CHANGING WHAT'S POSSIBLE

ARPA-E perspectives on solid-ion conductors

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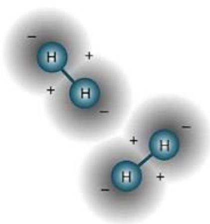
Note: The purpose of this workshop is to inform the research community of an area of interest to ARPA-E and to obtain input on leading technical approaches. However, no targeted program in this area is currently under development.

Outline

- **Importance of solid ion conductors, our activities so far.**
- Workshop goals and your role.

Chemical reactions are energy currency



H_2 (gas)

Na (solid, liquid)

CH_4 (gas)

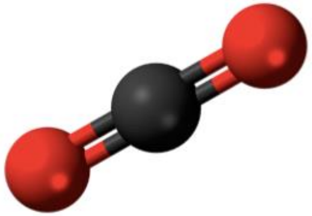
H_2O (liquid, gas)

Li (solid)

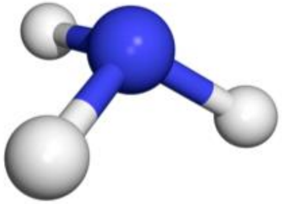
Mg (solid, liquid)

C_6 (solid)

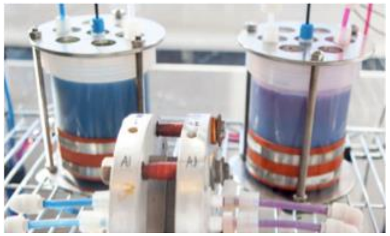
O_2 (gas)



CO_2 (gas)



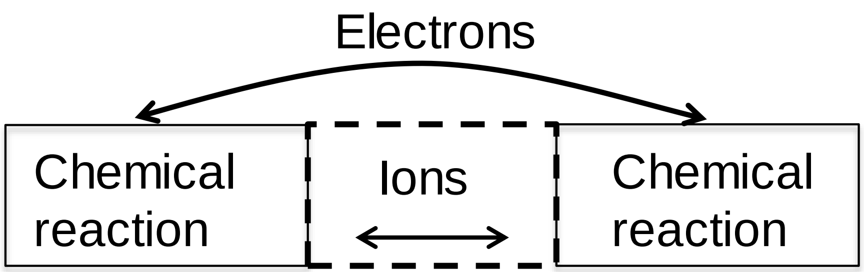
NH_3 (gas)



Quinones (liquid)

Synthesis | Separations | Batteries | Fuel cells | Other

Reactions can be electrochemical



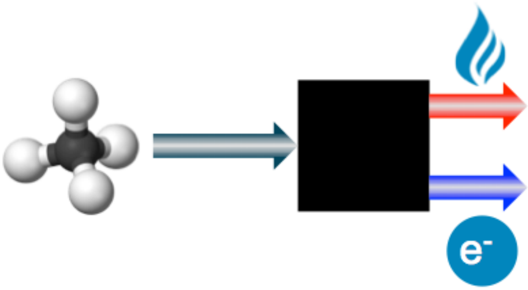
<u>Solid</u> ion conductors are versatile

- Block gases, liquids, and solids
- Chemical stability
- Mechanical integrity

Solid ion conductors impact ARPA-E missions

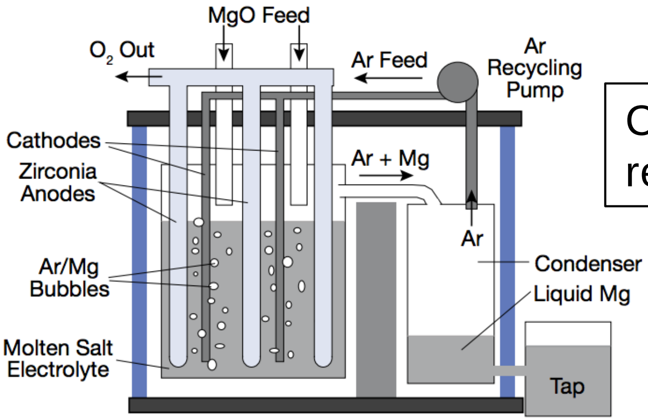
Energy storage
Solar & wind to >20%

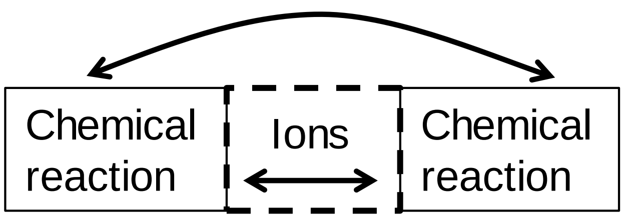
Distributed generation
60 quads of thermal energy



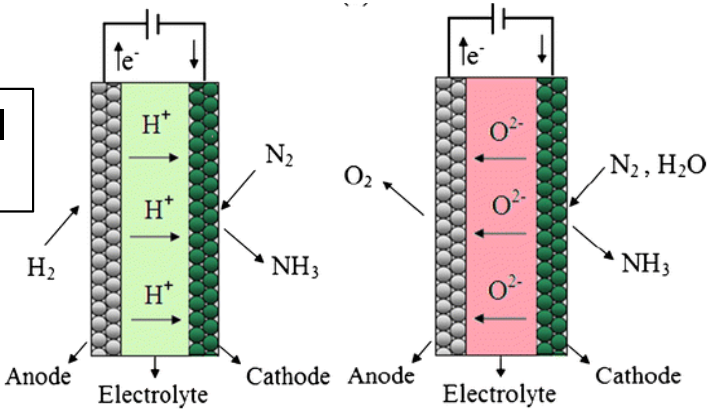
Electric vehicles and fuel cells
16 quads of oil

Electrosynthesis: light metals
>1 quad from making and using





Electrosynthesis: NH_3
Distributed NH_3 production

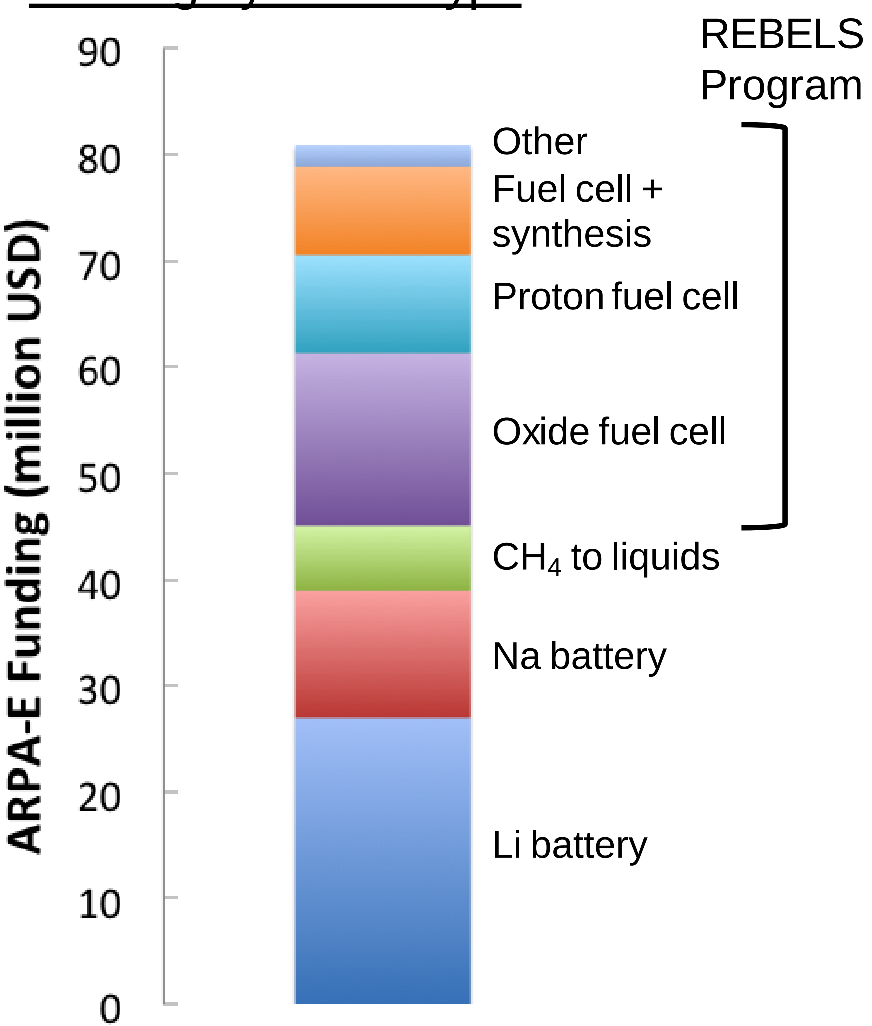


"Zero-Emissions Magnesium Process Debuts," Chemical Engineering Progress, March, 2014.
Amar et al., "Solid-State electrochemical synthesis of ammonia: a review," J. Solid State Electrochem.,

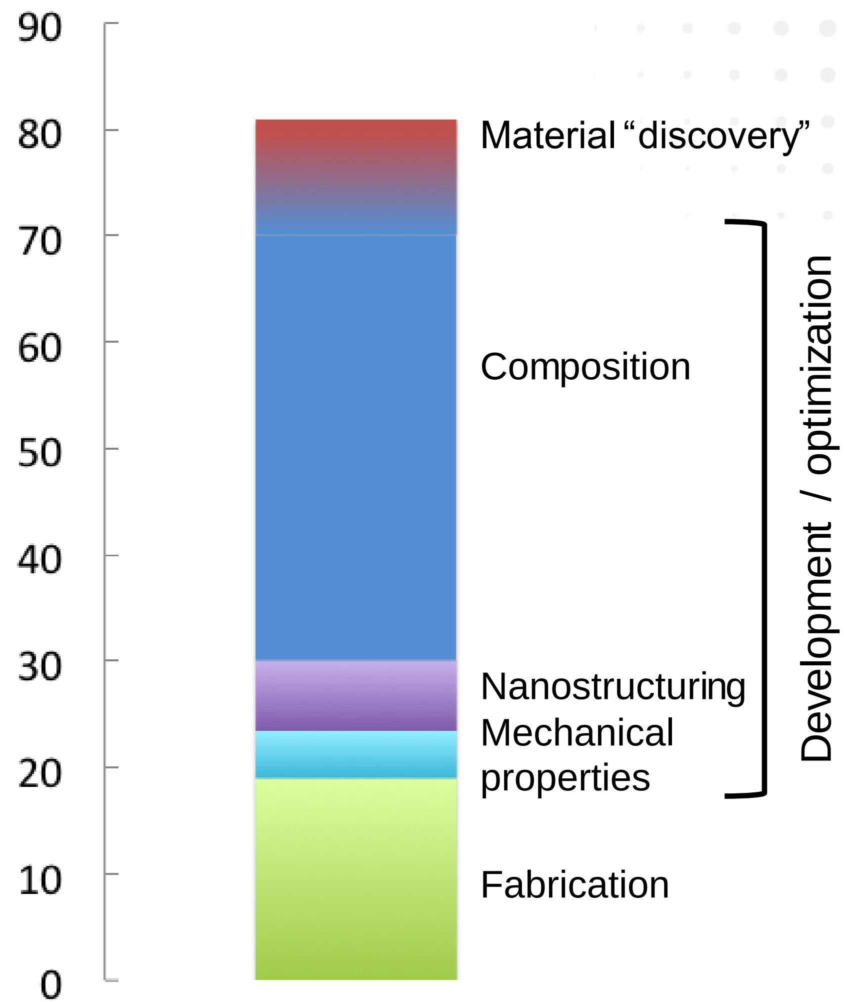
Solid ion conductors have long-term importance for ARPA-E.

ARPA-E has already invested ~$80M

Funding by device type

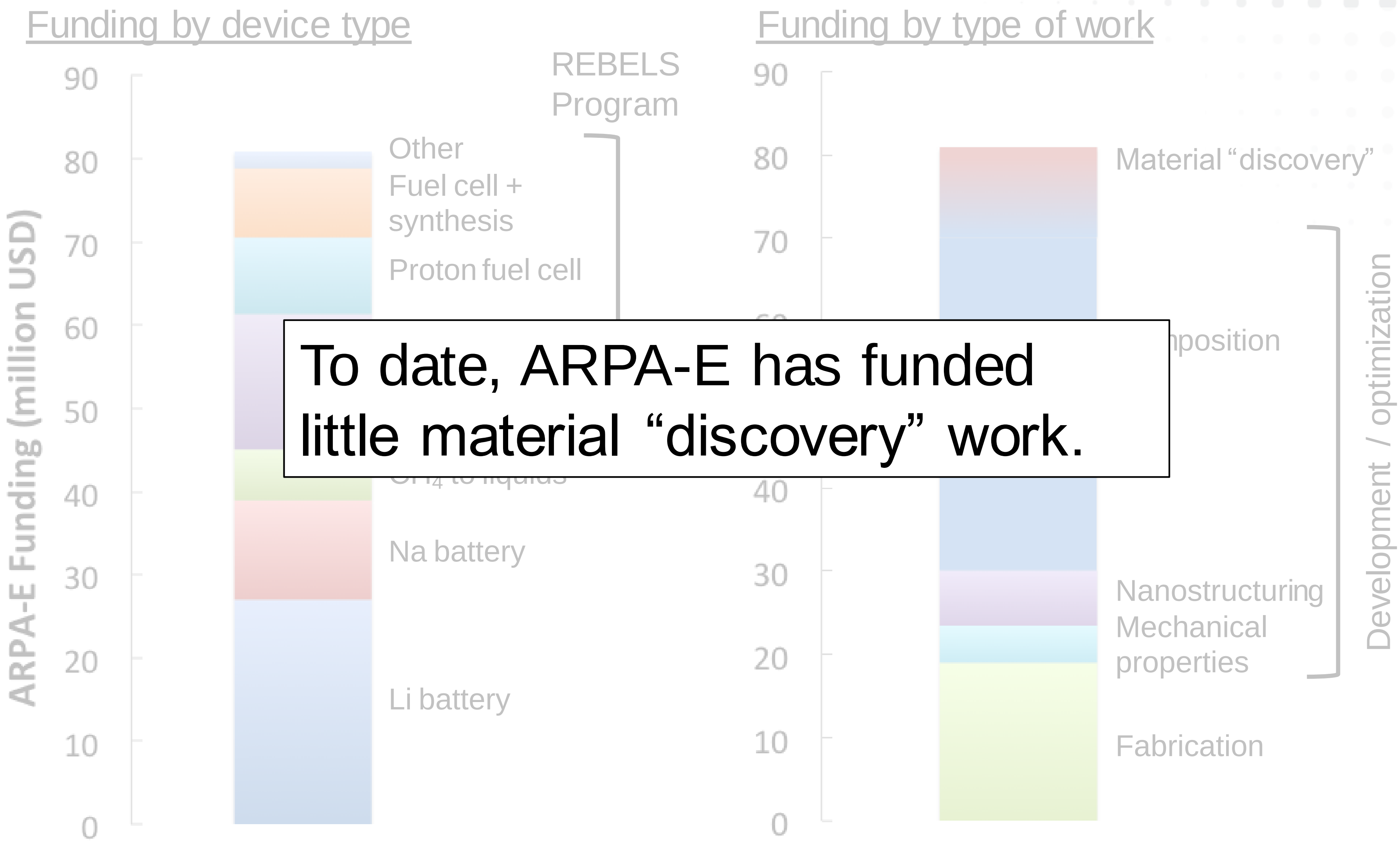


Funding by type of work



Note: funding levels shown are totals for projects making use of solid ion conductors, not the amounts for the solid ion conductor work alone.

ARPA-E has already invested ~$80M



To date, ARPA-E has funded little material "discovery" work.

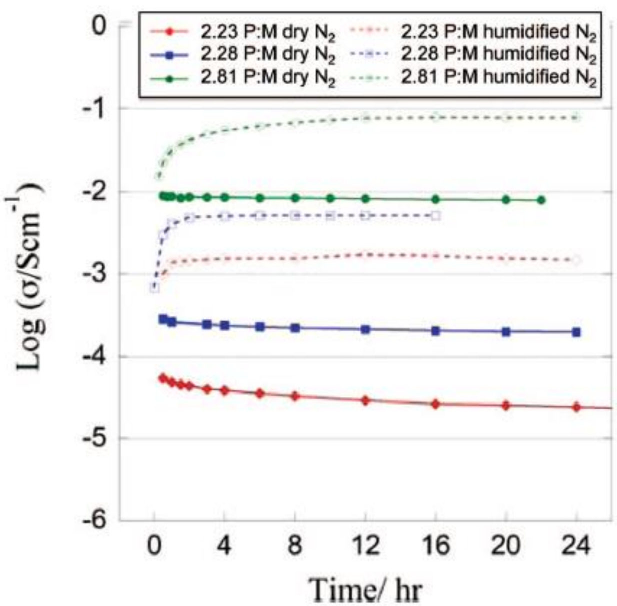
Note: funding levels shown are totals for projects making use of solid ion conductors, not the amounts for the solid ion conductor work alone.

Example: $Sn_{0.9}In_{0.1}P_2O_7$ proton conductor

- Material first reported in 2006 at Nagoya Univ. (Prof. Hibino).
- Picked up by LANL for further development.
- ARPA-E funded under OPEN 2012 for further development and transfer to Ceramatec for scale up.

PROJECT DETAILS

- Targeting 250°C operation.
- Benefits compared to standard PEM:
  - Lower PGM loading
  - Simpler balance of plant
  - Better fuel tolerance
- 0.1 S/cm shown at 250°C
- Polymer/ITPP composites are being scaled up.



Conductivity of $Sn_{0.9}In_{0.1}P_2O_7$ with varying P:M at 250°C in dry and humidified N_2 (pH_2O = 0.04 bar)

Kreller et al., ECS Electrochem. Letters, 2 (9), F61-F63.

ARPA-E's role in materials

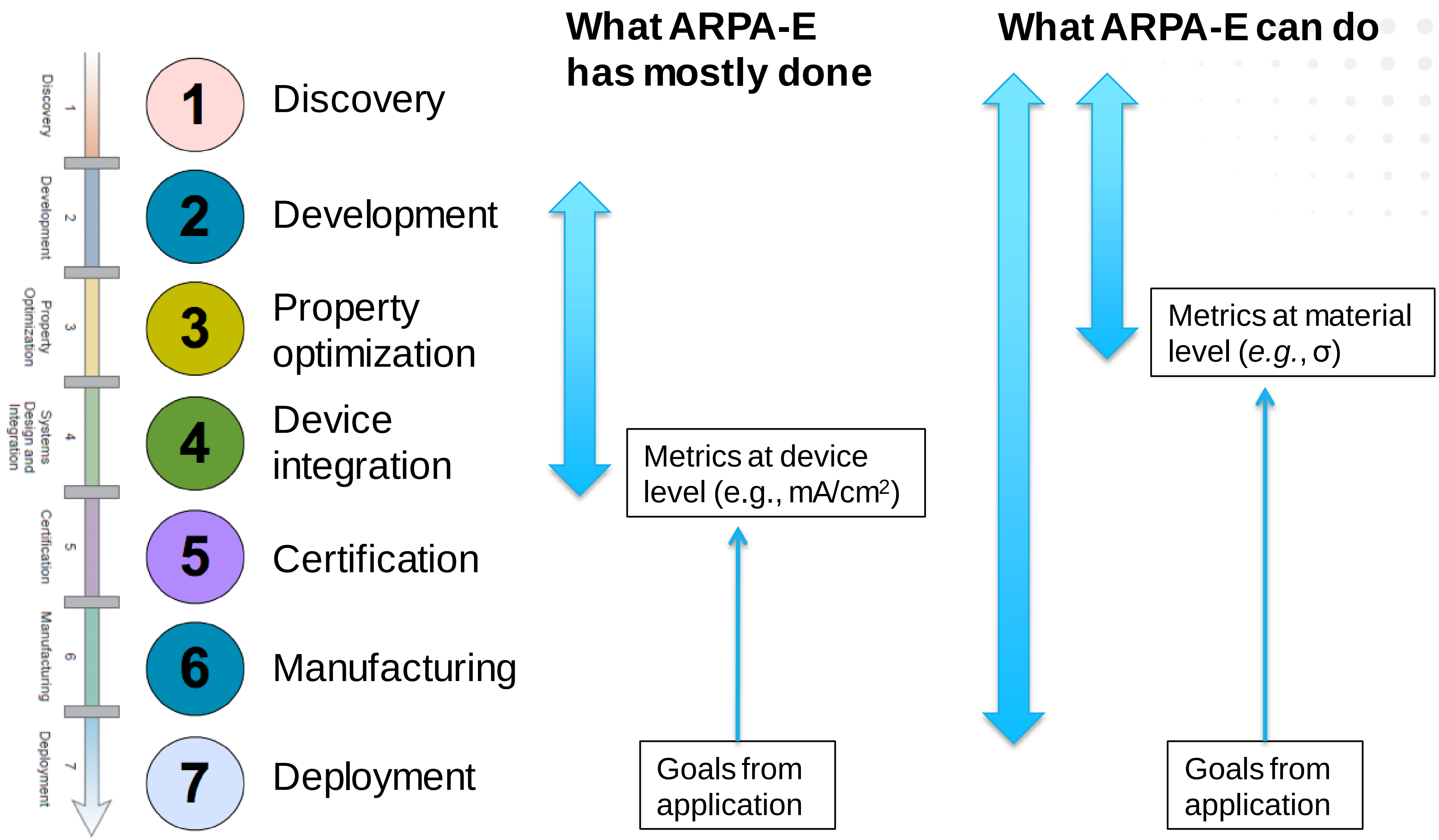
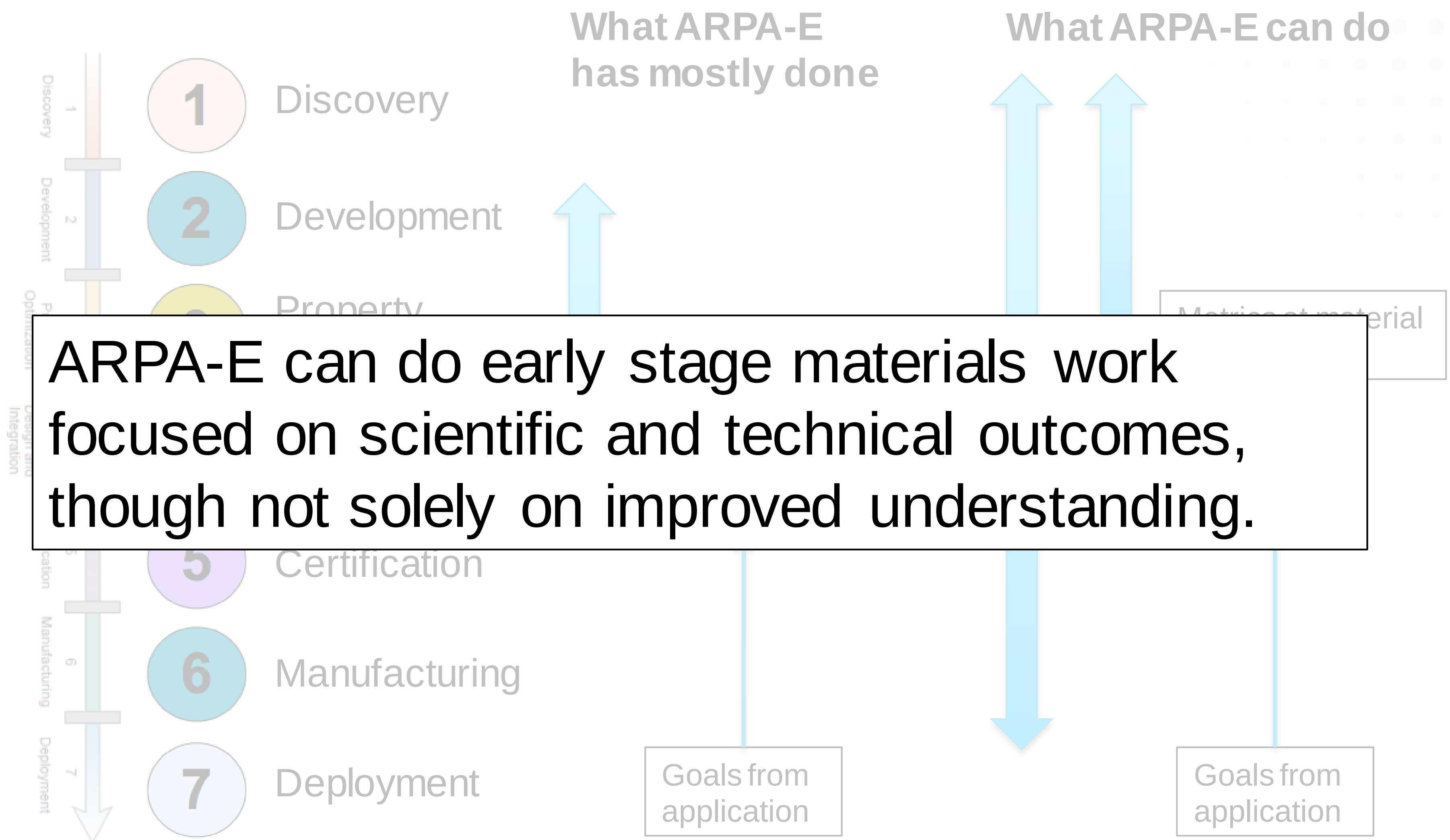


Image: http://www.whitehouse.gov/sites/default/files/docs/microsites/mgi/wadia_mgi_talk.pdf

ARPA-E's role in materials



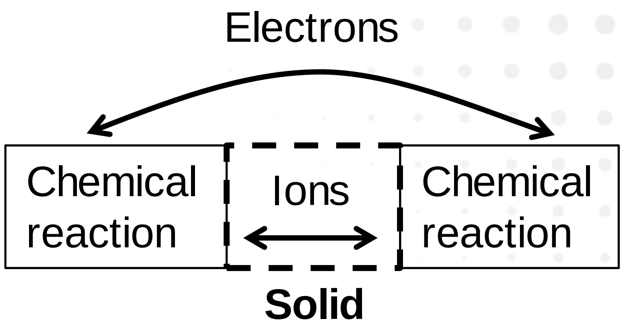
ARPA-E can do early stage materials work focused on scientific and technical outcomes, though not solely on improved understanding.

Image: http://www.whitehouse.gov/sites/default/files/docs/microsites/mgi/wadia_mgi_talk.pdf

Our proposed problem statement

ARPA-E constraints

1. Electrochemical cell
2. ***Solid*** ion conducting layer
3. Off roadmap of NSF, DOE



Proposal requirements

1. Tell us the application and impact
2. Tell us where you want to start and end

Expected approaches

Category 1:	Category 2:	Category 3:
New materials	New approaches using existing materials	Other

Takeaway messages

- Solid ionic and mixed ionic/electronic conductors enable compartmentalized electrochemical reactions and are of long-term interest for ARPA-E.
- We have mostly focused on materials development leading to devices with standard architectures.
- We are exploring technical opportunities to expand the set of approaches and materials.

Outline

- Importance of solid ion conductors, our activities so far.

- **Workshop goals and your role.**
  - What you give us today will help us decide whether and how to run a program in this area.

Many (small) successes over ~175 years

LARGE DEPLOYMENT

SMALL DEPLOYMENT

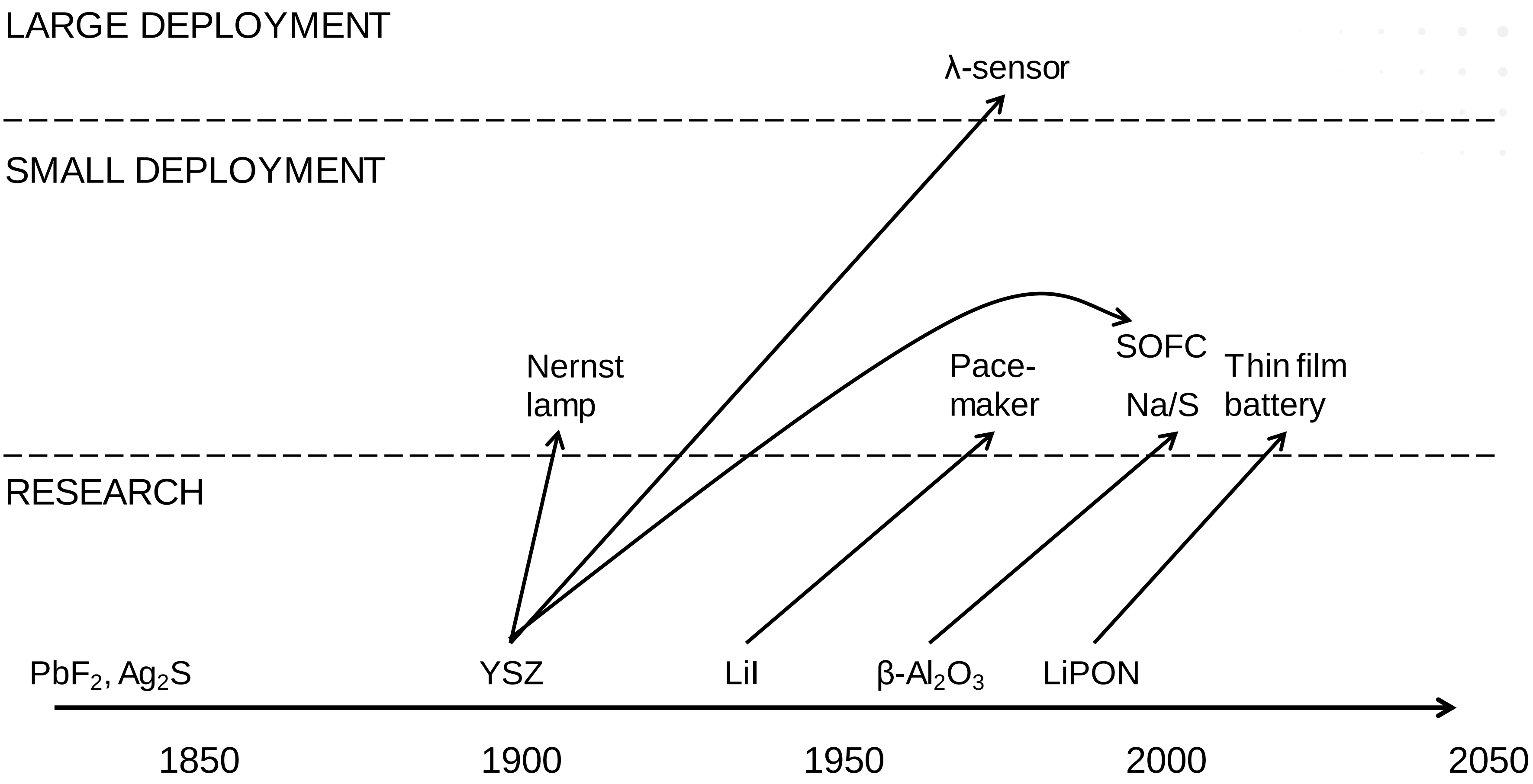
RESEARCH

PbF_2, Ag_2S

1850 1900 1950 2000 2050

Applications not shown: other sensors, electrochromics, etc.

Many (small) successes over ~175 years



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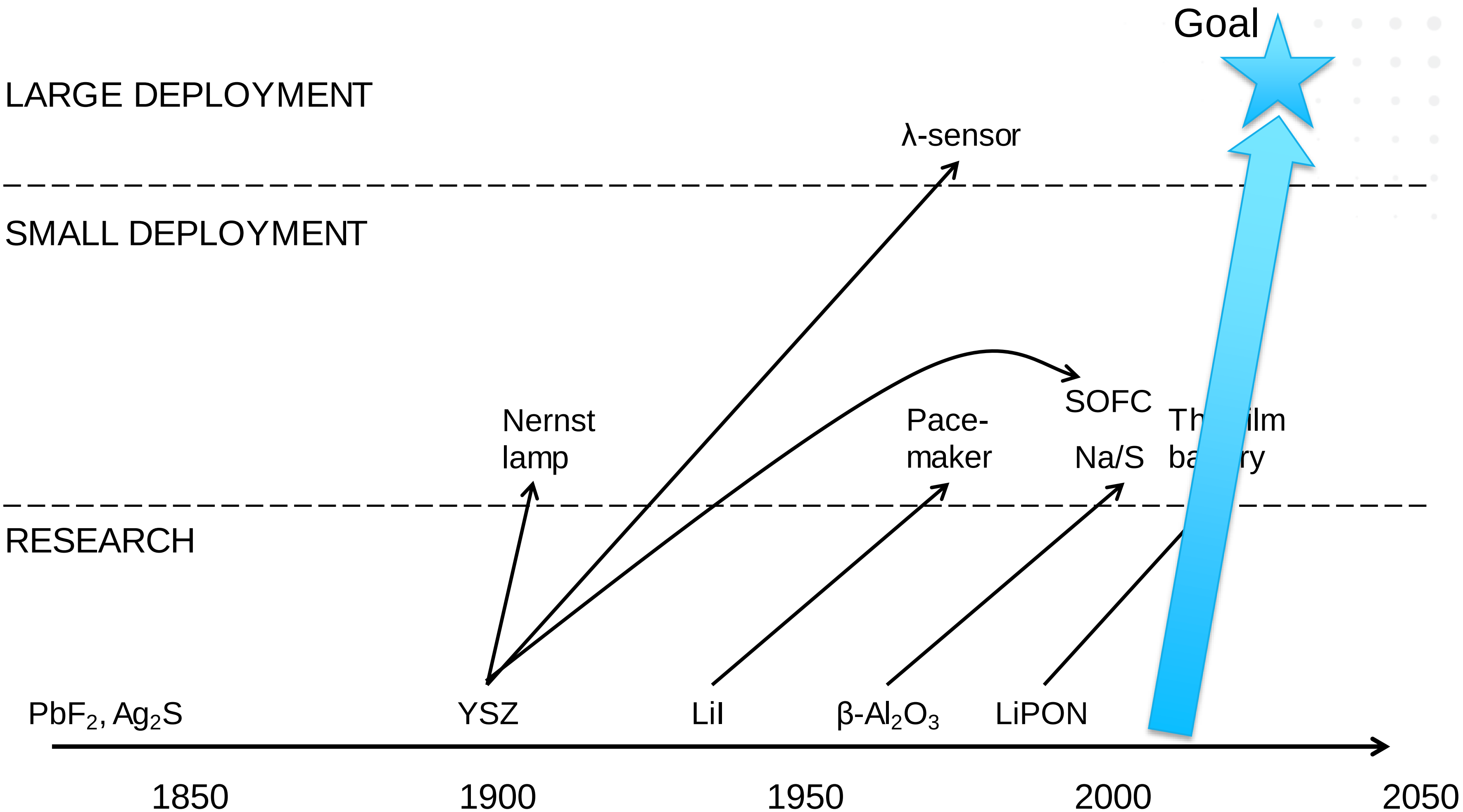

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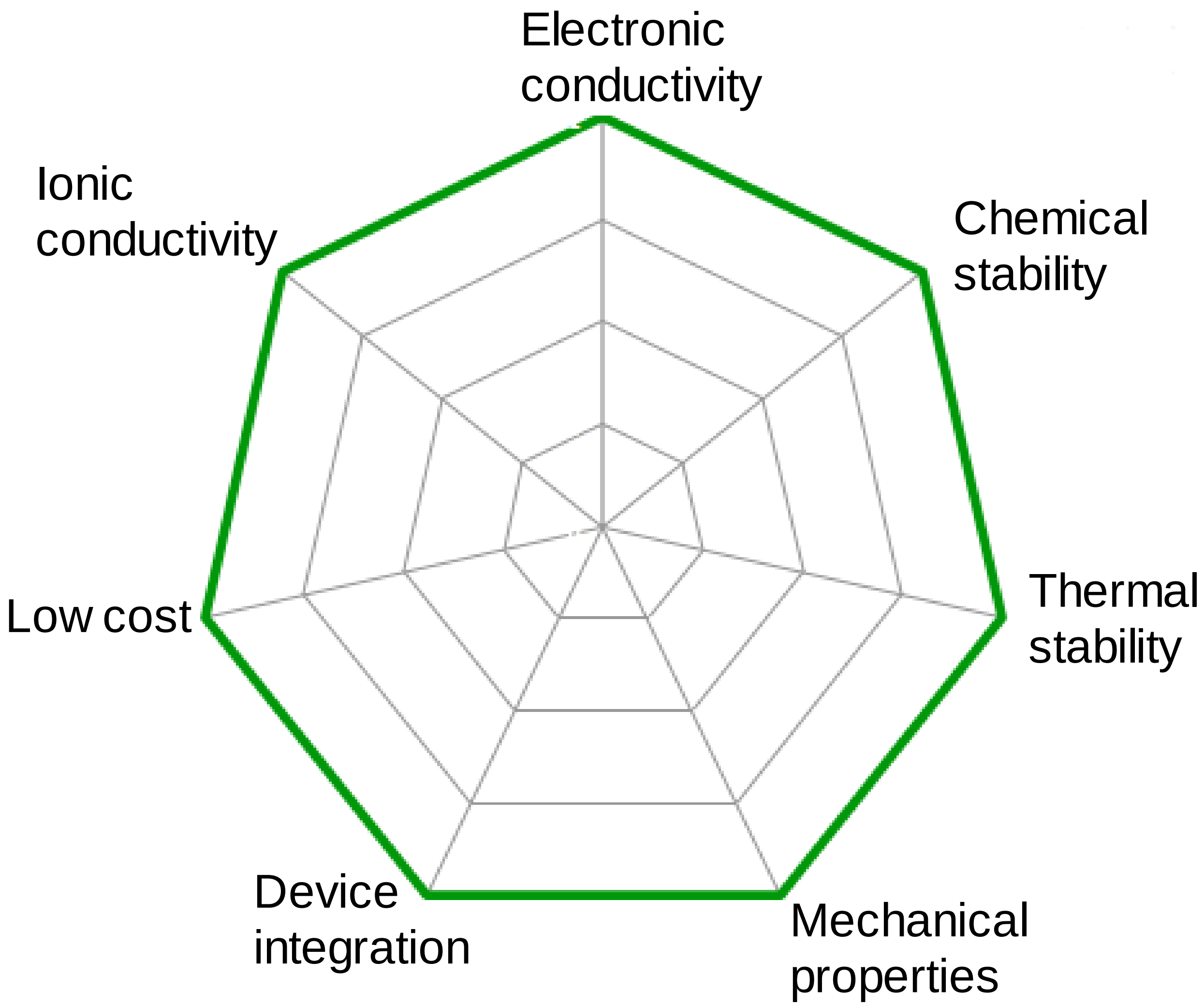
Breakout #1: Looking forward

- What would a material or approach need to look like to help us reach the goal of getting a solid ion conductor into large deployment?
  - Do we know the ideal structure of a solid ion conductor, ignoring constraints?
  - How should we think about the limits of what can be achieved by solid ion conductors?
  - What are creative material end points?
  - What is an ideal way to make and integrate a solid ion conductor in a device?

Breakout #2: what we can draw on

- What tools and examples are available to us now that weren't available 5 years ago?
  - Examples: synthetic techniques, computations, characterization.
  - What can we learn from materials or fabrication processes with features we care about in unrelated areas?
  - What other communities of researchers or inventors should be engaged for our problem statement?

The material requirements are many



Additional comments to Paul.Albertus@hq.doe.gov

Questions