Flywheel Energy Storage System

AMBER_KINETICS

2016 Visayas Energy Investment Forum

Energy Storage

- **Energy storage** is the conversion of energy to other forms so that it may be used at a later stage when required.

- Energy storage technologies are measured in terms of their power output (MW) and their capacity (MWh).

Energy Storage Technology

Energy Storage Association

- Solid State Batteries
- Flow Batteries
- Flywheels
- Compressed Air Energy Storage
- Thermal
- Pumped Hydro-Power

History of Flywheels

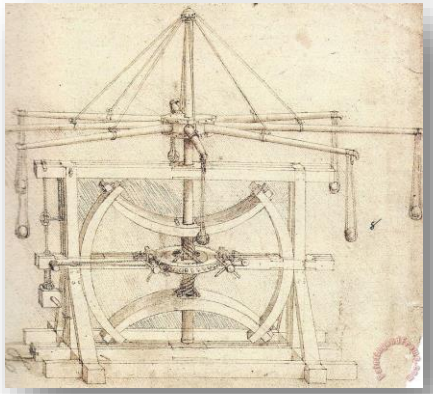
4500 – 2000 BC

Stone Age

Original pottery wheel developed in stone age

1450 – 1500 AD

Leonardo Da Vinci



Conceptualized mechanical flywheel for continuous motion

1760 - 1840s

Industrial Revolution

Watt steam engine used heavy flywheel to smooth output

Today's Flywheels

Application	Application	Application	Application
Electric Vehicles	**Backup Power**	**Grid Support**	**Grid Capacity**
time duration seconds	*time duration seconds - minutes*	*time duration minutes - hour*	*time duration 1-4 hours*

Prototype
Lab-Stage

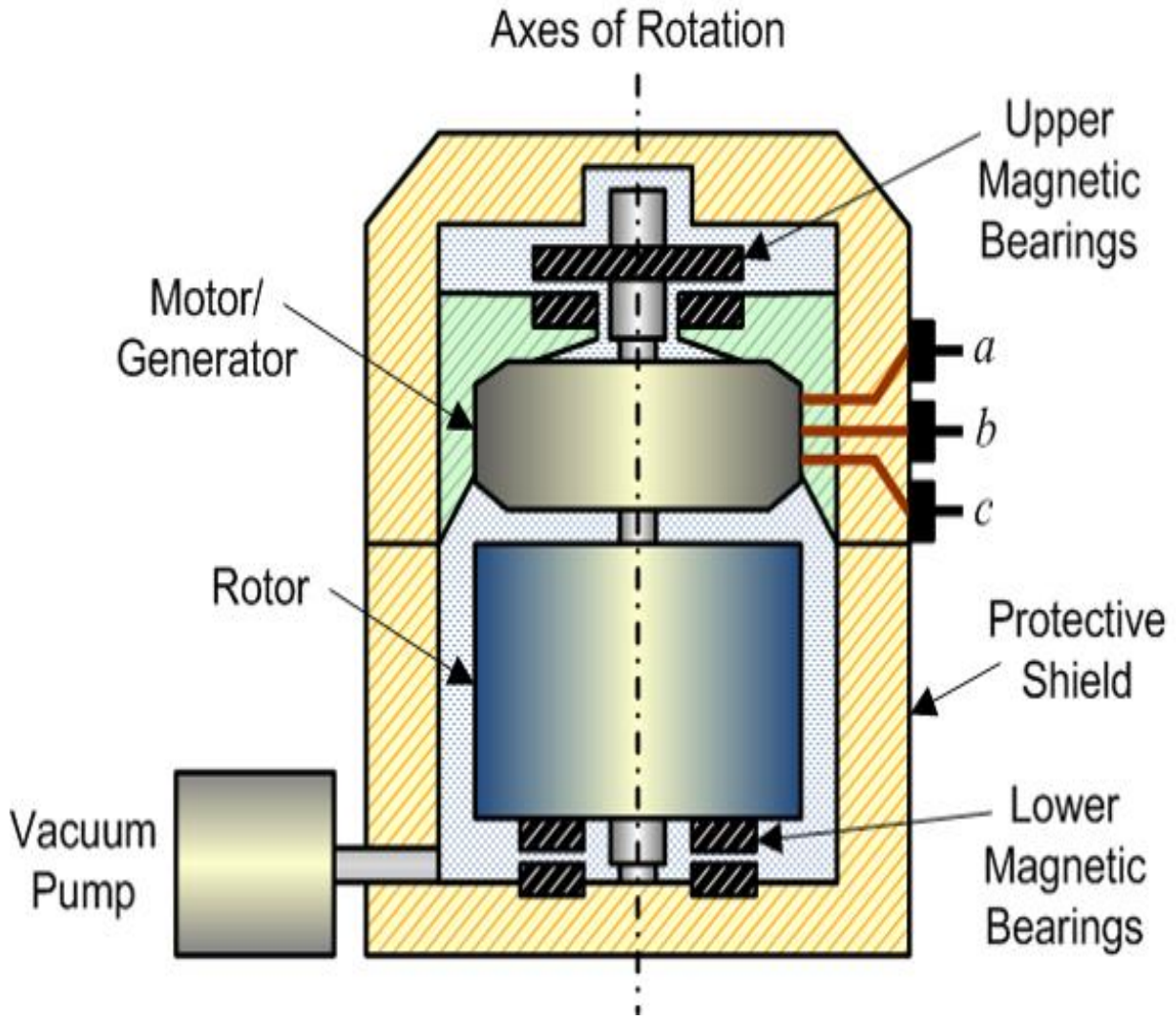
> 5,000 flywheels sold
Millions of commercial hours

40 MWs commercial flywheels
Millions of commercial hours

Expanded storage duration
Driving cost out with scale

1980-1990 **1990-2000** **2000-2010** **2010-Present**

Flywheel Energy Storage System



Kinetic Energy Storage - Flywheel

- Flywheel in essence is a mechanical battery – simply a mass rotating about an axis
- Store energy mechanically in the form of kinetic energy

Charging/discharging is carried out by a motor/generator

- Take an electrical input to accelerate the rotor up to the maximum speed by using built-in motor and and produce the stored electrical energy by decelerating the rotor using the same motor as a generator.

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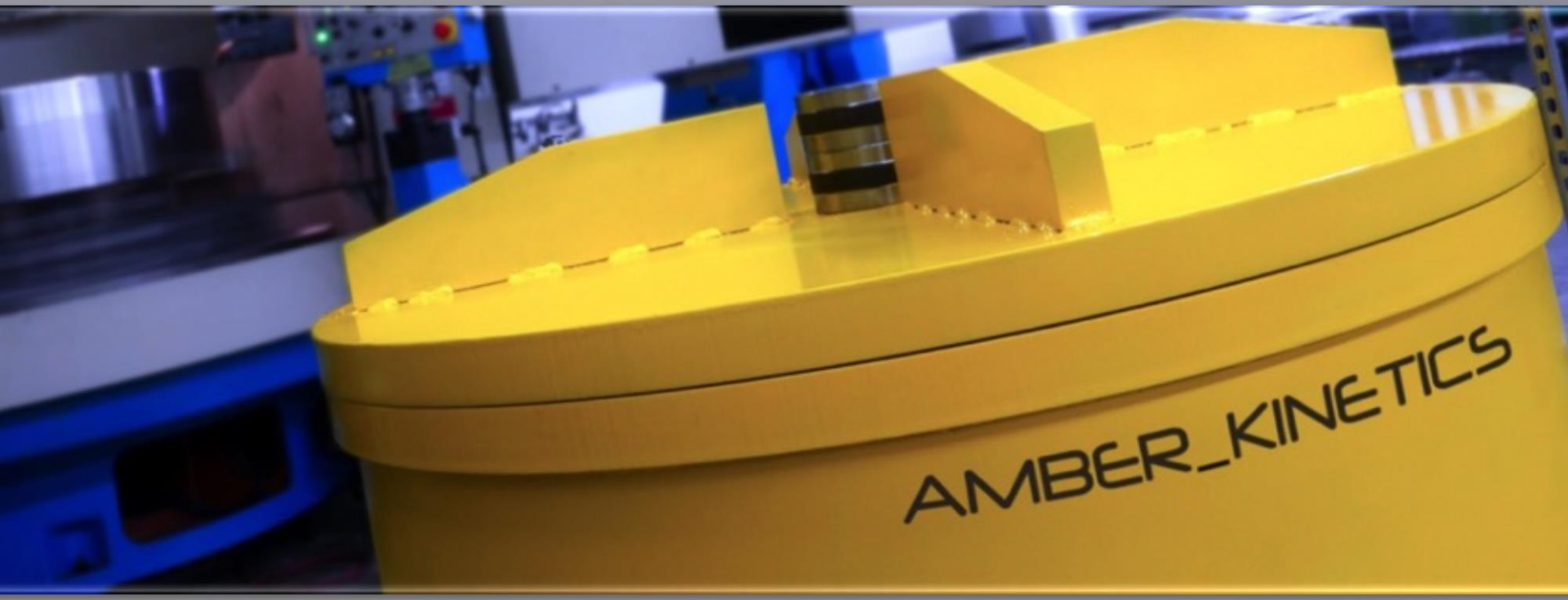
A REVOLUTION IN ENERGY STORAGE



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- The “Holy Grail” in Energy Storage

About Amber Kinetics

Berkeley EECS
ELECTRICAL ENGINEERING & COMPUTER SCIENCES

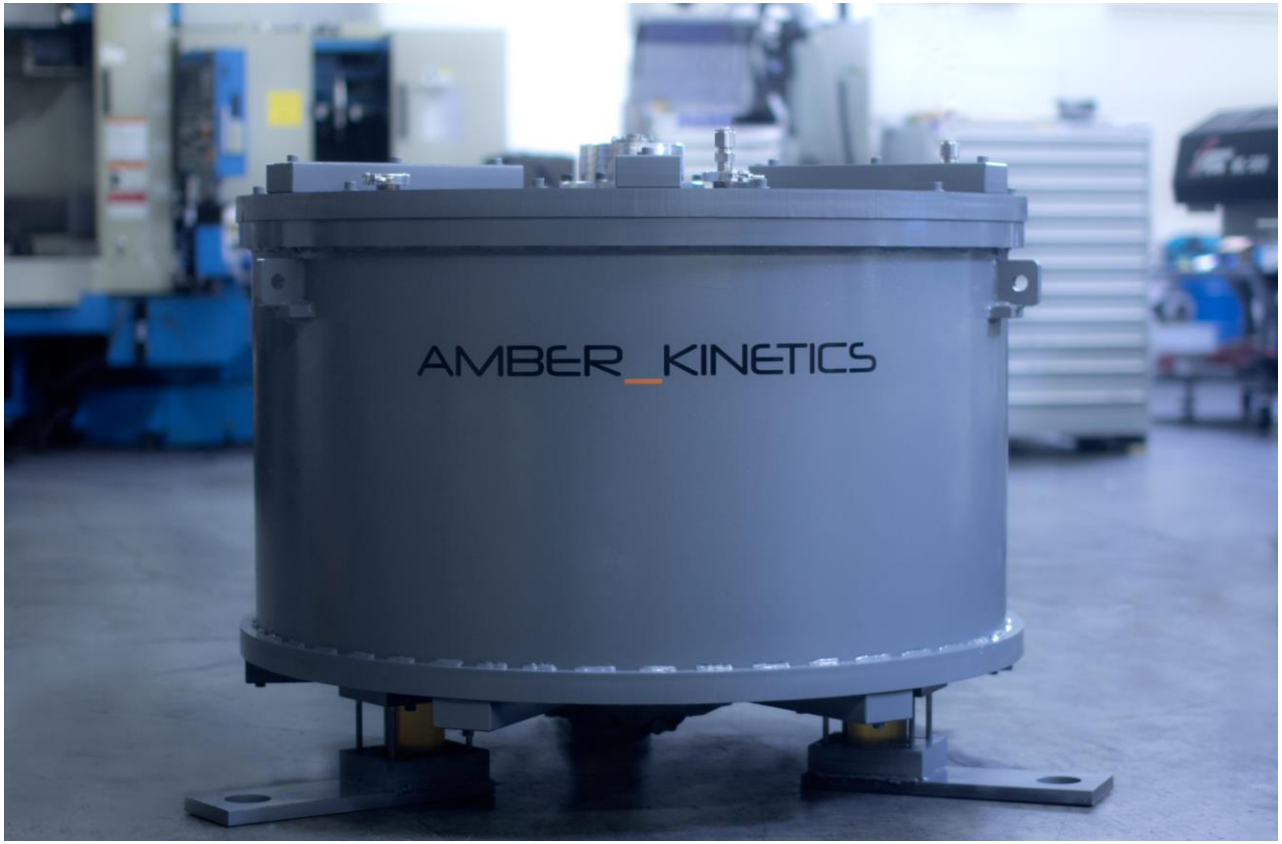
Seth R. Sanders

Professor

Research Areas:

- Energy (ENE)
- Control, Intelligent Systems, and Robotics (CIR)
- Integrated Circuits (INC)
- Power and electronics systems

About Amber Kinetics



World's First and Only 4 Hour Flywheel

About Amber Kinetics

Founded:	2009
Headquarters:	Union City, CA
Target Application:	Grid-Scale Energy Storage
Technology:	Steel Flywheels
Our Advantages:	DOE: promising storage technology

1. High efficiency / Low losses
2. Competitive technology cost
3. Focus on viable projects
4. Experience winning utility PPAs
5. Operational advantages vs. other energy storage

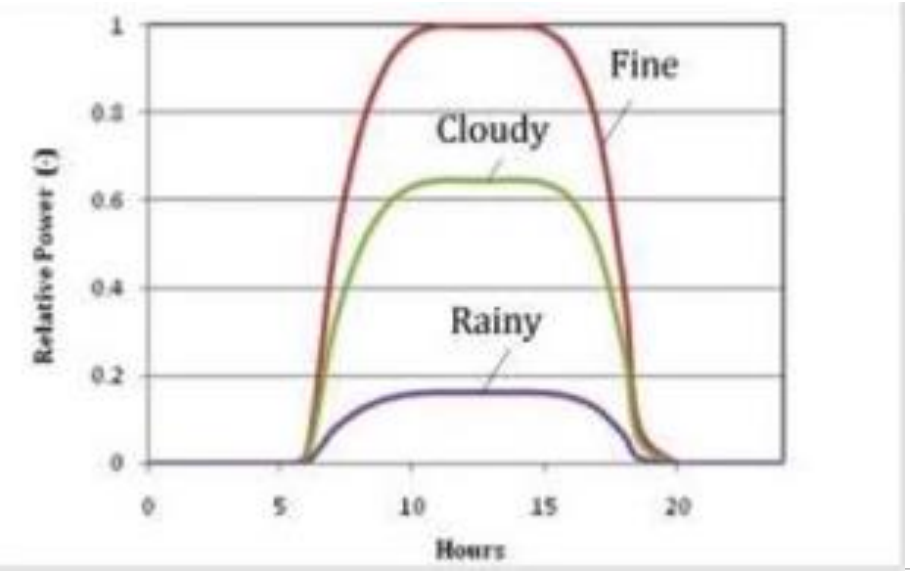
Areas of Application

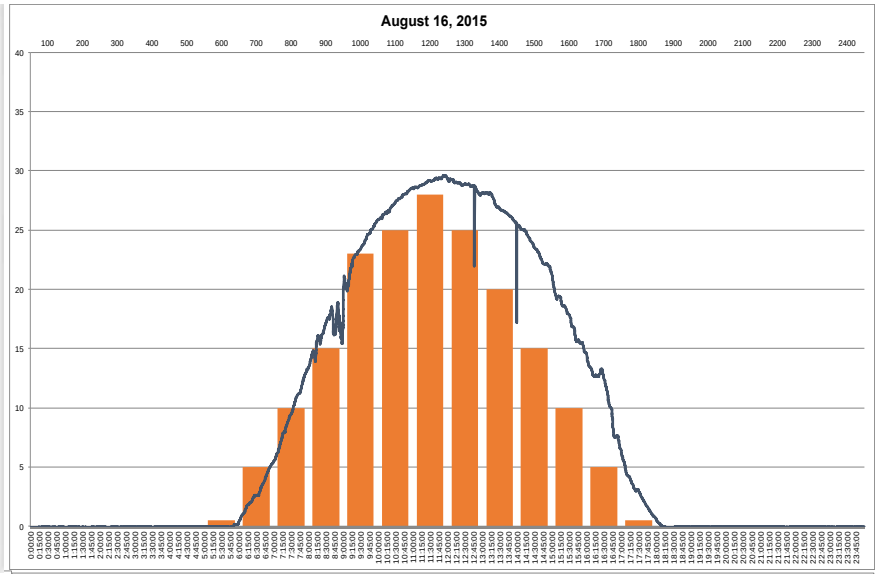
1. Island systems & off-grid/rural electrification	→ Hybrid System Variable Renewable Energy + Amber Kinetics Flywheels
2. Energy supply shifting	→ Amber Kinetics Flywheels as Peaking Plant
3. Variable renewable energy smoothing	→ Fast & short Charge/Discharge
4. Fast, & short-term electricity balancing/Ancillary Service	→ Amber Kinetics Flywheels For Frequency Regulation

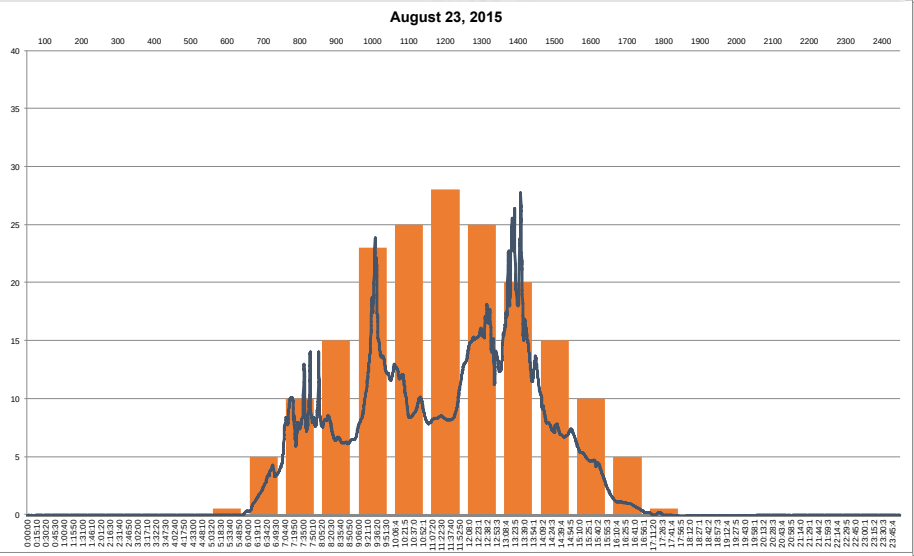
Renewable Energy

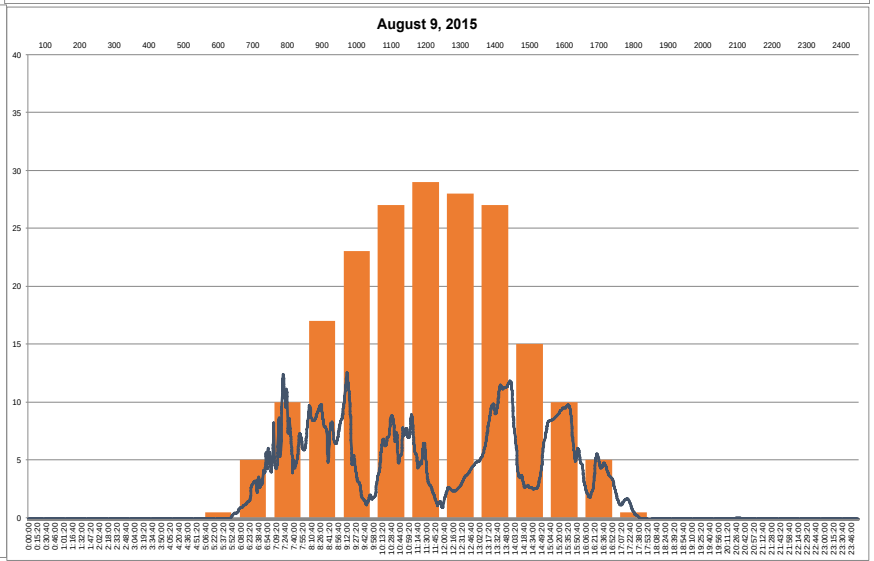
Resource	Dispatchability	Variability	Predictability
Biofuel	High	Low	High
Biomass	High	Low	High
Geothermal	Low	Low	High
Hydroelectricity	High	Low	High
Solar power	Low	Very high	Medium
Tidal power	Low	Very high	Very high
Wave power	Low	Medium	Medium
Wind power	Low	High	Low

Hourly Solar PV Generation Profile

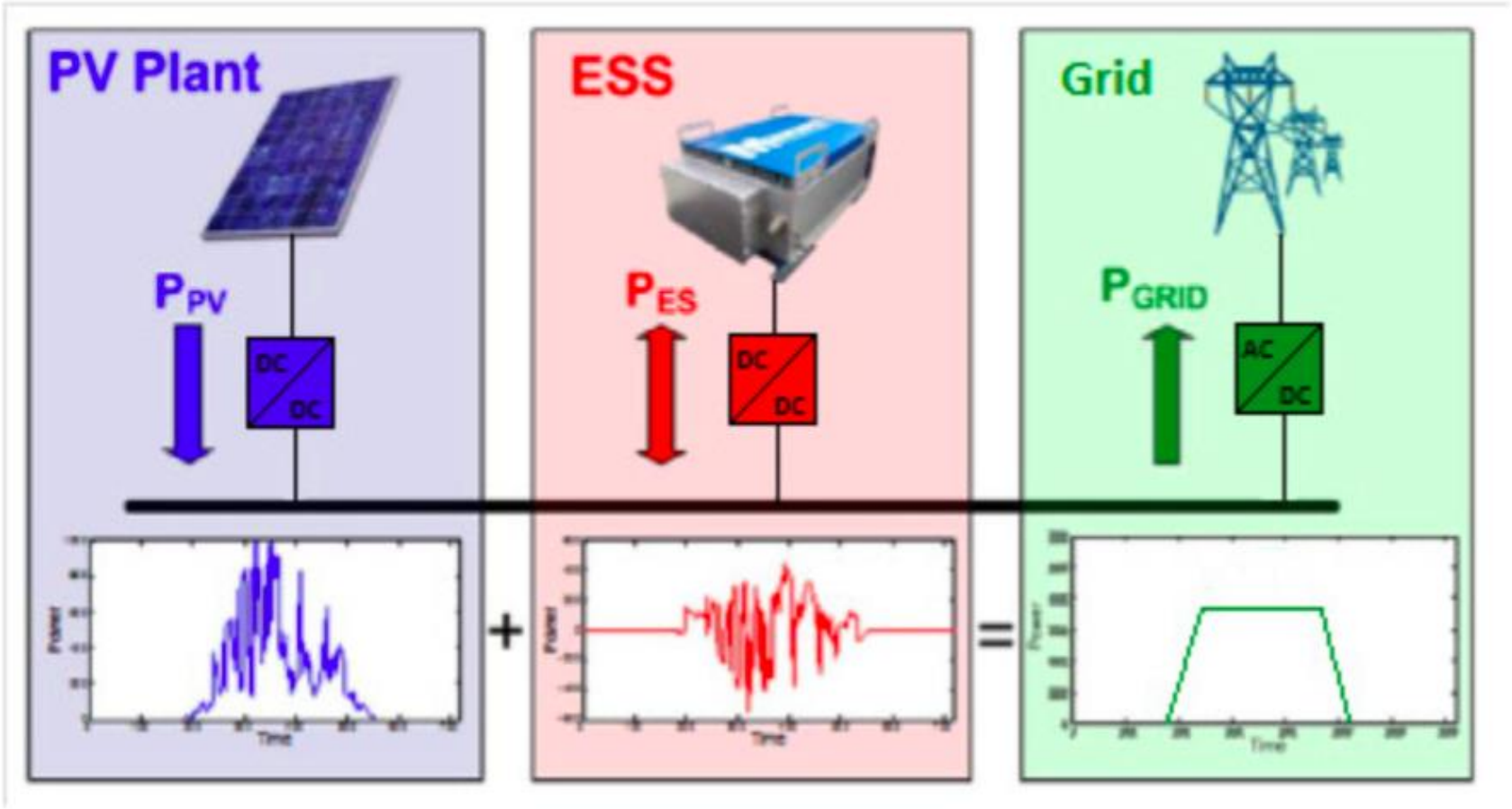




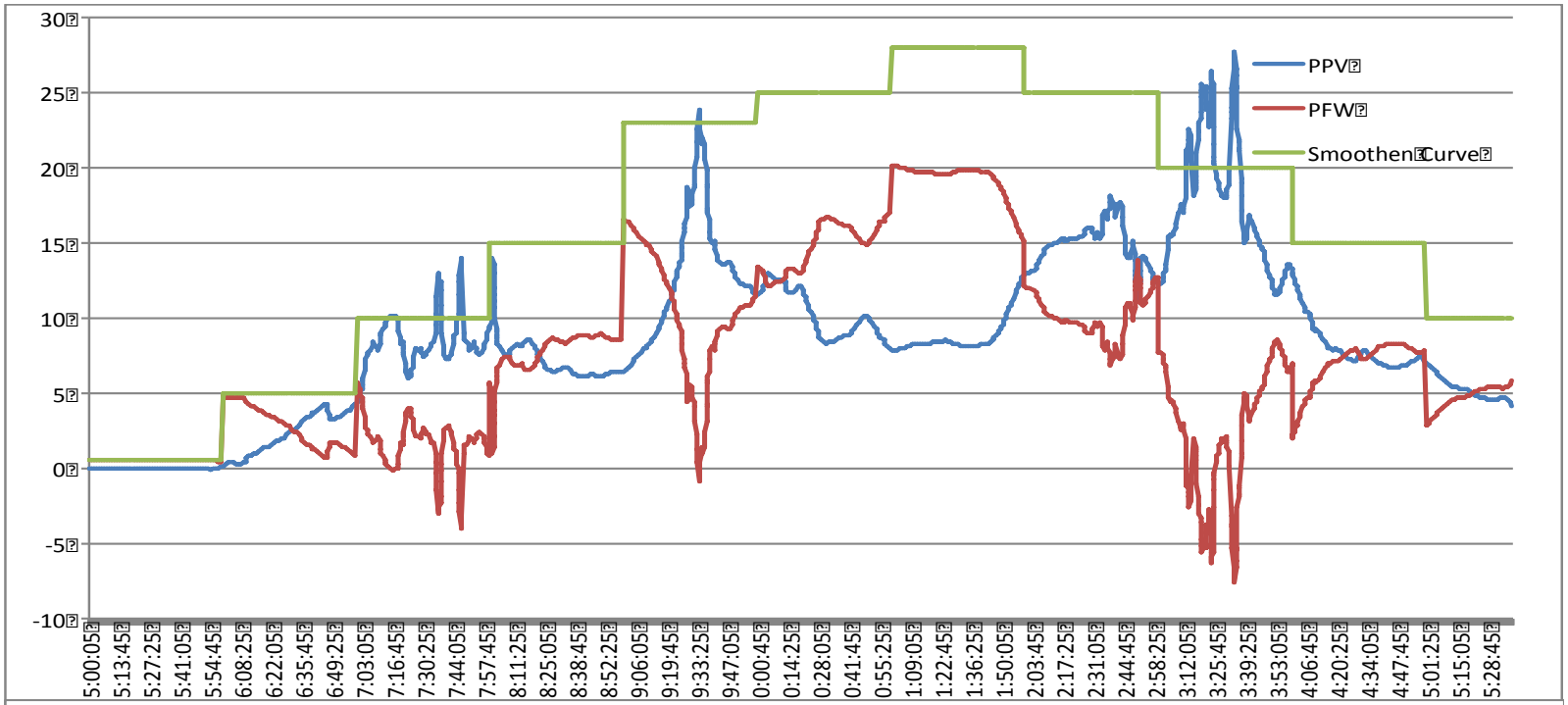




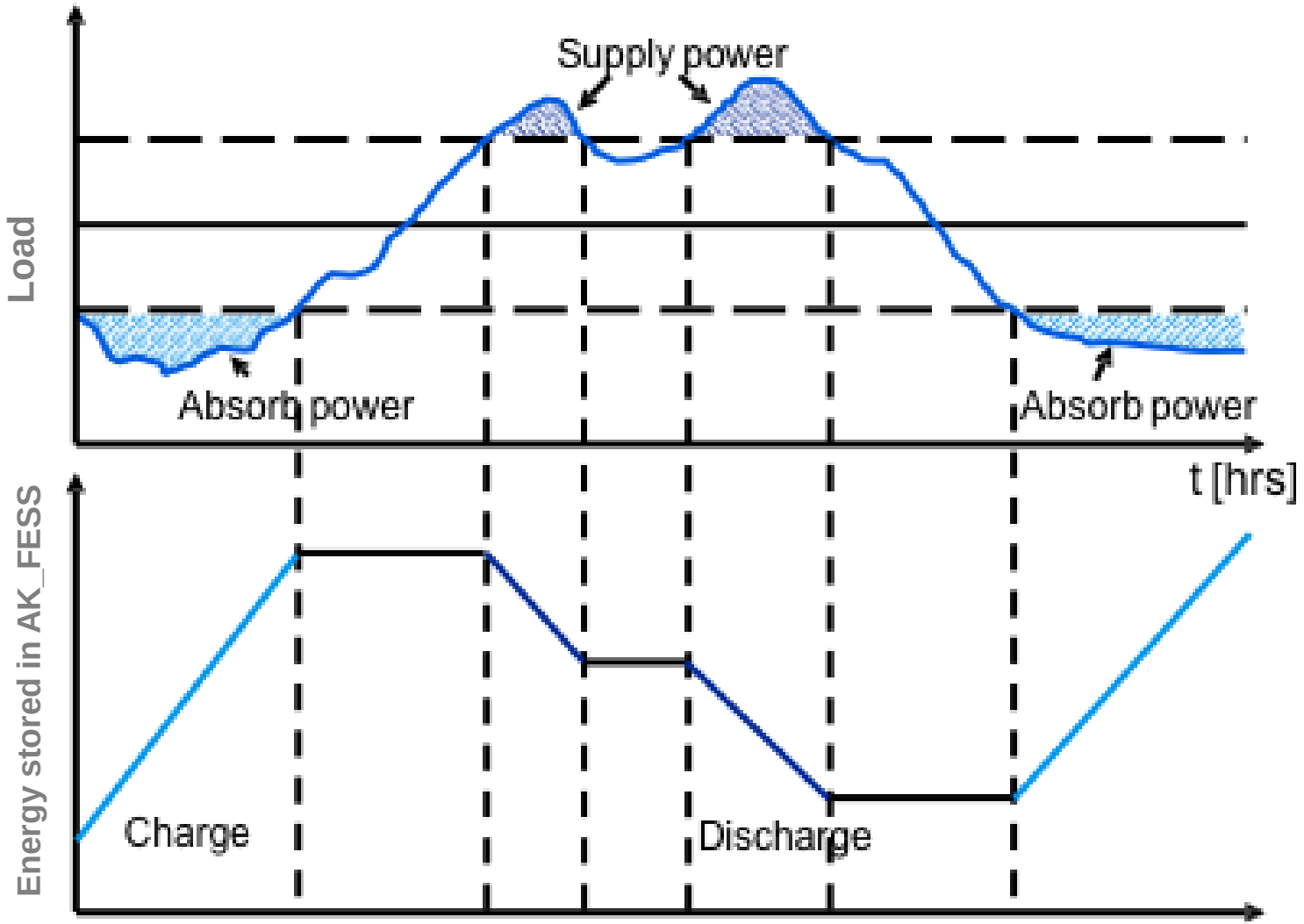
PV Generation with Energy Storage



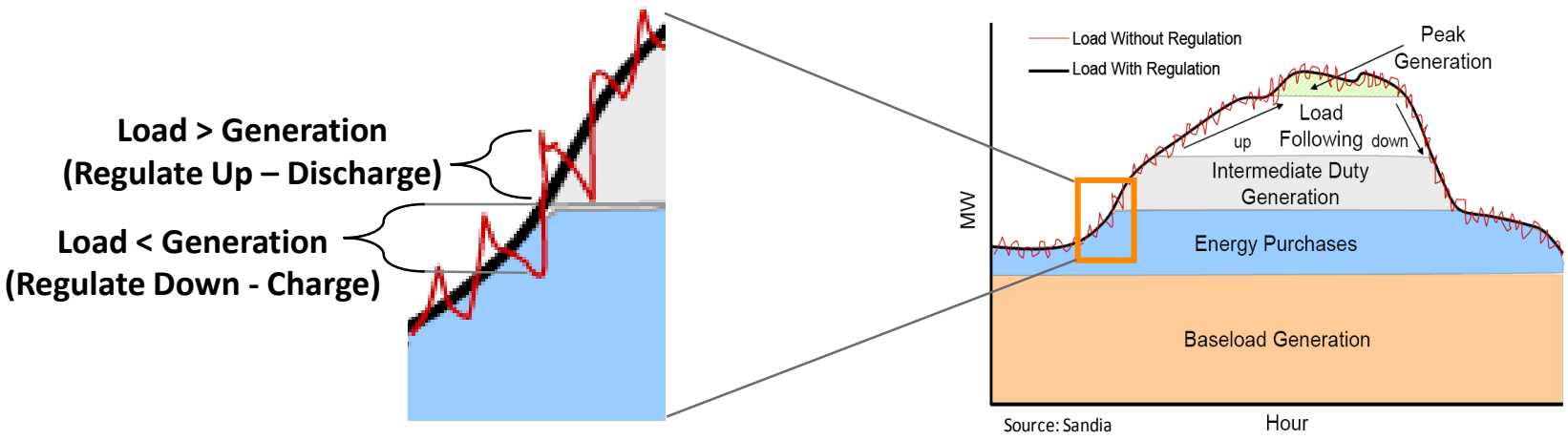
Smoothing PV Generation (Cloudy)



Flywheel for Energy Supply Shifting



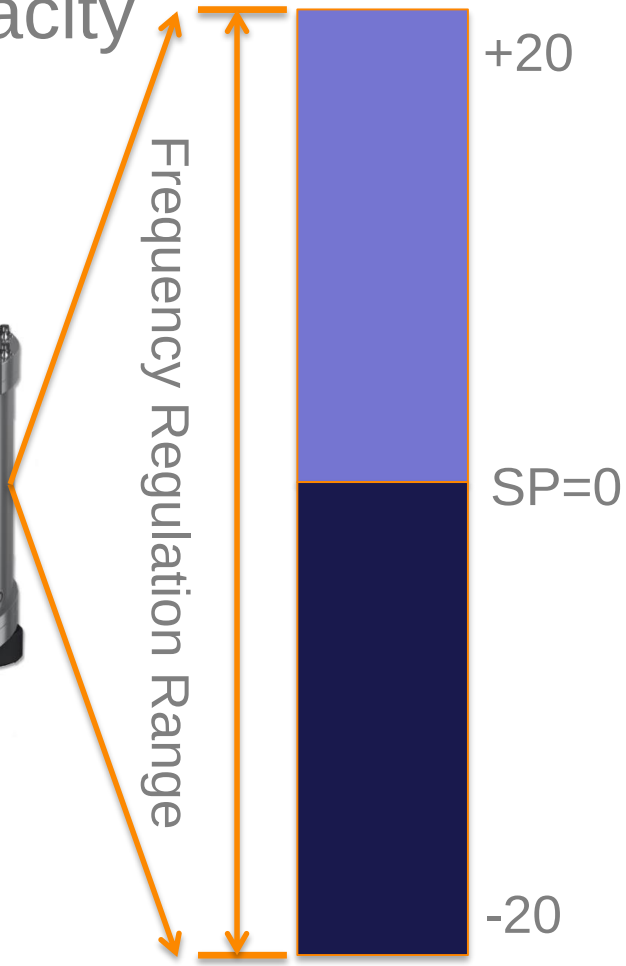
Frequency Regulation



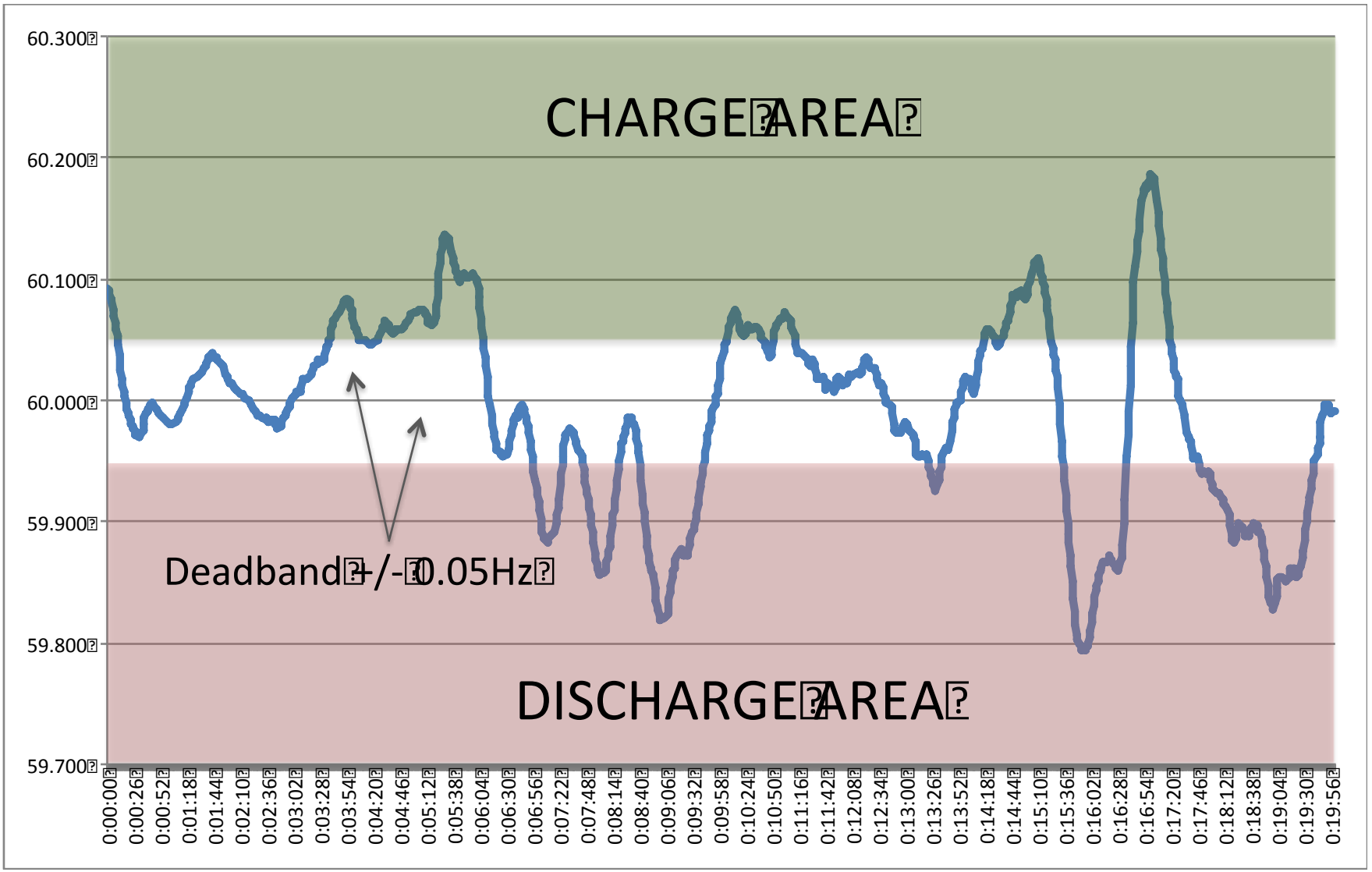
- Regulation is used to reconcile momentary differences between supply and demand.

AK as Source of Frequency Regulation

- Wide Range of Regulating Capacity
- Perform Fast Response Regulating Service
- Can provide full capacity from 3% SOC
- <1 Sec to Full Charge and Discharge Capacity
- Can operate in Primary and Secondary Regulation



Flywheel as Source of Frequency Regulation



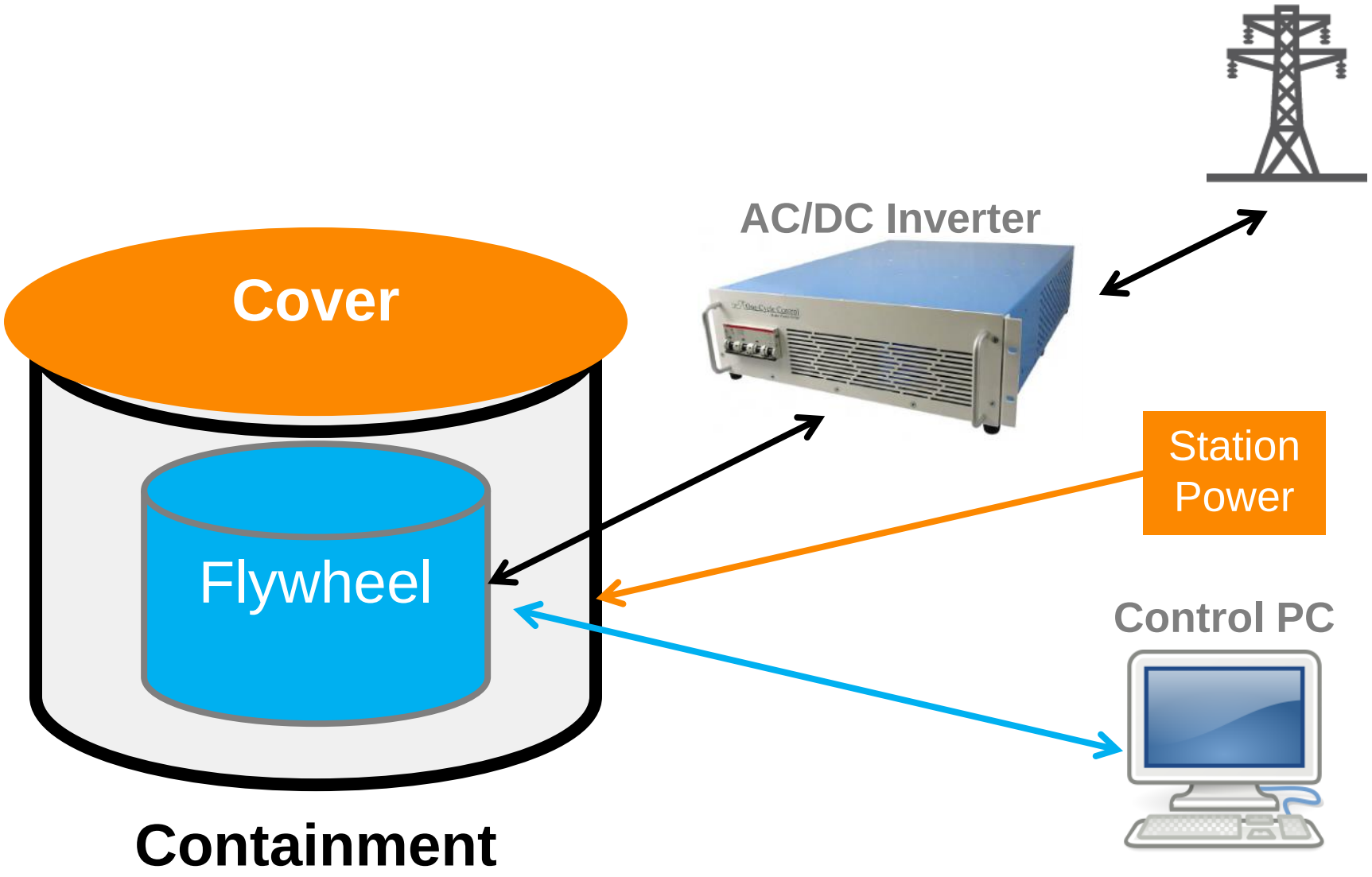
Amber – A Winning Track Record

- 2010 – Awarded $4mm from the U.S. Department of Energy
- 2010 – Closed Series A Investment
- 2012 – Awarded $2mm from the California Energy Commission
- 2013 – Awarded Contract Sponsored by U.S. Department of Defense (Hawaii)
- 2014 – Successfully Field Tested Amber 4-hour Flywheel
- 2014 – Closed Series B Investment
- 2015 – Awarded additional $2mm from the California Energy Commission
- 2015 – Signed Landmark Multi-Million ($) Contract with PG&E
- 2015 – Signed International Purchase Agreement with Emerging Power Inc.
- 2016 – Finalizing Terms of Purchasing Agreement with Hawaiian Electric

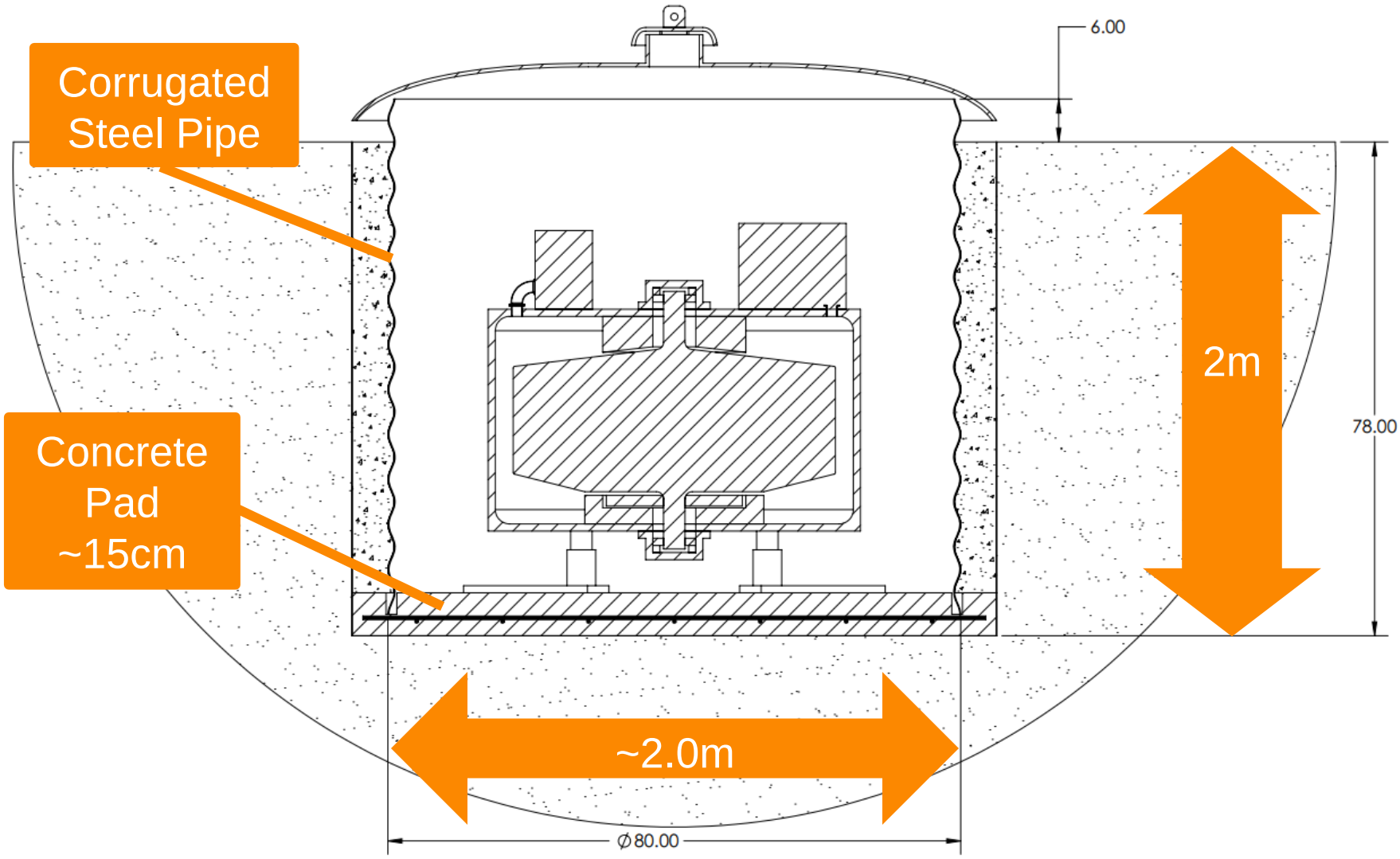
Why Amber Flywheels are Better

Li-Ion Battery (Today)	*$350 / kWh*	***2,000*** *deep cycles*	**$0.17 per kWh discharge**
(2025 Projected)	*$150 / kWh*	***3,000*** *deep cycles*	**$0.05 per kWh discharge**
Amber 4-hr Flywheel (Today)	*$500 / kWh*	***20,000*** *deep cycles*	**$0.02 per kWh discharge**
(2020-2025 Projected)	*$250 / kWh*	***20,000*** *deep cycles*	**$0.01 per kWh discharge**

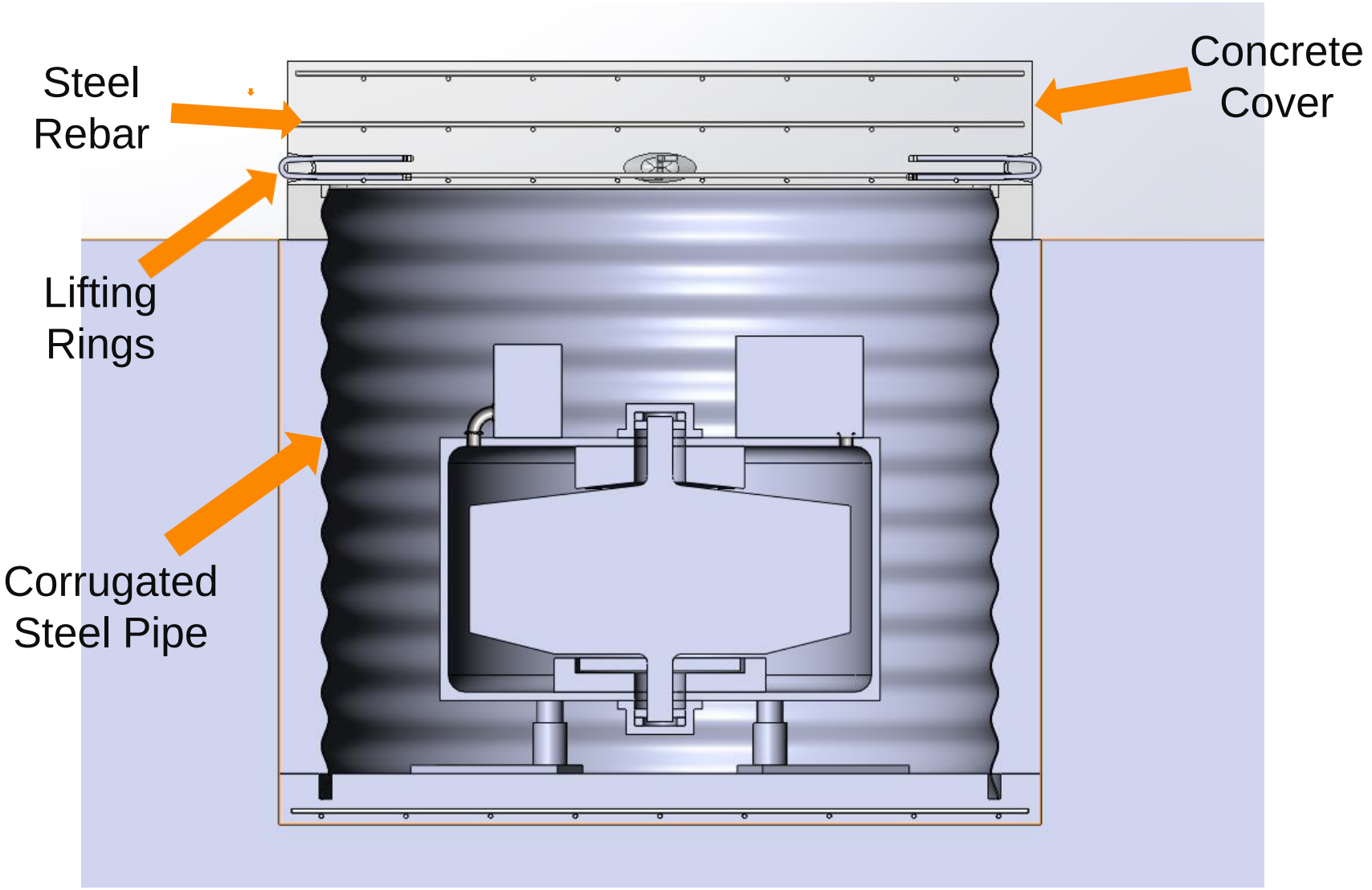
Overview of Single Flywheel System



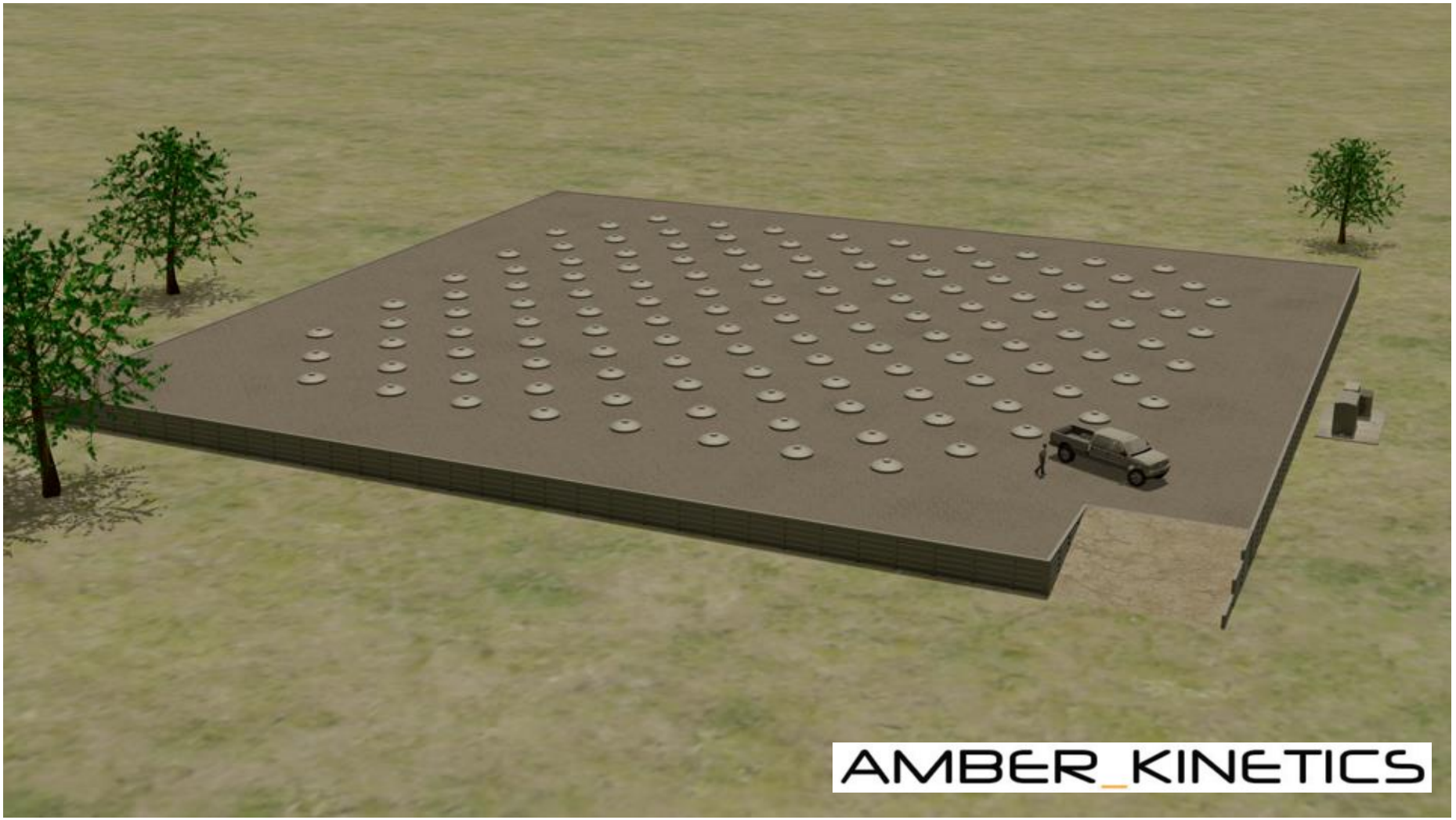
Site Requirements



Corrugated Steel Pipe & Cover



Overview 1MW System (0.125 ha)



Amber Kinetics “Model 32” Flywheel

- Mechanical Energy Storage
- No chemical reaction
- Performs in heat & humidity
- Peer-Reviewed Operating Data

“MODEL 32”	
Power	8 kW
Energy	32 kWh
Duration	4.0 hours
Cooling	Passive
Round-trip Efficiency	88%
Daily Cycling Limitation	None
Calendar Life	30 years
Electrical	
Input / Output Voltage	800 Vdc
Full Power Response Time	< 1 sec
Average Coasting Loss	< 200 watts

Amber Kinetics Leadership

Ed Chiao
CEO & Co-Founder
Prior Roles
Corporate Development, Solar Development,
Product Management & Engineering
Early employee in 3 start-ups, all acquired

Seth Sanders, Ph.D.
CTO & Co-Founder
Renowned Flywheel Technologist
Professor, Electrical Engineering, UC Berkeley

Rick Chong
Chief Financial Officer
Prior Roles
Investment Banking, Venture Capital

Wei-Tai Kwok
Chief Operating Officer
Prior Roles
Suntech Power, NRG, Andalay Solar

Will Sutherland
Senior VP, Manufacturing Operations
Prior Roles
Parker Hannifin, Bayer Material Science
Artificial Muscle

Kevin Swartz
VP, Business Development
Prior Roles
PG&E, Sempra Energy, Solel (Siemens)
Maine Maritime Academy

Mark Stout
VP, Project Development
Prior Roles
Meridian Energy, Cleantech America (acquired)

Matthew Senesky, Ph.D.
Director of Engineering
Prior Roles
Engineering R&D, Tesla Motors & TI
Ph.D. Electrical Engineering, UC Berkeley

Bill Barnes
Managing Director, Project Development
Prior Roles
Cleantech America (acquired)
Renewable IPP, Utility-Scale Development


THANK YOU...
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