid Air)
"Round-Trip" Efficiency	45% - 65%	78% - 83%	65% - 85%	Up to 90% or more
Duration of Power Release Period (per Day)	6-10 hours	6-12 hours	1-2 hours	4-10+ hours
Constant Power Release Rate	No	**Yes**	Mostly	**Yes**
Capital Cost: $/kWh of Daily Release Capacity	$300-$500	> $250	$500-$1,500	$150-$300
Capital Cost: $/kW of Storage & Release Capacity				
150 MW -- Field-erected w/ on-site air liquefaction	> $2,300	$1,500-$2,500	Too large	< $800
100 MW -- Field-erected w/ on-site air liquefaction	> $2,500	$1,500-$2,500	Too large	~ $900
50 MW -- Field-erected w/ on-site air liquefaction	> $3,000	$2,000-$2,500	Too large	~ $950
20 MW -- Factory-manufactured w/ on-site air liquefaction	Too Small	Too Small	$1,000-$4,000	~ $1,300
5 MW -- Factory-manufactured w/ truck-delivered liquid air or N2	Too Small	Too Small	$1,000-$4,000	~ $1,800
Footprint (Sq. Ft.; surface only)				
At 10 MW and less	Too Small	Too Small	5,000 to 10,000	2,000 to 10,000
At 100 MW	12,000	Two Reservoirs	Too large	20,000
Cycles per Lifetime of System	**No limit**	**No limit**	Limited	**No limit**
Benign Working Fluid	**Yes**	**Yes**	No	**Yes**
Waste Disposal Issues	**None**	**None**	Significant	**None**
Insensitive to Ambient Air Temperatures	Somewhat	No	No	**Yes**
Uses Available "Off-the-Shelf" Equipment	**Yes**	**Yes**	Limited	**Yes**
Site Selection Flexibility	No	No	**Yes**	**Yes**
Integration Potential with Existing Power Plants	No	No	Some	**Yes**
Deployable Near Load Centers & Urban Markets	No	No	**Yes**	**Yes**
"Fast-On" Potential	**Yes**	**Yes**	**Yes**	**Yes**
Scalable / Modular	No	No	**Yes**	**Yes**
Licensing Potential / Meaningful IP Protection	No	No	Some	**Yes**

VPS Cycle Deployment Options

- » **Distributed storage & power generation** near large end-users or load centers
- » **Distributed storage & generation** to address utility "tight spots" (T&D deferral)
- » **Point-of-use substitute for peakers & standard combined-cycle power plants**
- » **Retrofit existing peaker plants** – yielding up to 2 X more power output
- » **Retrofit existing combined cycle plants** – increase CCGT efficiency / increase MW output
- » Ultra-high efficiency **combined heat & power (CHP)**
- » Large "upstream" power storage projects (10's or 100's of MW)
- » Integrated at **wind, solar PV or CSP projects** at virtually any scale
- » Integrated with existing **ADG**- or **LFG**-to-power facilities
- » Integrated with **"inside-the-fence" power plants** at industrial facilities
- » **"Behind-the-meter"** generation & storage at **Commercial/Industrial/Military** sites
- » **Infrastructure resiliency** – recovery from natural disasters; grid outages; etc.
- » **Microgrids**

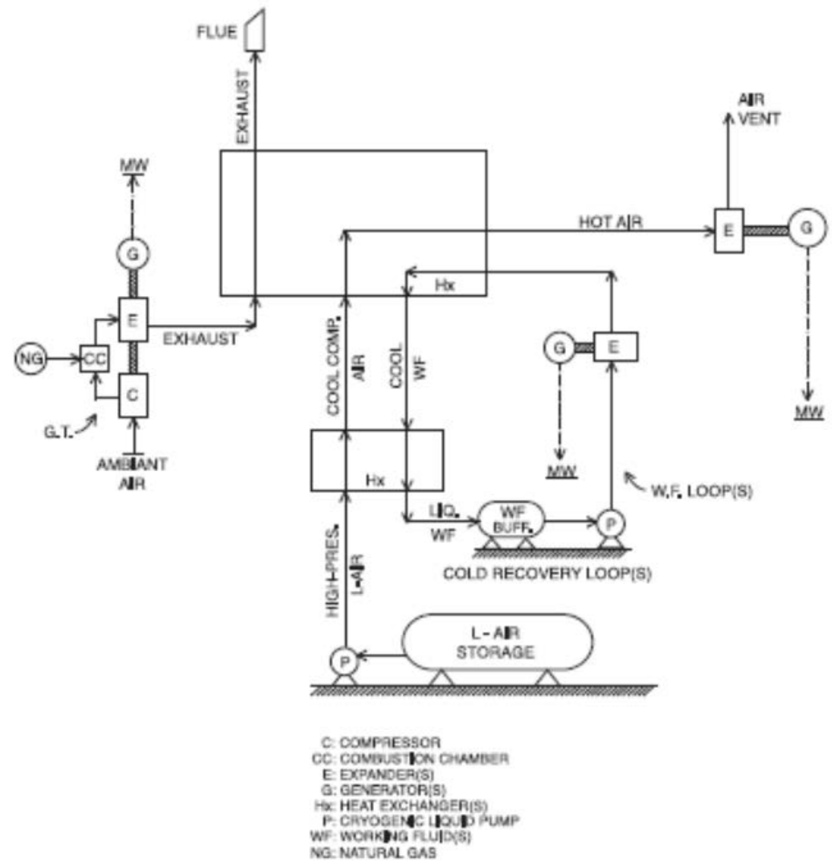
VPS Option #2: Integration with Existing Simple-Cycle Peakers

Inflow stage is the same as standard VPS deployments



Stage 1: POWER INFLOW TO STORAGE

Outflow stage integrated w/ an adjacent simple-cycle gas turbine



Stage 2: POWER OUTFLOW FROM STORAGE

U.S PATENTS: #7,870,746, #7,821,158 B2, #8,020,404, #8,063,511

VPS Option #2 (w/ Gas Turbine): Power Outflow Mode (Stage 2)

- Instead of building VPS as a "greenfield" plant, VPS can be integrated w/ existing gas turbines
- VPS Inflow stage is same as standard VPS plants
- VPS Outflow stage is integrated with a simple-cycle gas turbine (GT) or "peaker" plant
- Outflow stage occurs during peak power demand periods (e.g., daytime)
- Liquid air (L-Air) stored at optimal pressure and temperature is pumped to a high-pressure with cryogenic liquid pumps
- Refrigeration content of L-Air is used to condense two counter-flowing working fluids, which in turn vaporize the outbound L-Air
- Vaporized, high-pressure air is heated by waste heat from the GT and the hot, high-pressure air is expanded in a generator-loaded expander
- The condensed secondary working fluids are pumped to pressure, heated by GT waste heat and expanded in generator-loaded hot gas expanders
- The former L-Air leaves the Cycle as clean air, while the secondary working fluids are stored in buffer tanks after the Cycle is shut down during off-peak periods
- Approximately **50%** of the total power output is derived from the GT and **50%** is derived from the waste heat + the energy stored in the L-Air

VPS Option #2 (w/ Gas Turbine): Power Outflow Mode (Continued)

- Because the GT is now used in a “combined-cycle” mode (with VPS), its NG use can be compared to the NG used in a standard combined-cycle power plant, allowing the remaining power output (above and beyond the power output attributable to the NG) to be attributed to stored energy in the L-Air.
- The VPS Cycle is a **> 70% efficient (thermal efficiency) "combined-cycle"** power plant that also includes all the benefits of a power storage system.
  - This is significantly higher than existing combined-cycle technology, which can only achieve 50-60% efficiency.
- **VPS allows for all future power plants to be constructed in a distributed basis** (rather than in very large, “centralized" deployments), matching the highest power plant thermal efficiencies now achievable, and offering various (and many) bonus features that come from its ability to store off-peak renewable or surplus power.
- The only “sacrifice" is that VPS produces no power during the off-peak (nighttime) period. But most grids have surplus power during off-peak periods, so the grid will not suffer.
  - Instead, VPS plant owners can sell & deliver power when it is most needed and valuable—at peak

VPS Option #3: A New Type of Advanced, Combined-Cycle Power Plant

» Gas Turbine + VPS Cycle, instead of Gas Turbine + HRSG (traditional CCGT)
  - VPS CCPP's "bottoming cycle" uses L-Air + a Refrigerant (closed loop ORC), instead of water/steam

» Cost-effective at **much smaller scale** (**20-50+ MW**) versus today's CCGTs (usually only > 500 MW)
  - Important because Power industry is moving steadily toward distributed generation (& storage)
  - **Modular fabrication** (instead of field construction) $\Rightarrow$ **Lower cost; predictable; scalable**

» Can be **turned down "on the fly" or turned off daily**, without sacrificing efficiency (CCGTs cannot)

» Can convert existing GTs into highly efficient CCPPs $\Rightarrow$ **More efficient use of GT heat vs. standard CCGTs**

» **Does not consume water** and **does not require cooling towers** or rivers/lakes for cooling

» Unlike standard CCGTs and GTs, VPS **does not lose efficiency in hot and/or humid conditions**

» Air emissions—NOX, CO2, etc.—**reduced 25-40% per MWh vs. CCGTs** and **50-65% vs. GTs**

» **Lowest Heat Rate** plants are first to dispatch in many markets $\Rightarrow$ **VPS deployed before CCGTs & GTs**

Natural Gas Power Generation Technologies	Heat Rate (Btu/kWh)	Thermal Efficiency
Average Heat Rate of US Simple Cycle GTs (EIA, 2014)	**11,378**	**30.0%**
Typical US Combined Cycle Power Plant (CCGT)	**7,615**	**44.8%**
VPS Cycle Integrated 1:2 with GT-to-VPS (No additional NG; Large or Small Scale)	**5,903**	**57.8%**
Best in Class, **Large Scale** CCGT at Ideal Operating Conditions	**5,690**	**60.0%**
VPS Cycle Stand-Alone CCPP without GT; w/ Direct-fired NG Combustion (Large or Small)	**4,500**	**75.8%**
VPS Cycle Stand-Alone CCPP with GT Exhaust + Afterburner / Duct Heater (Large or Small)	**1,710**	**N/A (199.5%)**

VPS Option #4: Integration with Existing Combined-Cycle Plants

VPS can be integrated with existing or new standard CCGTs to increase MW + efficiency and/or to lower CAPEX:

» **More efficient utilization of the CCGT's steam content**

» Pressurized, low-temperature air sent to GT front-end to **reduce compressor load** and **raise MW and/or reduce NG consumption**

» Increase CCGT value during off-peak—to produce & storage energy

» Allow Heat Recovery Steam Generator (HRSG) turn-down during Peak period—greater flexibility

» Use HRSG waste heat to pre-heat VPS's Cold Recovery Loop (ORC)—for higher efficiency

» **Reduce or eliminate** the need for the CCGT's **cooling towers**

For New-Build combined-cycle plants + for Retrofits of existing CCGTs

VPS Option #5: Commercial-Scale VPS – ~ 5 MW to 20 MW

» A factory-built, modular "appliance" version of the VPS Cycle

» Enables "distributed" power storage + generation

» Serves a scale too small for CAES or pumped hydro and too large for batteries – ~ 5 MW to 20 MW

» Delivered on several skids that are connected at the deployment site – constructed in days/weeks

» Pre-designed/pre-engineered + mass-produced

» Market potential = Thousands of deployments

» Provides both a daily duty cycle (delivery of power during peak period) + reliability/back-up power

» Surplus power (beyond the needs of the owner) can be sold to the grid for profit

» Potential owners of Commercial-Scale VPS plants include (partial listing):

- Industrial facilities / factories / refineries
- Utility – T&D "tight spots" / capacity upgrades
- Military bases
- Hospitals
- Office parks / corporate campuses
- Shopping centers
- Airports & shipping ports
- Microgrids
- Wind farms & solar farms
- University campuses
- Data centers / server farms
- Food processing / refrigerated warehouses
- Mines & quarries
- Other critical buildings / infrastructure

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