EERE- Incubator award; 1/2015-12/2016

"A Disruptive Concept for a Whole Family of New Battery Systems"

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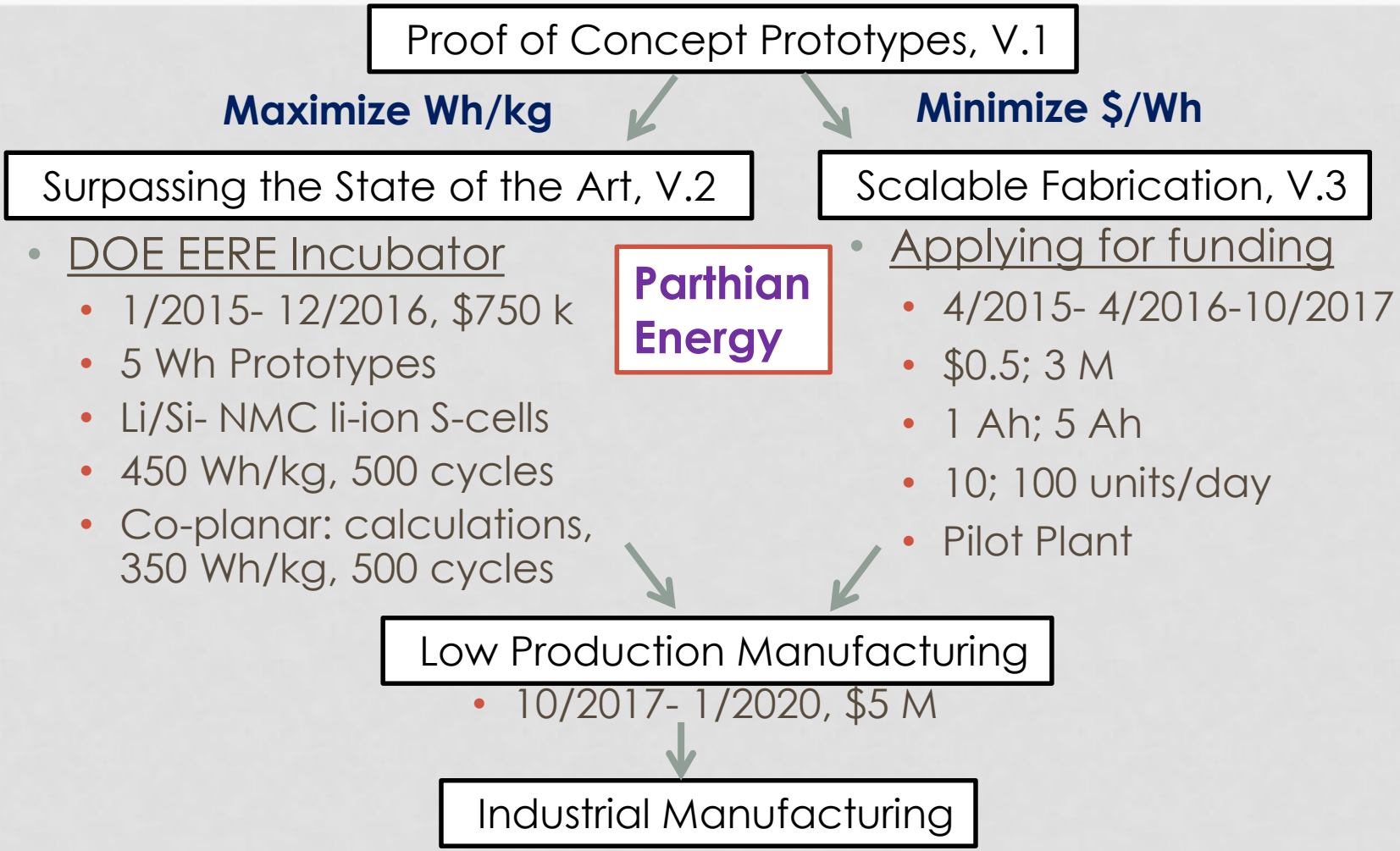
"This presentation does not contain any proprietary, confidential, or otherwise restricted information"

SUMMARY

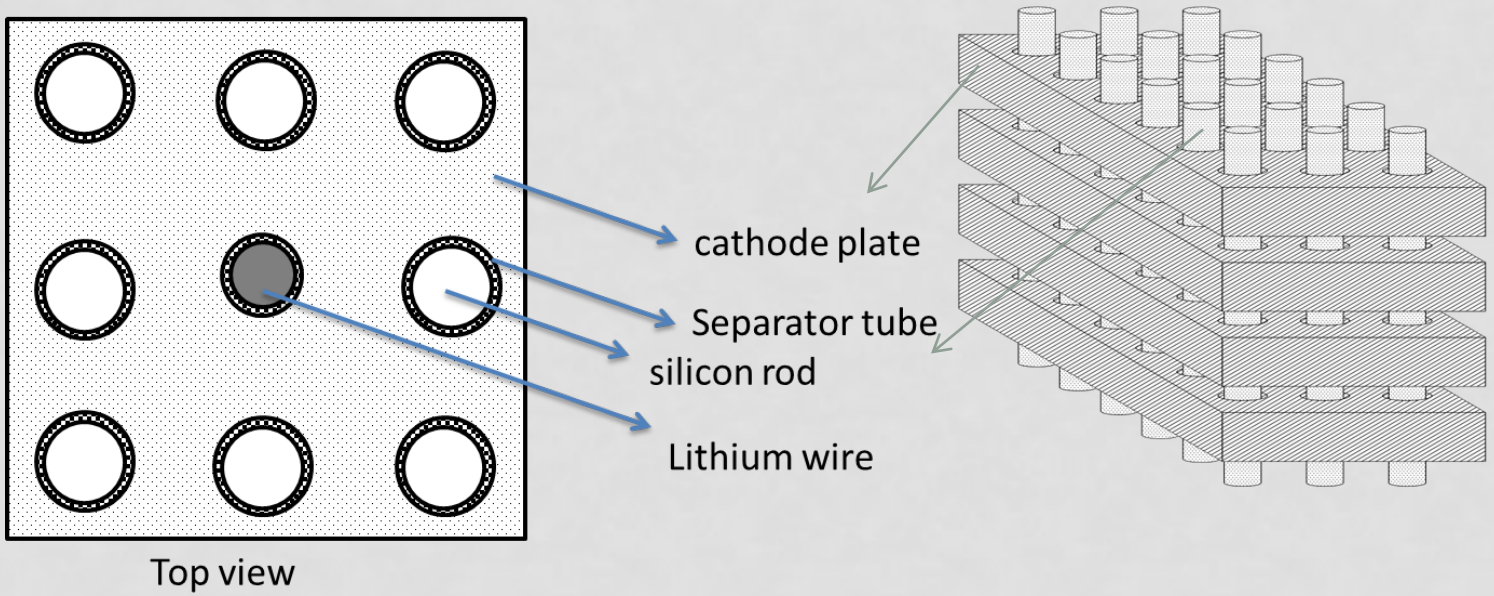
- **Completely Out-of-the Box!**
- Possibly Revolutionary!

- Novel Modular Architecture for Electrochemical Cells-Packs
- A radically unique architectural design, S-cell,
- Replaces the traditional coplanar "cell and module" designs with "scalabe modules" of higher performance
- Chemistry agnostic: Any Battery
- 5 US and International Patents, Caltech

ROADMAP


Proof of Concept Prototypes, V.1
Maximize Wh/kg
Minimize $/Wh
Surpassing the State of the Art, V.2
Scalable Fabrication, V.3
DOE EERE Incubator
1/2015- 12/2016, $750 k
5 Wh Prototypes
Li/Si- NMC li-ion S-cells
450 Wh/kg, 500 cycles
Co-planar: calculations, 350 Wh/kg, 500 cycles
Parthian Energy
Applying for funding
4/2015- 4/2016-10/2017
$0.5; 3 M
1 Ah; 5 Ah
10; 100 units/day
Pilot Plant
Low Production Manufacturing
10/2017- 1/2020, $5 M
Industrial Manufacturing

ARCHITECTURAL CONCEPT



Hybrid S-cell with silicon anode (slow discharge, fast charging) and lithium anode (fast discharge, slow charging). Also, enabling non-lithiated cathode and anode materials.

FABRICATION METHOD, VERSION 1

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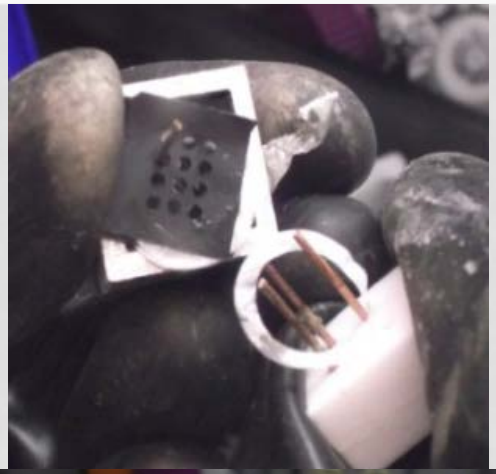
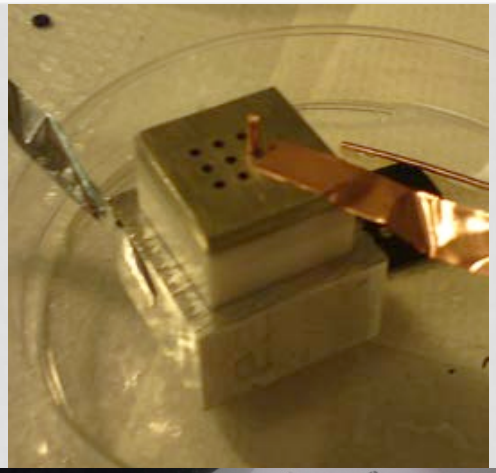
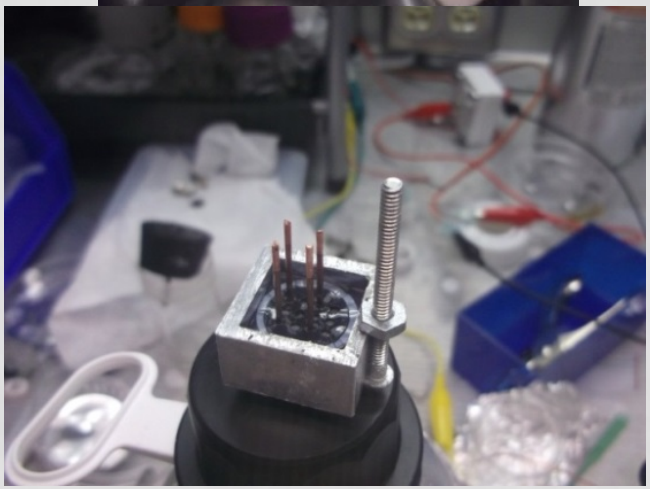
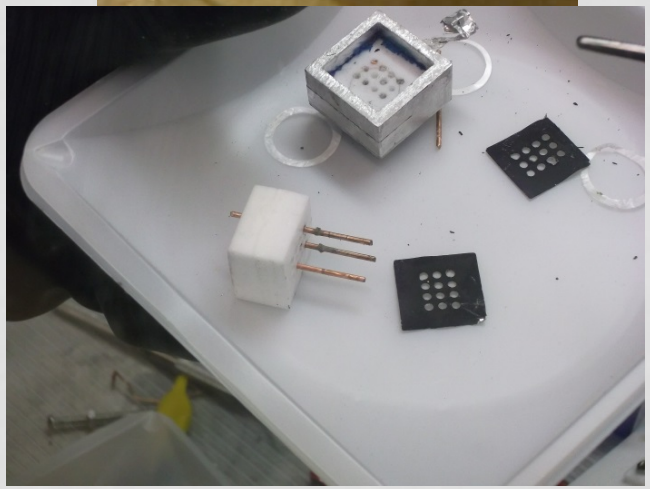
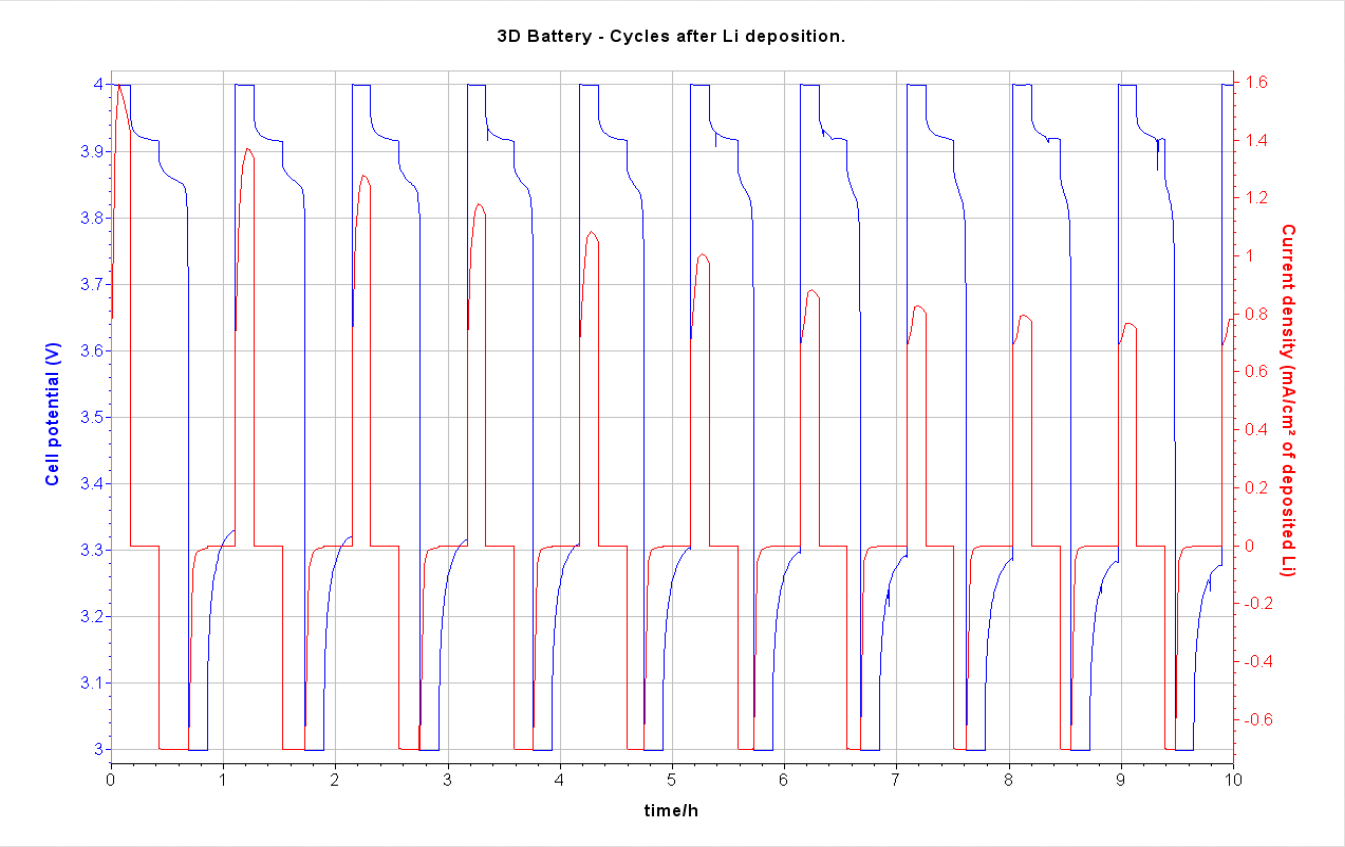






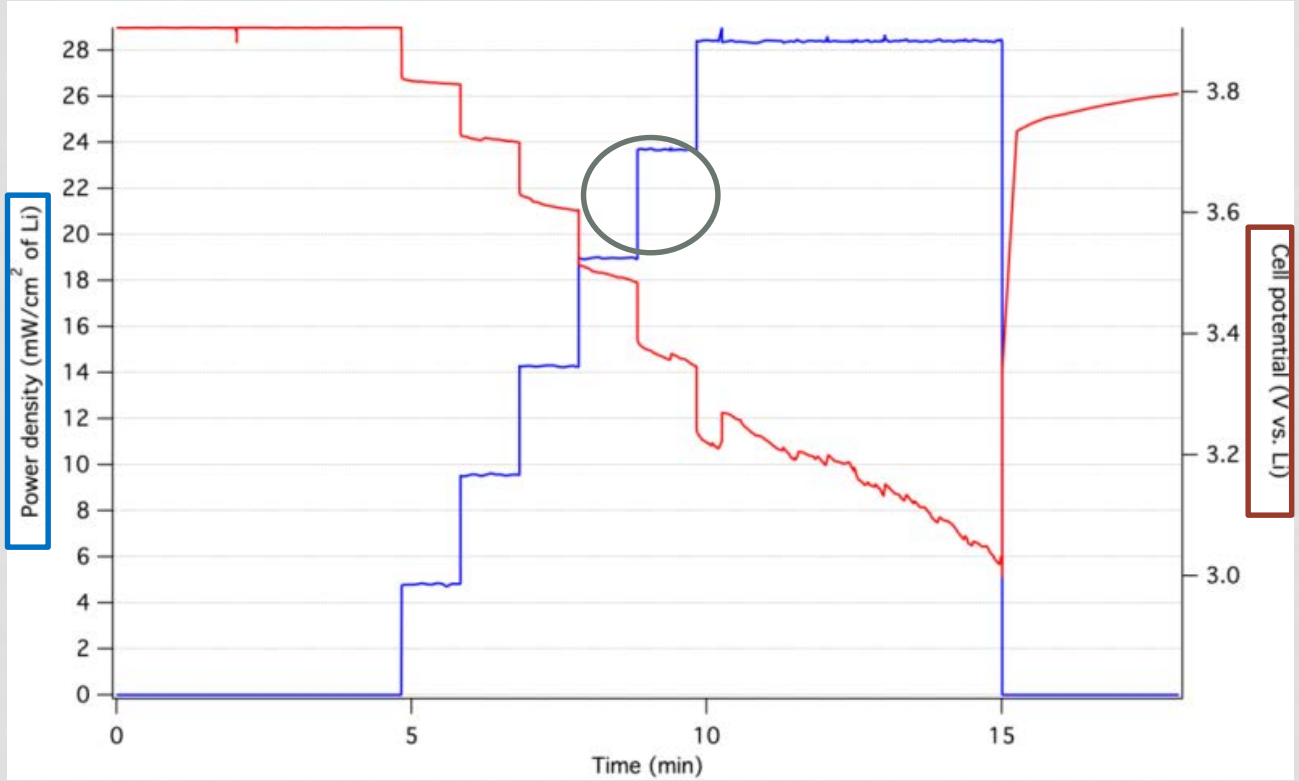


PROOF OF CONCEPT



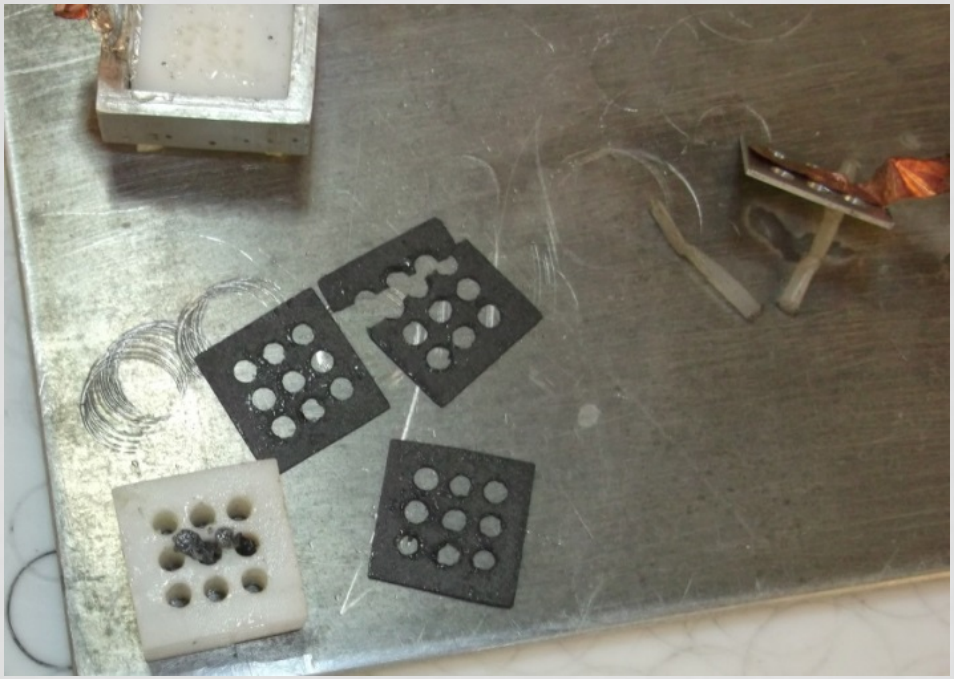
Copper–$LiCoO_2$ experiment: no formation cycling was done.

PROOF OF CONCEPT



Lithium–$LiCoO_2$ experiment: Discharge rate and power of about 10 mA/cm² and 30 mW/cm² of anode rod was possible even though the distance between the rod and plates can be as high as 1 mm. Note: other 3d batteries: 1 mW/cm², not scalable, only nano.

PROOF OF CONCEPT



Lithium–Oxygen experiment: Electrolyte was Merck LP 71 with no additional additives, no catalysts.
May increase the rate of metal-air batteries by an order of magnitude.

CONCLUSION

S-cell to traditional coplanar ≡ Li-ion to Alkaline

Architecture, 2020 Chemistry, 1990

SUMMARY

- DOE EERE Incubator
  - 1/2015- 12/2016, $750 k
  - 5 Wh Prototypes
  - Li/Si- NMC li-ion S-cells
  - Goal: 450 Wh/kg, C/3, 500 cycles
  - Commercial silicon powder
  - Growing silicon or Silicon slurry
  - Commercial cathode plates, electrolyte

DELIVERABLES

D1: Final TEA results summary

D2: Potential next-stage funding sources engaged

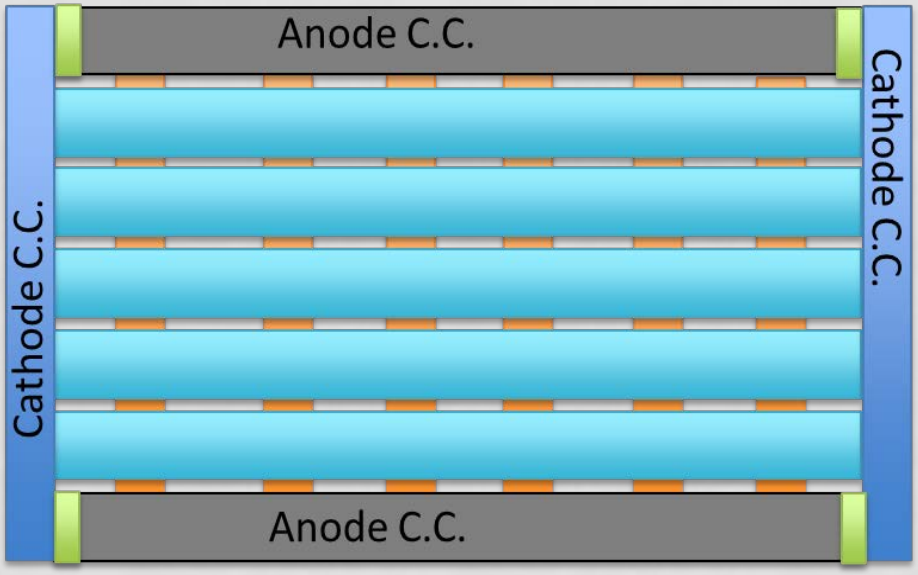
D3: Report of perforated plate electrode fabrication and testing

D4: Report of rod electrode fabrication and testing

D5: Report of S-cell fabrication and testing + 10 Sample S-cells

D6: Final report and 5 Wh sample S-cells

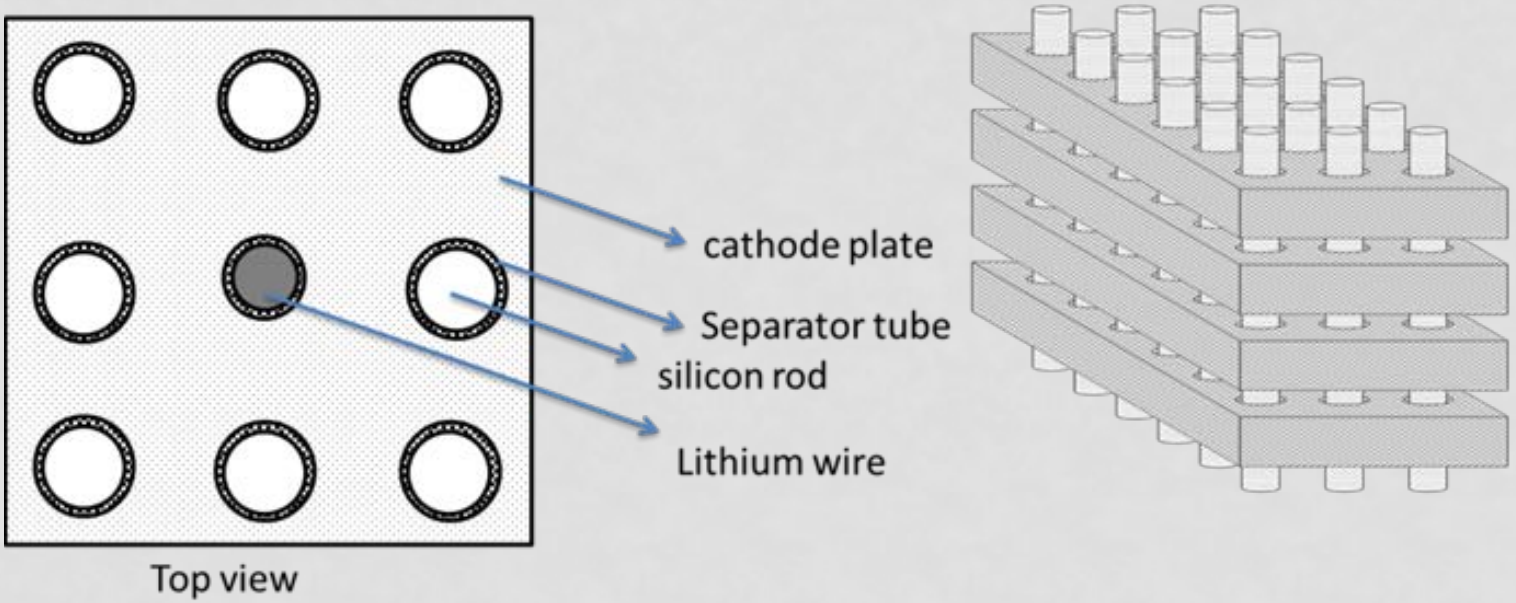
POWERING MID-SIZE PEV



Proposed S-cell may deliver 125 Wh, (10, 10,1cm) (250 gr).

100 units of this S-cell may power a mid-size PEV to run for 50 miles (Total: 15 L, 30 kg).

LI-ION LOSS PREVENTION



The presence of auxiliary lithium rods can compensate for the lithium-ion loss.

TUNABLE ARCHITECTURE

Rods Radius [cm]	Pitch (c-c) [cm]	Total # holes	Cathode mAh/ cm height	Anode mAh/cm height	Wh/cm height	Wh/L	Wh/kg
0.05	0.22	2116	33356	33221	123	1016	484
0.1	0.43	529	33356	33221	123	1016	484
0.2	0.83	144	32765	36173	121	1002	477
0.3	1.25	64	32765	36173	121	1002	477
0.4	**1.67**	**36**	**32765**	**36173**	**121**	**1002**	**477**
0.5	2.00	25	32150	39250	119	983	468

Proposed S-cell, assuming 1000 mAh/g for lithium-silicon anode and 200 mAh/g for NMC cathode. State of art, Panasonic 18650, is 570 Wh/L and 210 Wh/Kg.

1-TECHNOLOGY TO MARKET

Deliverables:

D1: Final TEA results summary

D2: Potential next-stage funding sources engaged

1-1 Techno-Economic Analysis (TEA); FY1M1-FY1M6

1-2 Pursue Next-Stage Funding; FY1M6-FY1M12

2-FABRICATION AND DEVELOPMENT

- Fabrication of the individual rod electrodes and perforated plate electrodes and also developing the techniques
- FY1M1-FY2M3

- Current Collectors and Case
- Rod Electrode Manufacturing
  - Silicon slurry vs. Silicon growth
  - Pick and Place; Spacer instead of separators; Guides
  - Developing "In-Situ" Techniques: separator hollow rods and electrode rods

2-FABRICATION AND DEVELOPMENT OF S-CELL

Deliverables:
D3: Report of perforated plate electrode fabrication and testing
D4: Report of rod electrode fabrication and testing
D5: Report of S-cell fabrication and testing + 10 Sample S-cells

2-1 Novel Rod Electrode Fabrication; Si/Li; FY1M1-FY1M6
2-2 Conventional Rod Electrode Fabrication; FY1M1-FY1M6
2-3 Perforated Plate Fabrication; FY1M3-FY1M9
2-4 S-cell Fabrication and Development; FY1M3-FY1M12
2-5 Half S-cell: Novel Rod Electrode; Si/Li; FY1M3-FY1M12
2-6 Half S-cell: Lab-developed Rods; Si/Li; FY1M3-FY1M9
2-7 Half S-cell: Perforated Plates; NMC & $LiFePO_4$; FY1M6-FY2M3

3- FULL S-CELL TESTING, LITHIUM-SILICON/NMC-LIFEPO$_4$

- Optimized S-cells with NMC cathode perforated plates and silicon anode rods and lithium rods
- 450 Wh/Kg; 500 cycles
- FY1M9-FY2M12

3- FULL S-CELL TESTING, LITHIUM-SILICON/NMC-LIFEPO4

Deliverables:

D6: Final report and 5 Wh sample S-cells

3-1 Testing S-cells, Lab-method Fabricated, Lithium-Silicon/NMC-$LiFePO_4$; FY1M9-FY2M3

3-2 Testing S-cells, Industrially Fabricated, Lithium-Silicon/NMC-$LiFePO_4$; FY2M3-FY2M9

3-3 Full S-cell testing, 450 Wh/kg; FY2M6-FY2M12

ESTIMATED ROADMAP TO COMMERCIALIZATION