Pacific Northwest NATIONAL LABORATORY

NATTBatt Sodium-Zinc Battery Workshop, Houston
Nov 30-Dec 1
“The State of the Art in Molten Sodium Metal Batteries”

Intermediate Temperature Na Battery Research at PNNL

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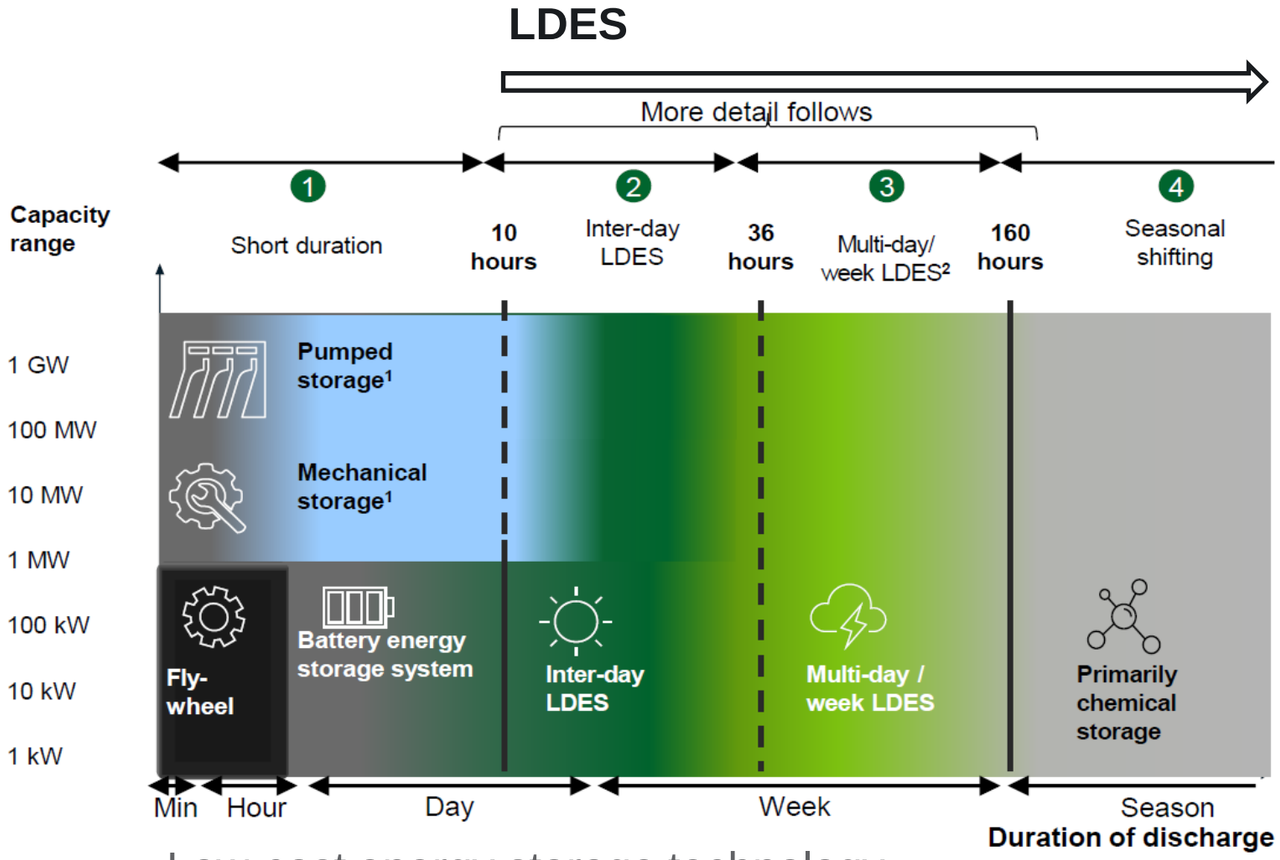
U.S. DEPARTMENT OF ENERGY BATTELLE

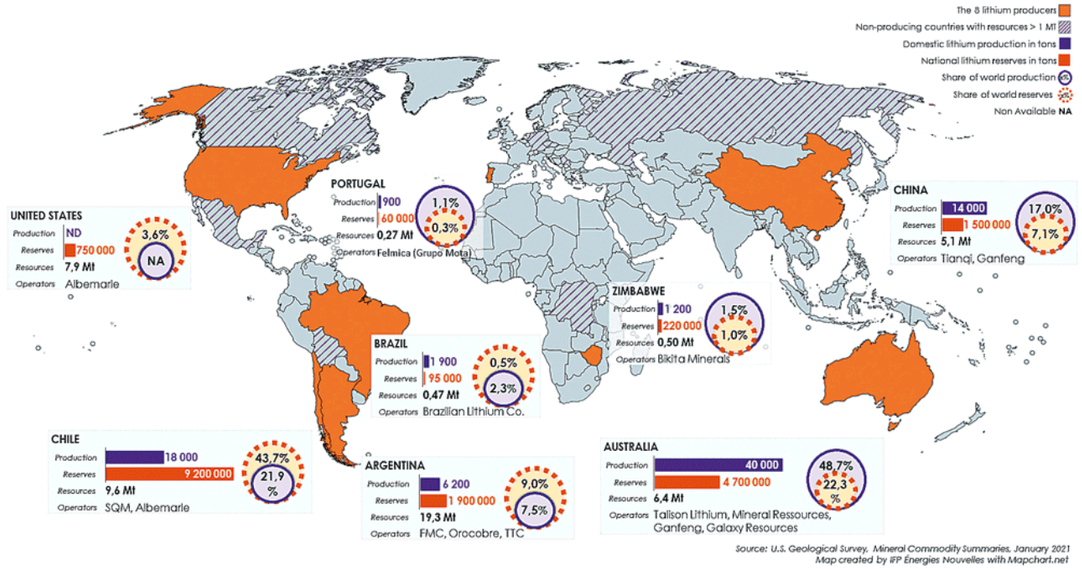
PNNL is operated by Battelle for the U.S. Department of Energy

Long Duration Energy Storage (LDES) Technologies



- Low-cost energy storage technology
- Enable for long duration discharge capability
- Long cycle and shelf life
- Safe and reliable technologies
- Durable under various climate conditions

Global Lithium Production and Reserves



Sodium (Na):

- Abundant resources in Earth's crust (Na_2CO_3, etc.) and Ocean (NaCl).
- Low cost and less environmental pollution.

From "*Pathways to Commercial Liftoff: Long Duration Energy Storage*" https://liftoff.energy.gov/

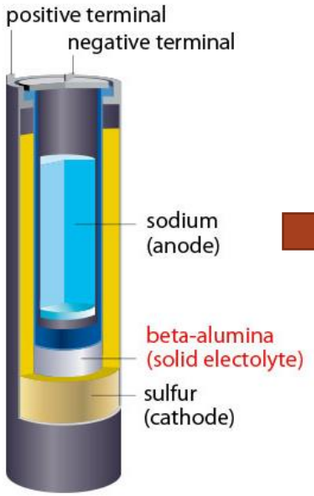
Challenges & Opportunities for High Temperature Na Batteries

Batteries	Temp. (°C)	OCV (V)	Duration (hours)	SSE	Cycle life	Safety	Cost ($/kWh)
Na-$NiCl_2$	280	2.58	**4-6**	β″-alumina	>1,000	No thermal runaway	**1,000**

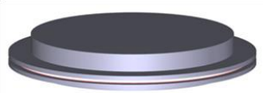
Tubular type

Increase tube diameter for larger cathode loading (LDES)

1. Manufacturing cost /challenges of large β″-tubes
2. Cell processing cost & technical difficulties. Glass seal, TCB, etc.



PNNL

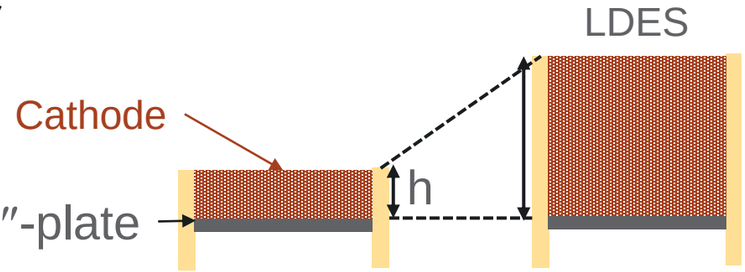


IT Na-MH: 190°C
(< $100/kWh)

Planar type

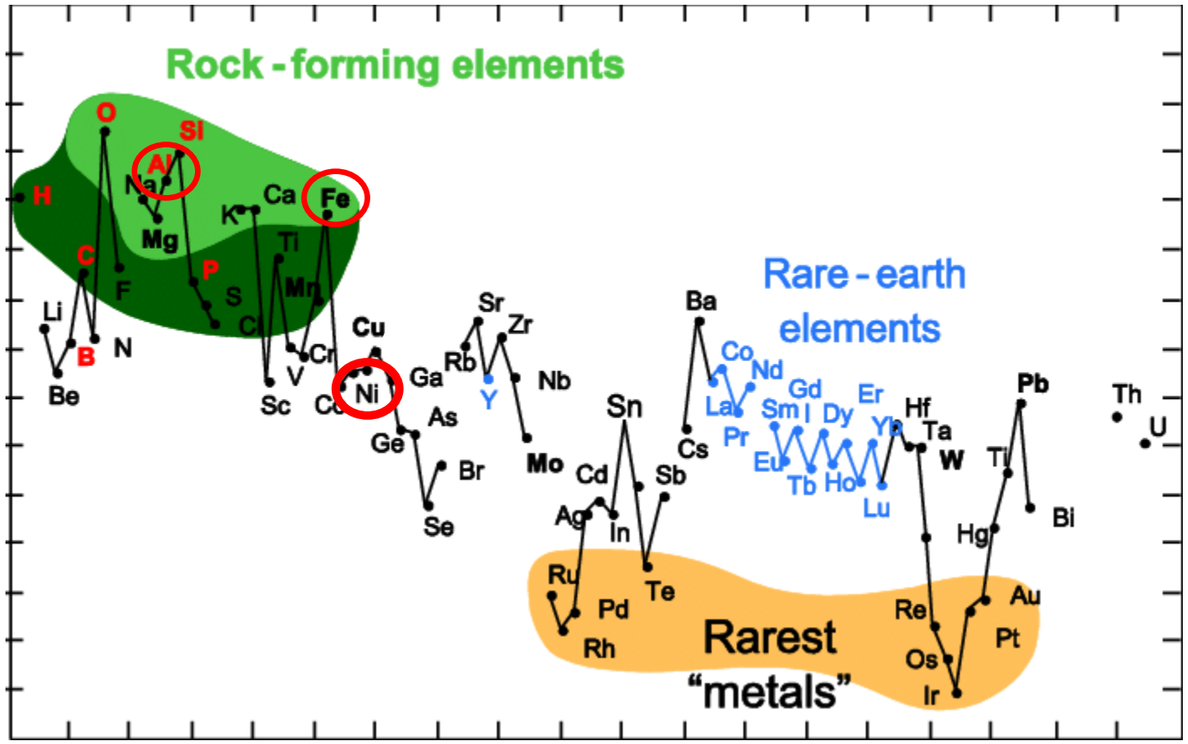
Increase cathode thickness for larger cathode loading (LDES)

1. No size change for β″- plates
2. Similar cell assembly



Advanced Na-Metal Halide Battery Technologies

- 2Na+ $NiCl_2 \Leftrightarrow 2NaCl + Ni$ (Conventional)
- Operation Temp: 265°C (High Temp.)
- Cathode: $Ni/NiCl_2$ (High Cost)



- Low-cost metal cathode:
  - Fe (PNNL)
  - Al (PNNL)
  - Zn (PNNL, Solstice)
- Lower temperature operation:
  - 180°C ($NaAlCl_4$ M.P. at 157°C)
  - ~110°C (Sulfur, Iodine, etc.)
- Na wetting:
  - Low cost, benign wetting agent and process

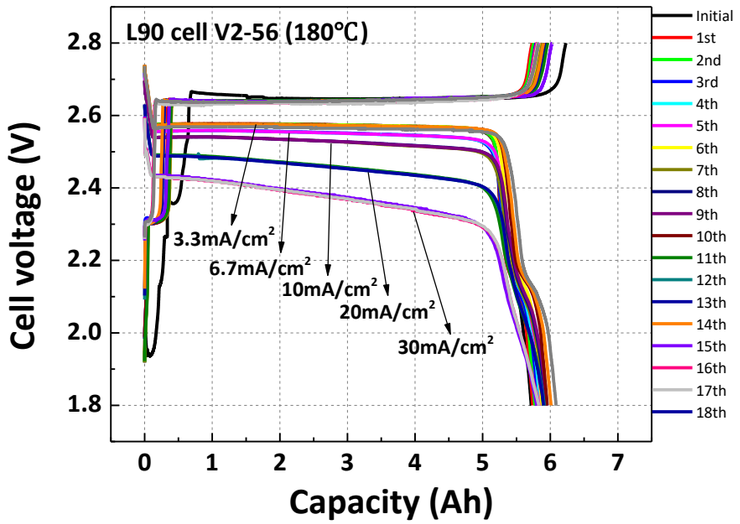
International Collaboration with ROK (1)

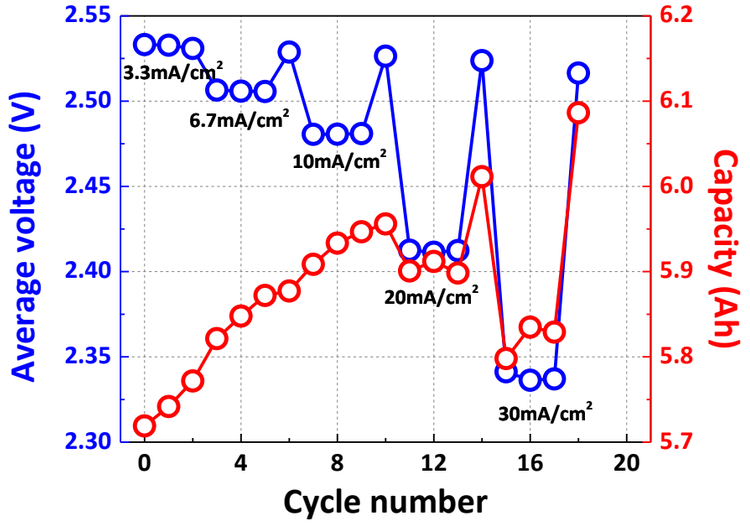
DOE/KETEP International Collaboration

- Phase 1: 2015− 2018 (OE, KETEP, POSCO)
- Goal: Demonstrate planar-type Na-metal halide battery large single cell.

Cell: 15Wh, SOC utilization 80% @30mA/cm^2

Cycling condition: UCV/LCV=2.8V/1.8V, CC 3.3~30mA/cm^2



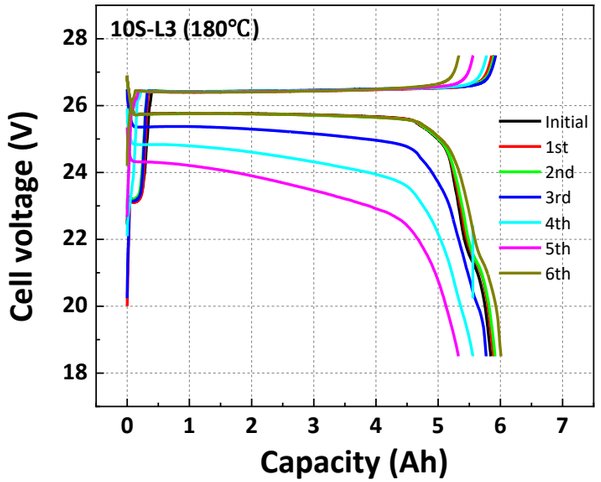


International Collaboration with ROK (2)

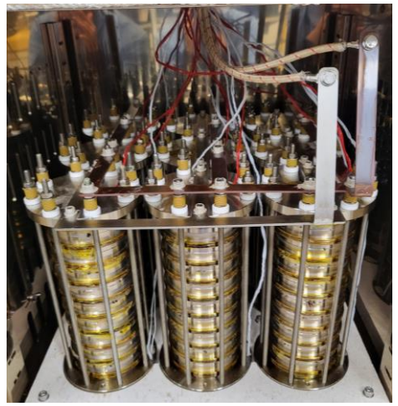
- Phase 2: 2015− 2018 (OE, KETEP, KEPCO)
- Goal: Demonstrate planar-type Na-metal halide battery module.

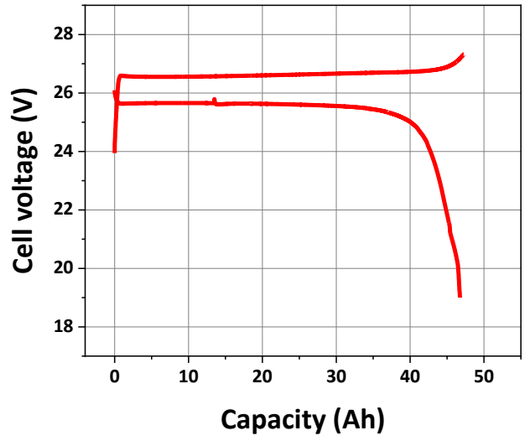
10s stack (26V, 150Wh)

- Chemistry: Ni/NaCl=1.8
- Cathode loading: 156 mAh/cm^2
- Solid electrolyte: β″-Al_2O_3
- Temperature: 180^{o}C
- V window: 19-27V
- DC current densities: 3.3~30 mA/cm^2

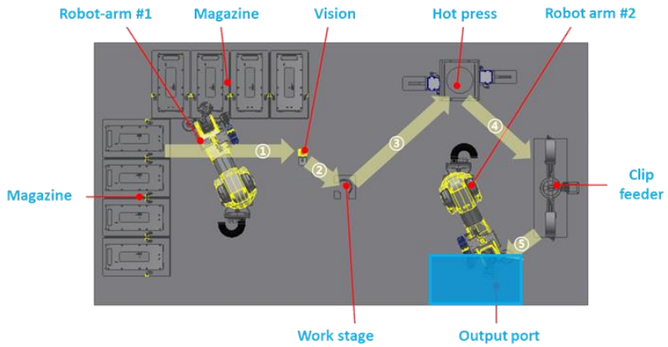


90 (10sx9) module (26V, 1.3kWh)





Semi-automated Battery Assembly



Low-Cost Cathode Materials for Na-Metal Halide Battery Technologies

	Na-$NiCl_2$	Na-$FeCl_2$	Na-Al
Cathode	Ni/NaCl	Fe/NaCl	Al
E (V)	2.58	2.35	1.6
Capacity (mAh/g)	305.4	310.4	308.4
Materials cost ($/kWh)	<100	<5	<5
Duration (hr)	4-6	12	20

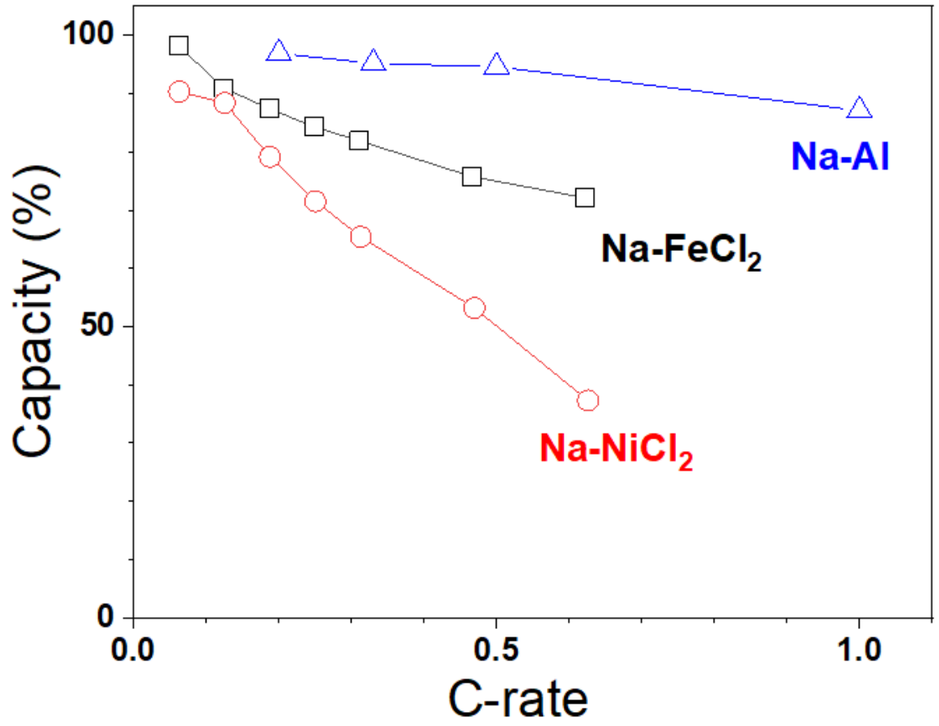
[1]**Na-$NiCl_2$:** $2Na + NiCl_2 = 2NaCl + Ni$

[2]**Na-$FeCl_2$:** $6Na + 4FeCl_2 = Na_6FeCl_8 + 3Fe$

$2Na + Na_6FeCl_8 = 8NaCl + Fe$

[3]**Na-Al:** $3Na + NaAlCl_4 = 4NaCl + Al$

$3Na + 4NaAl_2Cl_7 = Al + 7NaAlCl_4$

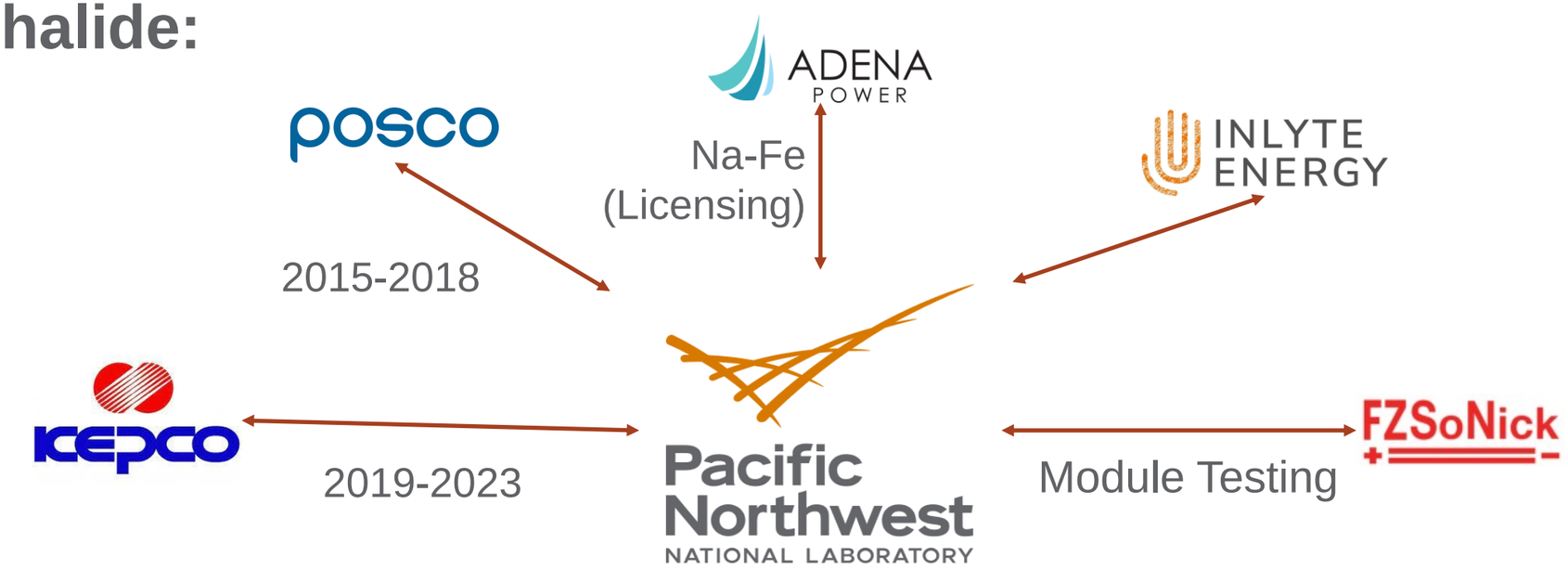


- Lower materials cost for Fe and Al cathode
- Fe and Al cathodes offer faster redox kinetics vs Ni cathode
- Longer duration discharge

(1) Li et al. *Nat. Commun.* 7, 10683 (2016),
(2) Li et al. *Adv. Energy Mater.* 5, 1500357 (2015); Zhan et al. *Adv. Energy Mater.* 10, 1903472 (2020).
(3) Zhan et al. *Adv. Energy Mater.* 10, 2001378 (2020); Weller et al. *Energy Storage Mater.* 56, 108 (2023).

Working with Industry

Na-Metal halide:



Grid Storage Launchpad (GSL) by OE

$75M
Total Facility cost

$35M
Non-Federal Funding

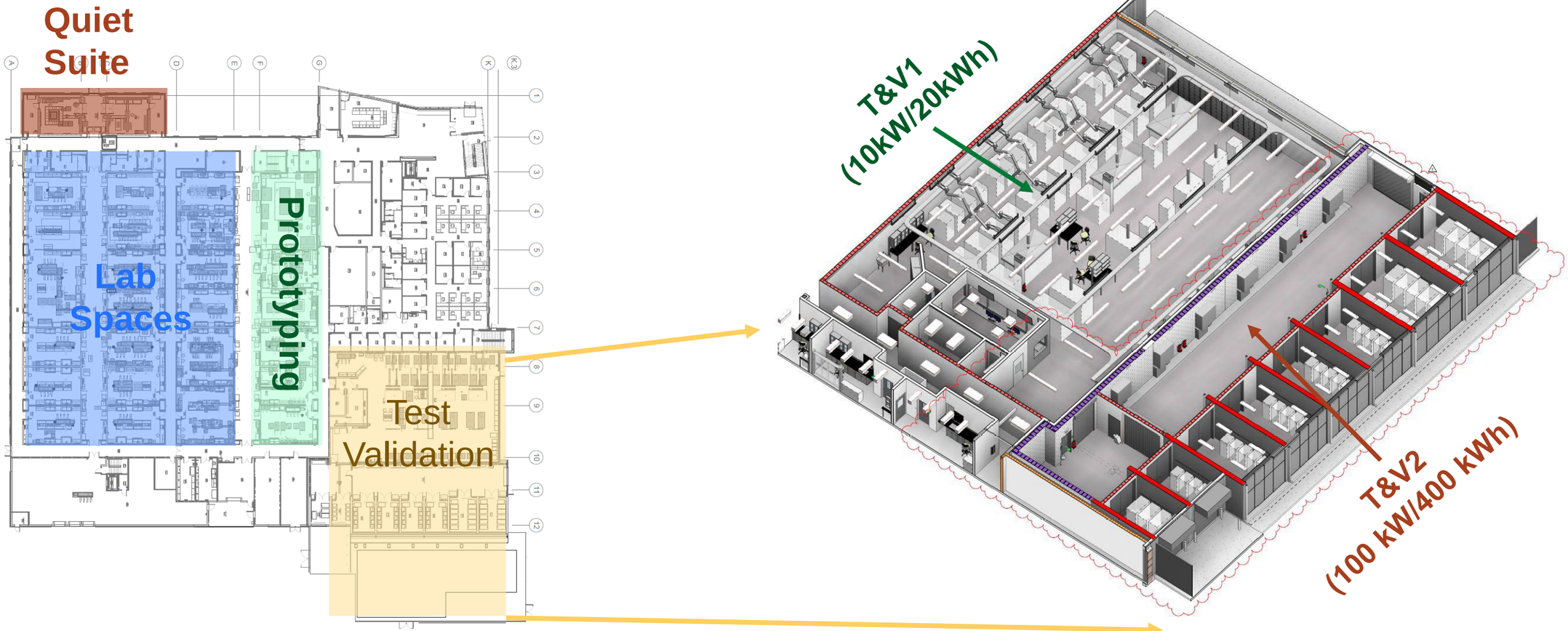
105
Workstations

30
Lab modules

- First DOE Office of Electricity facility for energy storage R&D
- Expected occupancy/start of operations: Spring 2024
- 91,000 sq. ft facility at PNNL
- Provide systematic and independent validation of new grid storage technologies from basic materials and components, through prototyping,

GSL Capability

- ❑ **Validate:** Conduct independent testing of next-generation storage materials and systems (100kW/400kWh)
- ❑ **Accelerate:** Minimize risk and expedite the development of innovative technologies
- ❑ **Collaborate:** Establish a collaborative center connecting the DOE, R&D communities, and industry
- ❑ **Educate:** Offer standardized training programs for the next generation workforce for energy storage



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KETEP

Thank you

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