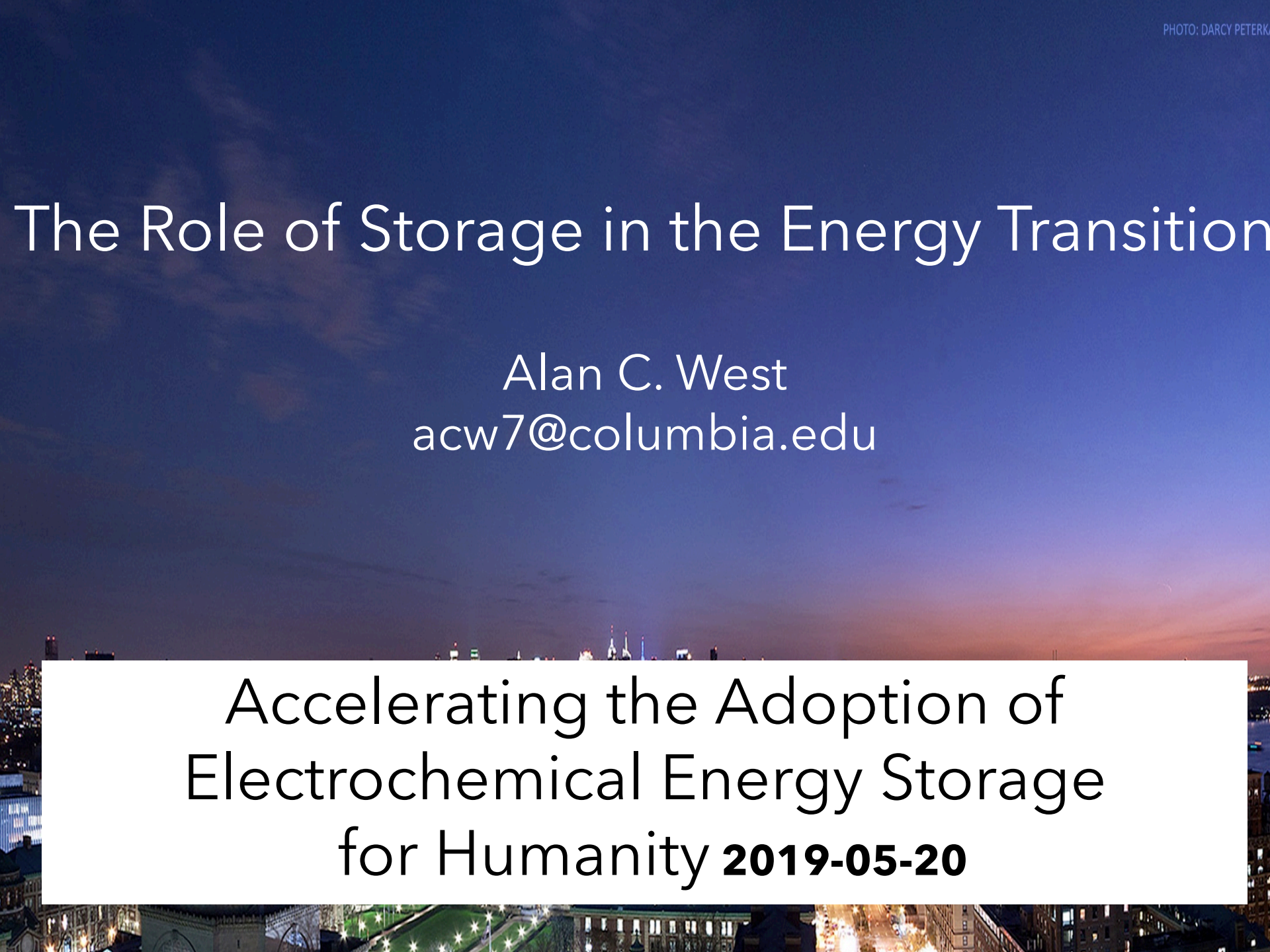

The Role of Storage in the Energy Transition

Alan C. West
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Accelerating the Adoption of Electrochemical Energy Storage for Humanity **2019-05-20**

Columbia Electrochemical Energy Center

Alan West and Dan Steingart, co-Directors

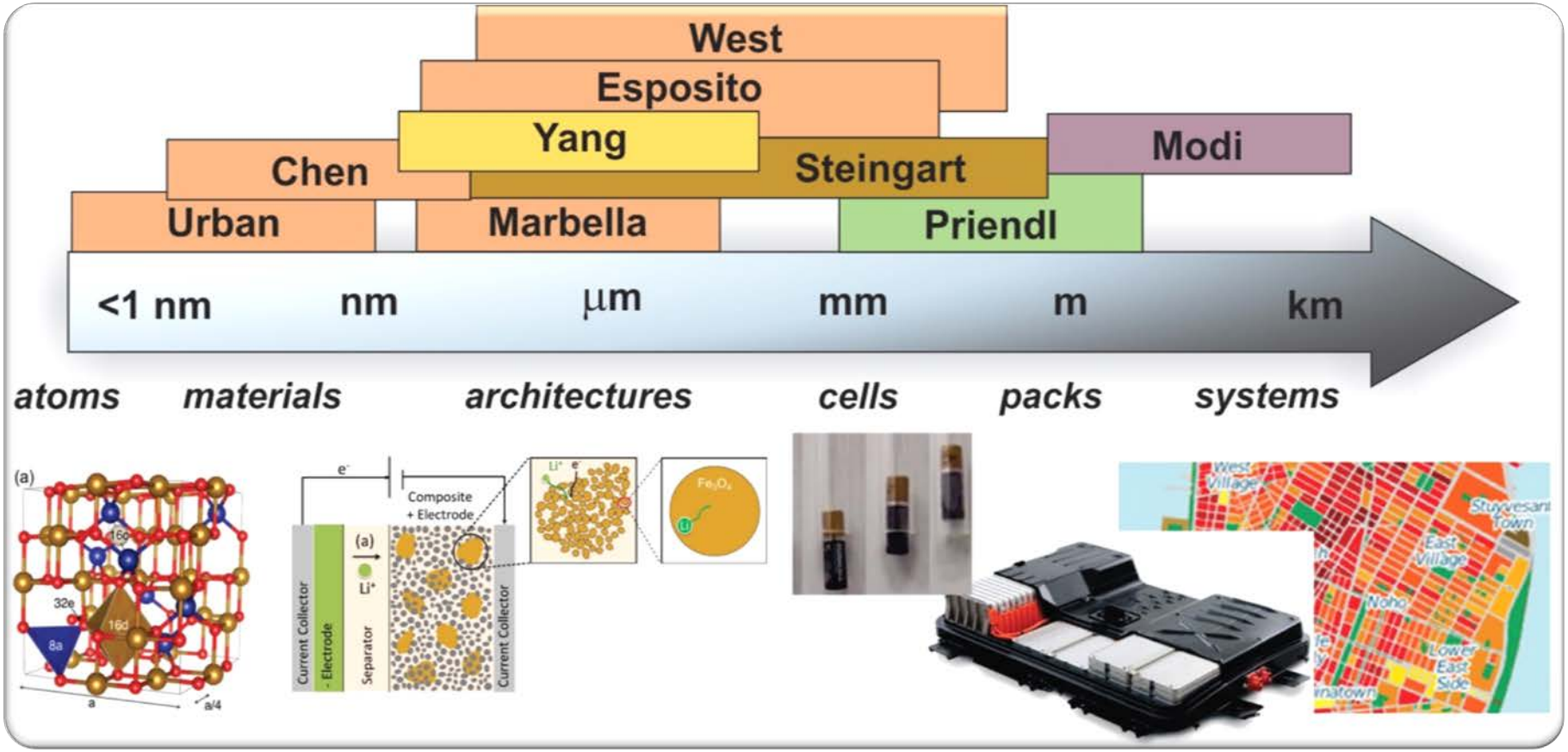
Enable and Exploit Renewable Electrons from Wind and Solar

1. Batteries for Storage
2. Electrolyzers

   hydrogen + …
3. Fuel Cells to exploit hydrogen

ceec.engineering.columbia.edu

CEEC: Atoms to Systems



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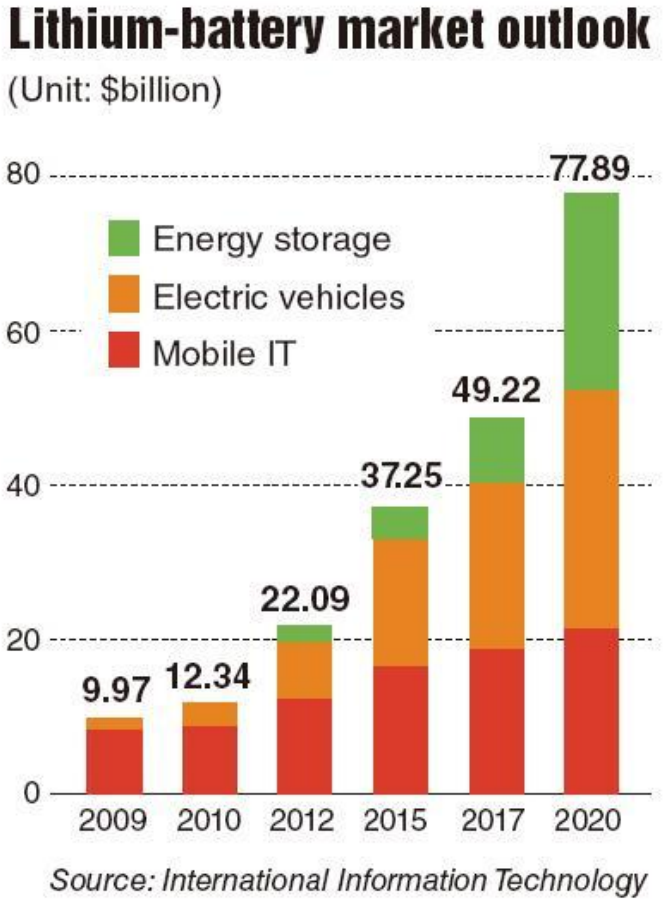
Electrochemical Energy

- Electric Vehicles
  - At 1 million EV, market size (kWhr) is same as electronics
- Chemical Process Industries
  - Electrochemistry for sustainable and economical processes



Historic Opportunity for Grid

Renewables on the Grid

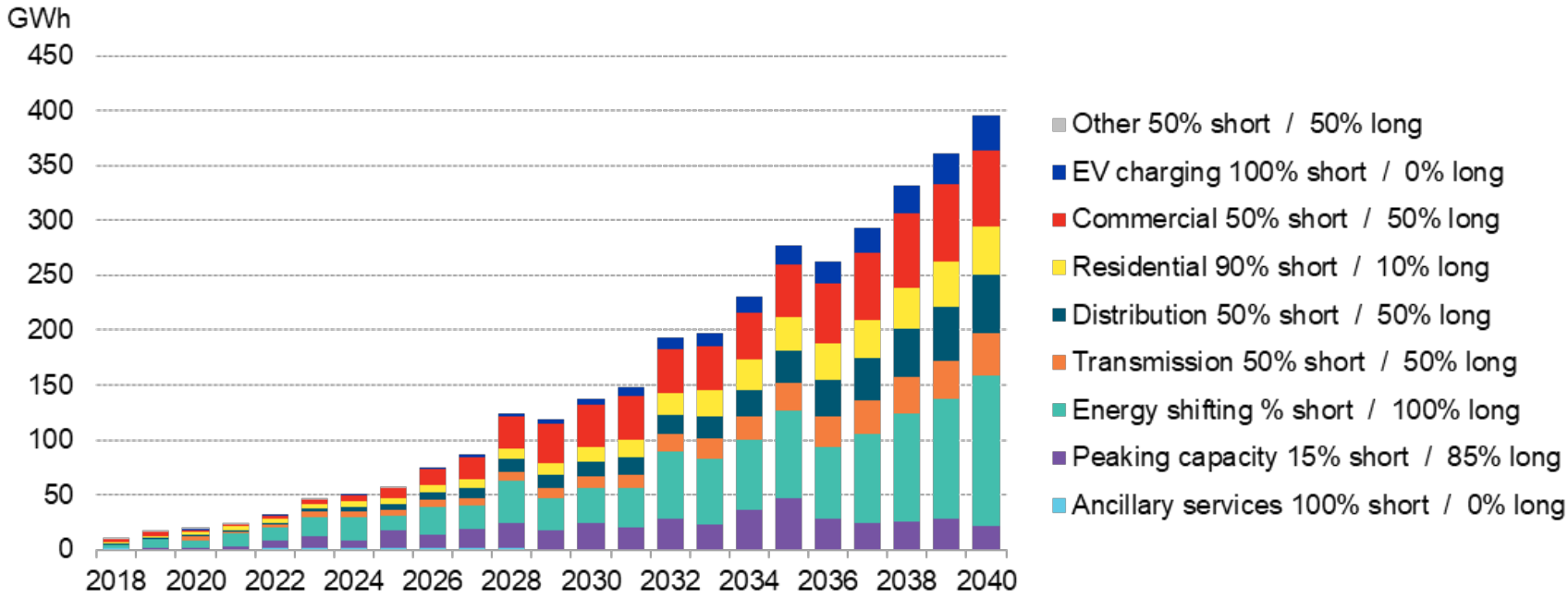
- NY State: 50% renewables by 2030
- NYBEST report: 4 GW in NYS alone

Storage Requirements Change as Renewable Energy Target Changes from 50 to 80 %...

Stationary energy storage market

Long 4-8 hour applications growing faster than shorter applications

Storage deployments by application



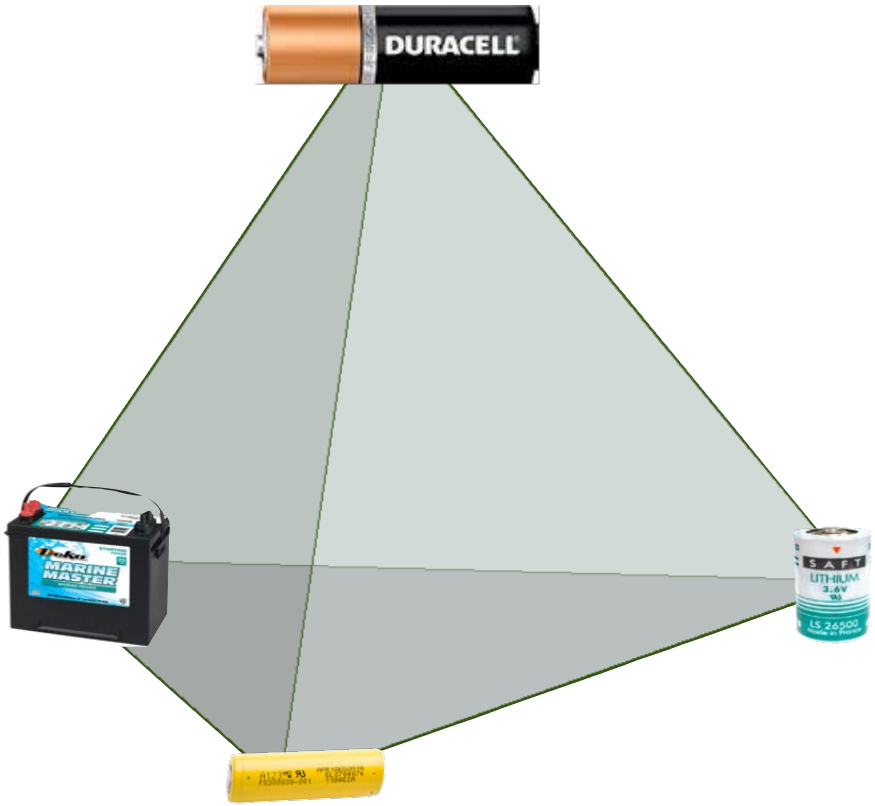
Source: data from Bloomberg New Energy Finance, *Long-Term Energy Storage Outlook, November 2018.* Long/short estimates from Primus Power.

PRIMUS POWER

Batteries 101. Different Applications Demand Different Tradeoffs

Dan Steingart

Capital Cost



Amortization/ Operating Cost

Energy Density

Power Density

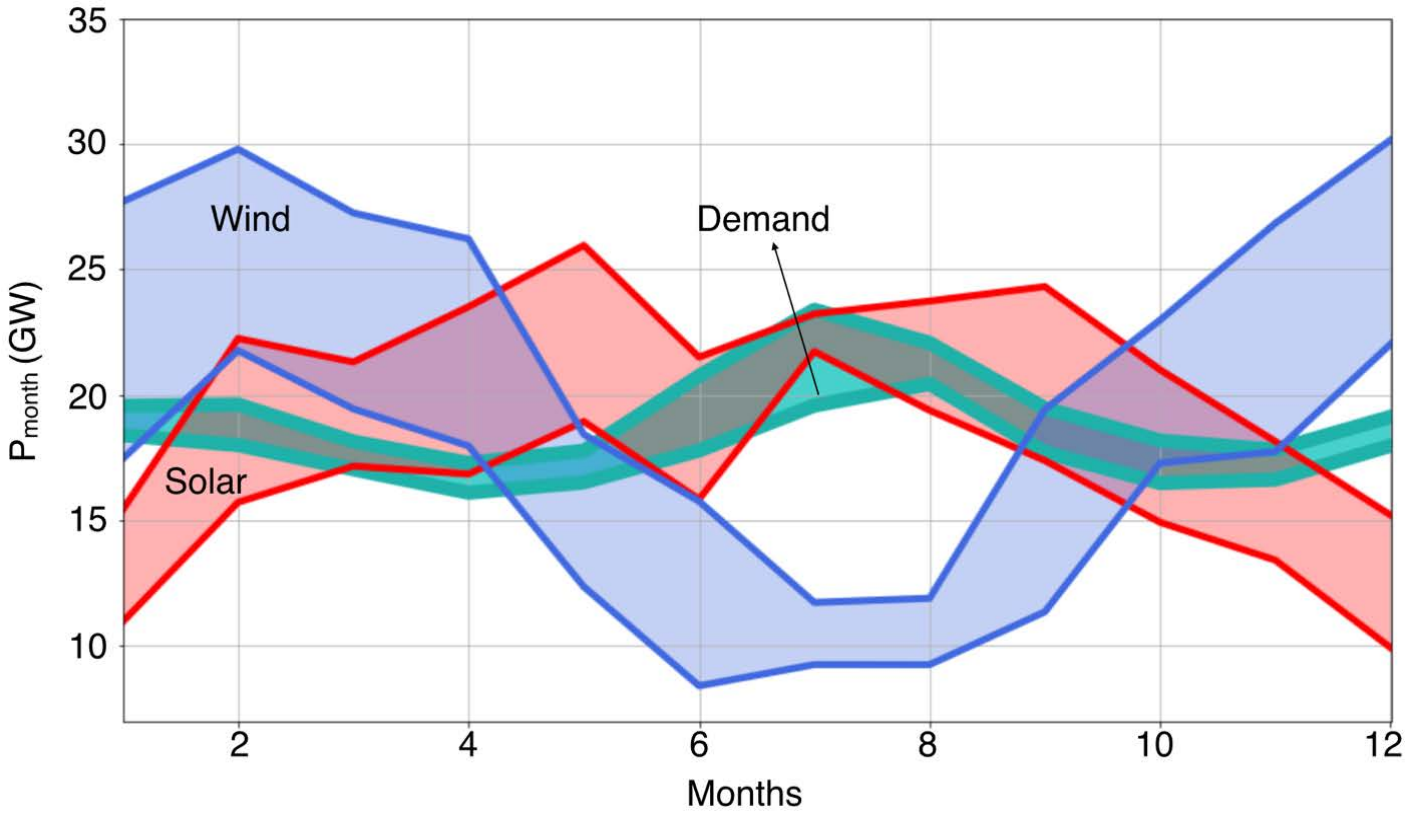
Adoption of Storage: Challenges

- Cost
- Policy/Regulatory Environment
- Safety (Real and Perceived)
- Power and/or Energy Density
- Lifetime

  including prediction…
- Sustainable materials

New York State: Renewables

Vijay Modi

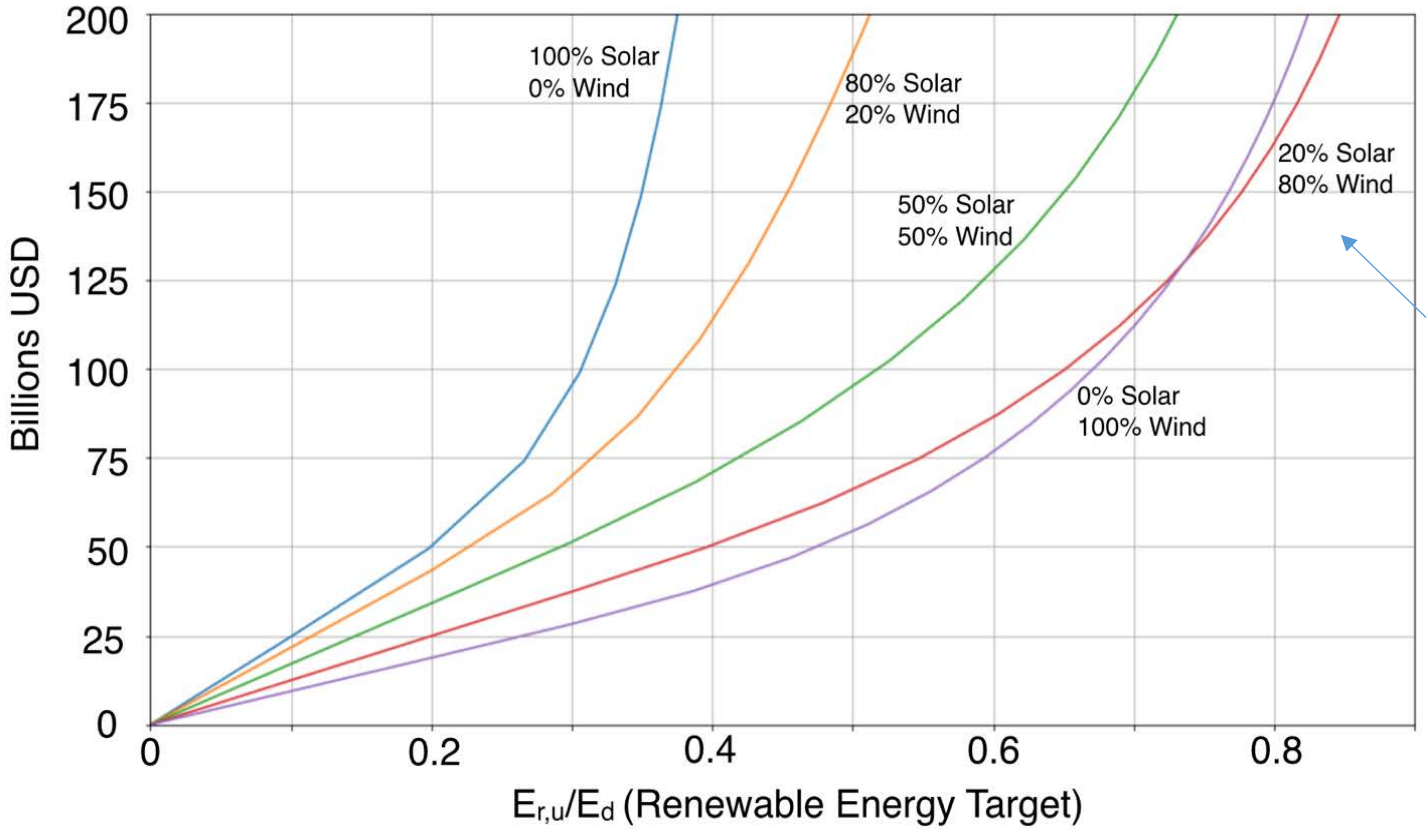


Wind: NREL 6 years of wind speeds (corrected using turbine power) and turbines at optimal locations (Applied Energy 183 (2016) 299–317).

Solar: NREL System Advisor Model.

Demand: NYISO

Approximate Investment Costs IF NO STORAGE : NY STATE

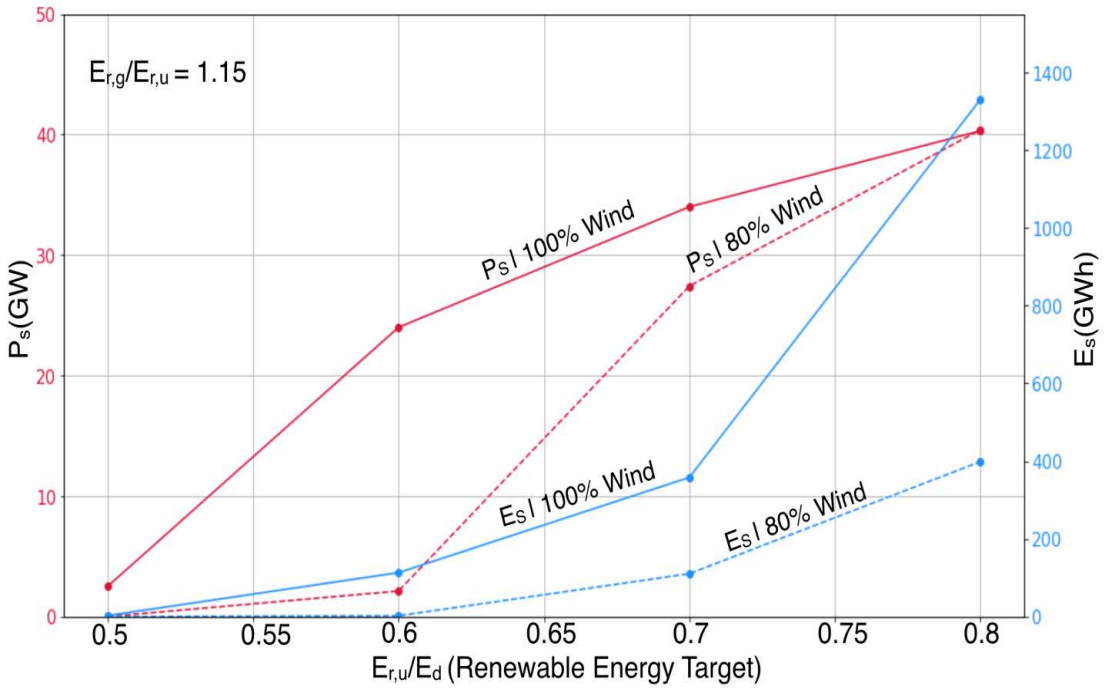


Other consumer reasons for solar

Transmission Costs not Included

Energy Need from Storage Increases More Rapidly than **Power**

Storage Needs in "Optimal" System

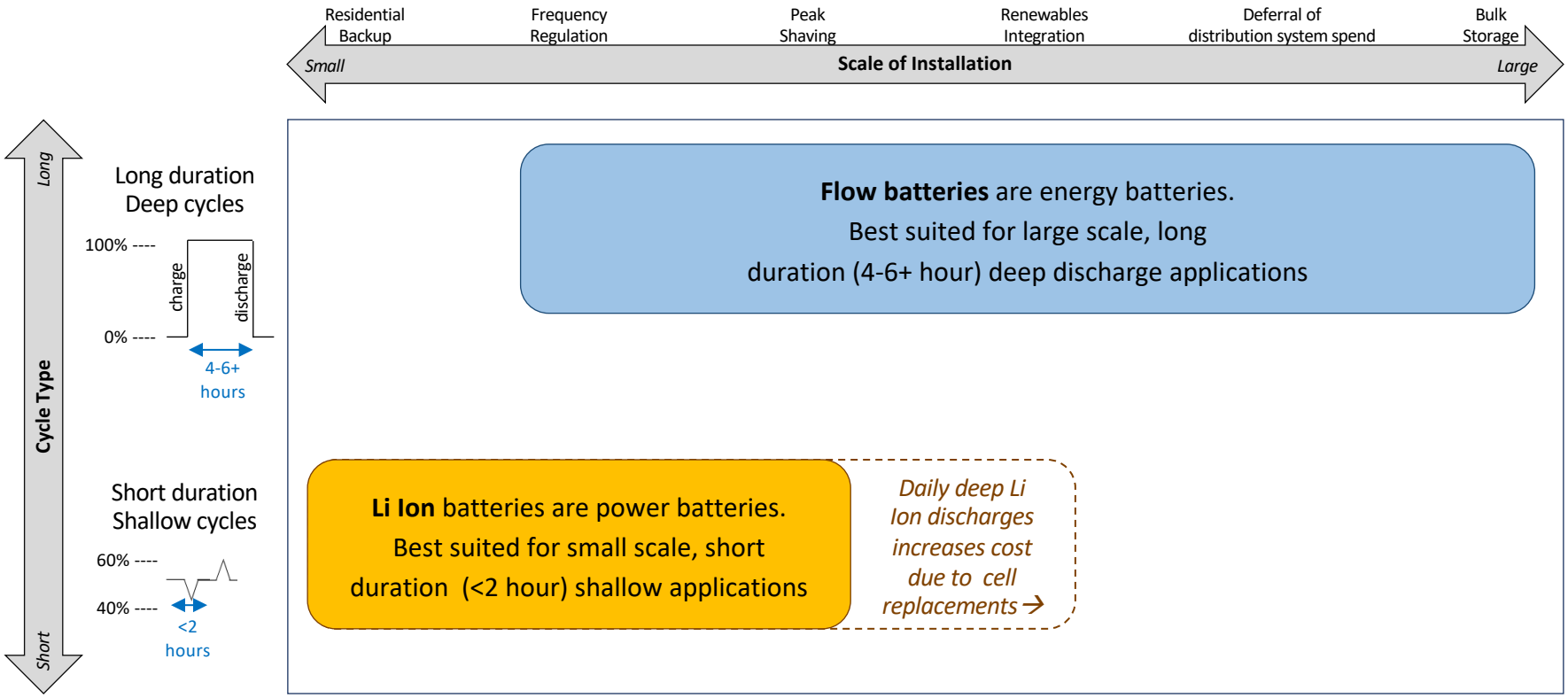


Battery costs : $/kWh

Fuel Cells : ~ $/kW

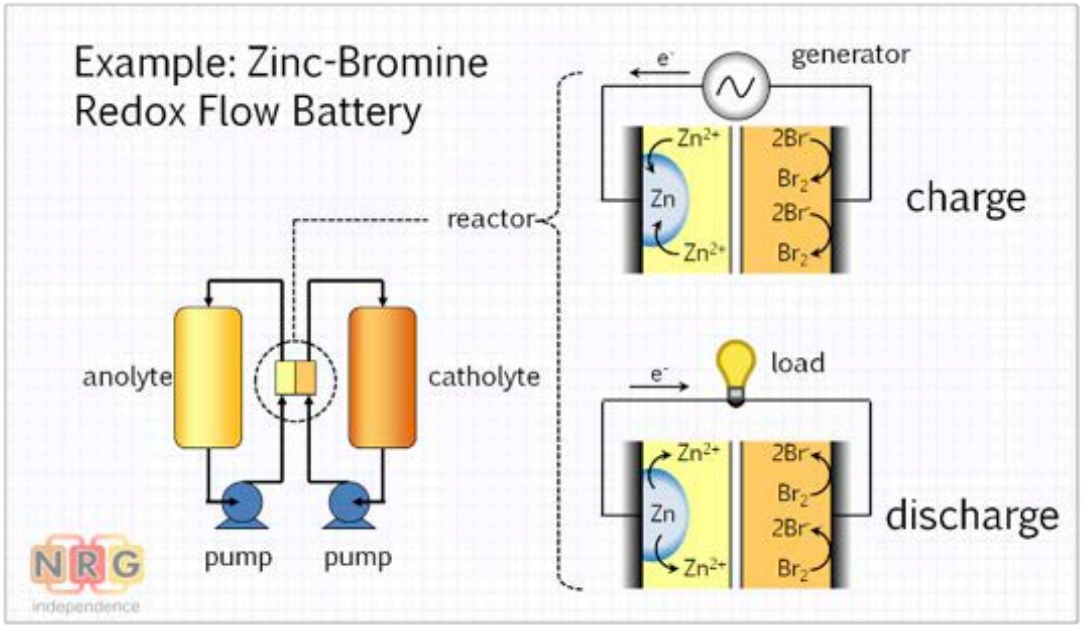
No single battery technology will serve all stationary energy storage applications

Li Ion is good for short duration, shallow discharges. Flow is best for long duration, deep discharges.



Adapted from The Great Battery Race, Goldman Sachs 2015

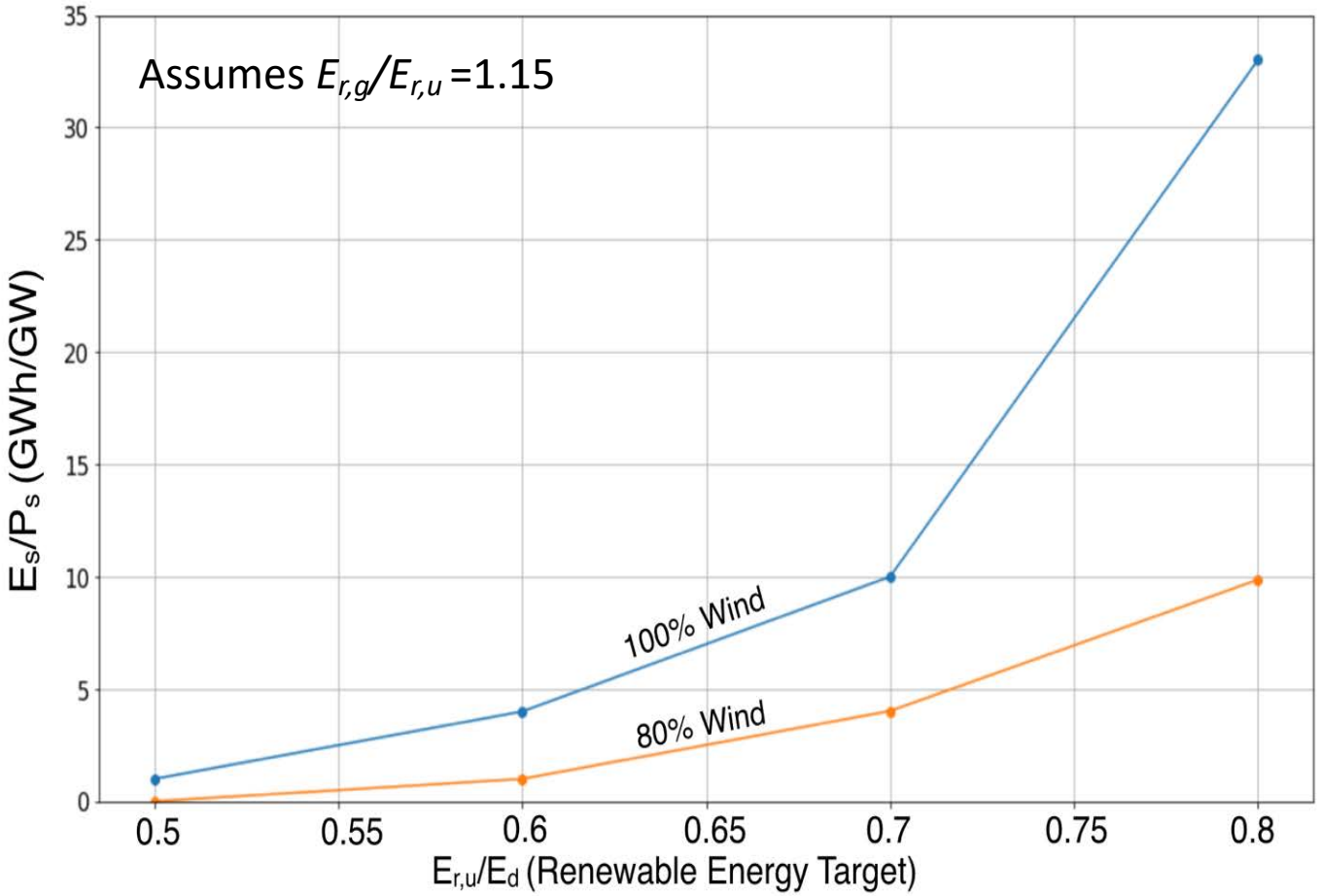
$ZnBr_2$ Batteries



Can we re-engineer to achieve < $25/kWh?

DOE Arpa-E (CU with Primus Power)

"Battery" Duration



$/kwh: Battery costs proportional to energy requirements

Alternative to a Battery: Technology with Costs that Scale with Power

e-

Electrolyzer
$/kW

Fuel Cell
$/kW

e-

H2

H2

H2 Storage

5-15 $/kWhr

NY GRID STORAGE: OTHER FACTORS

- Off-Shore Wind
  - LESS VARIABLE
- Electrification of Transportation
- Electrification of Heating
  - PEAK DEMAND NOW IN WINTER