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UNIVERSITY OF MINNESOTA
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CENTER FOR COMPACT AND EFFICIENT FLUID POWER

OPEN ACCUMULATOR –ISOTHERMAL COMPRESSED AIR ENERGY STORAGE (ICAES) FOR OFF-SHORE WIND ENERGY

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Wind energy with local storage

- Store excess energy when demand (price) is low
- Store locally → avoid transmission losses
- Realize predictable output ($$)
- Be “peaker” plant to meet arbitrary demand ($$$)
- Reduce CAPEX: downsize generator & transmission to average power (increase capacity factor)

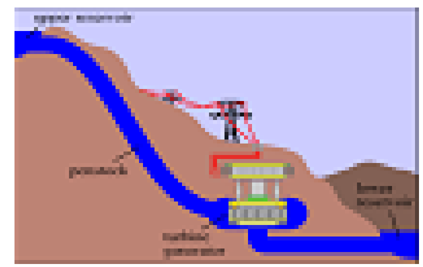
Capacity factor < 40%
Mismatch between supply/demand
Unreliable/unpredictable

Energy Storage System → Generator

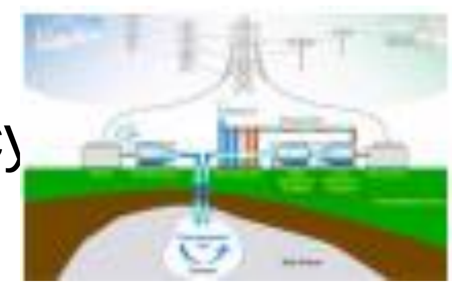
Alternate Energy Storage

- Batteries
  - High energy density (720kJ/liter)
  - Low power density
  - Expensive, life, recycling,

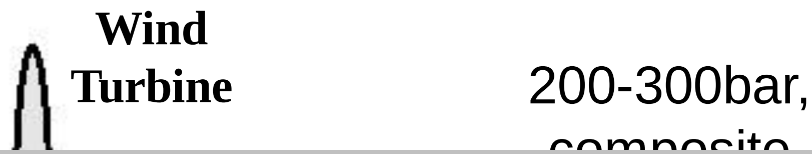
- Pumped hydro
  - Site specific,
  - low energy density (10J/liter/m)



- Conventional CAES
  - Compressed Air Energy Storage
  - Site specific, boost natural gas efficiency
  - < 40% efficient



Open Accumulator Isothermal CAES



- Hydraulic transmission
- Open accumulator
- Near isothermal air

- Real storage, no CO_2 footprint
- Power-on-demand
- Synchronous generator (low cost)
- Reliable, no exotic materials

- Isothermal compression/expansion → efficient
- Near constant pressure
- Fast turn on/off (1/10s or less) → mimic spinning reserve

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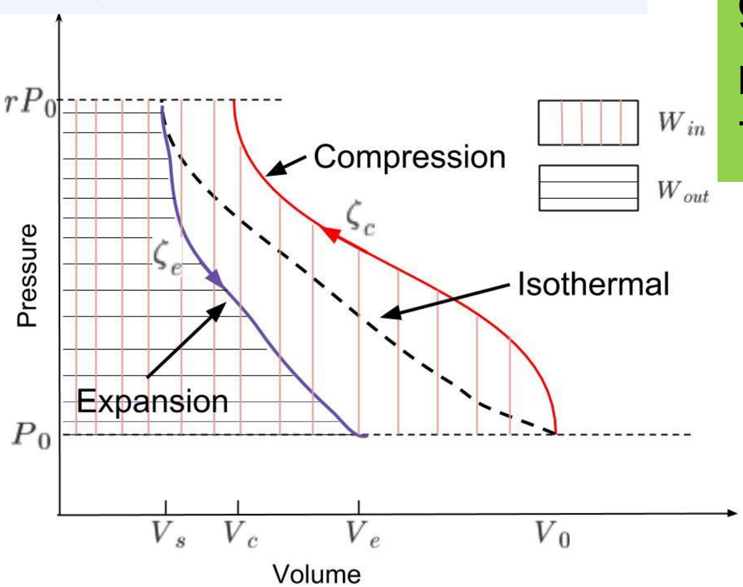
Research approach / results

1) Efficiency; 2) Power density ; 3) Storage density

Target: $150/kWh; $1000/kW

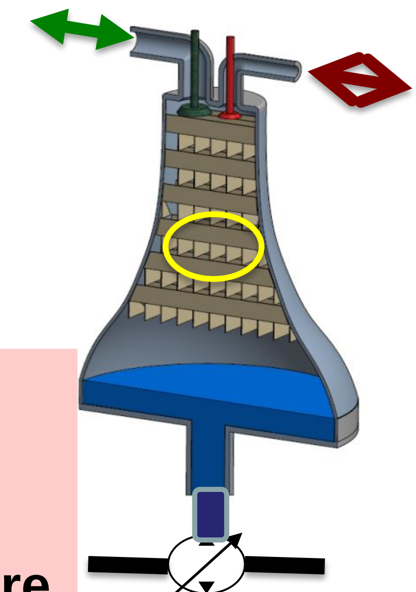
Disciplines:

- Fluid flow, heat transfer
- Nano-textured surfaces
- Machine Design
- Fluid power
- Systems, control
- Optimization



Energy density [kWh/m^3]:
25 (210bar) -47 (350bar)
5.5-10 x of conventional CAES

Efficiency:
90-95% (thermodynamic) at nominal power
73% (wind to electricity)



Power density: (1-2 sec 200:1 pressure ratio)
~ 1-1.5 MW/m^3
(200x improvement before we began)

Technology	Power Sub-system cost[1] (\$/kW)	Energy Storage Subsystem cost (\$/kWh)	Efficiency: Captured wind energy to electricity	Power Density	Energy density	Response time	Cycle life	Comments
Wind turbine w/ Open Accumulator Isothermal CAES	1000	150	73% [1] [8]	10kW/kg ~ hydraulic accumulator	91 MJ/m^3 @210bar 170MJ/m^3 @350bar	10-100ms	>10k	Power on demand Cap. factor → 1 34-80% more revenue 17% less CAPEX Ancillary service, Long life
Conventional wind turbine	onshore: 2213 offshore: 6230	N/A	86% Gearbx=90% generator & Power elec. = 95%)	N/A	N/A	N/A	N/A	Intermittent, Curtailment, Un-reliable, disruptive to grid Cap. factor<0.5
Conventional CAES	960-1150	60-120 varies w/ geology	25-37% [7] 29-43% (exc. wind turbine).	Low (~Low pressure pneumatics)	17 MJ/m^3	many mins	25k	Requires natural gas and U/G caverns, low efficiency
Pumped Hydro	1500-5600	250-430	70% 81% (exc. wind turbine)	Low-moderate - dep. on elevation	10kJ/m^3 per meter-elevation	many mins	2.5k	Requires specific geographies and large installation
Advanced Lead Acid	1700-1900	425-475	75% 85-90% (exc. wind turbine)	180W/kg	252MJ/m^3 35Wh/kg	20ms	2k	Environmental concerns, poor cold climate operation. , cost
Li Ion	1085-1555	4340-6200	77% 89% (exc. wind turbine)	Low 300W/kg	900-2200 MJ/m^3	20ms	4k	Cost, scare resource
Sodium Sulfur	3200-4000	445-555	65% 75% (exc. wind turbine)	Low 260W/kg	100-250Wh/kg	1ms	4.5k	Low cycle life, env. impact 1ms response