Oak Ridge National Laboratory

MODERATE-TEMPERATURE MOLTEN SALT ELECTROLYTE FOR AN ALUMINIUM-BASED BATTERY FOR ENERGY STORAGE

PI: C. Y. Kwok;[1] Vaidyanathan Sethuraman;[2] Mahalingam Balasubramanian;[1] Lei Cheng;[2] Mengya Li;[1] Guang Yang[2]
[1]Electrification and Energy Infrastructures Division, Oak Ridge National Laboratory, Oak Ridge, TN 37831, USA
[2]Chemical Sciences Division, Oak Ridge National Laboratory, Oak Ridge, TN 37831, USA

U.S. DEPARTMENT of ENERGY

Project Profile

Topic: Next Generation, Large Scale Energy Storage

Vertical: Materials and Systems Innovation

Strategic Pathway: Grow

Project start and finish: FY24 - FY27

Problem

Background

- Energy storage is needed across all time scales, from fast grid services to seasonal storage
- Batteries enable distributed energy resources to support a reliable, resilient, affordable, and flexible grid
- Data centers, AI technology, and advanced manufacturing increase the need for dependable infrastructure
- Diversifying battery chemistries reduce foreign supply-chain dependence and strengthen U.S. energy security

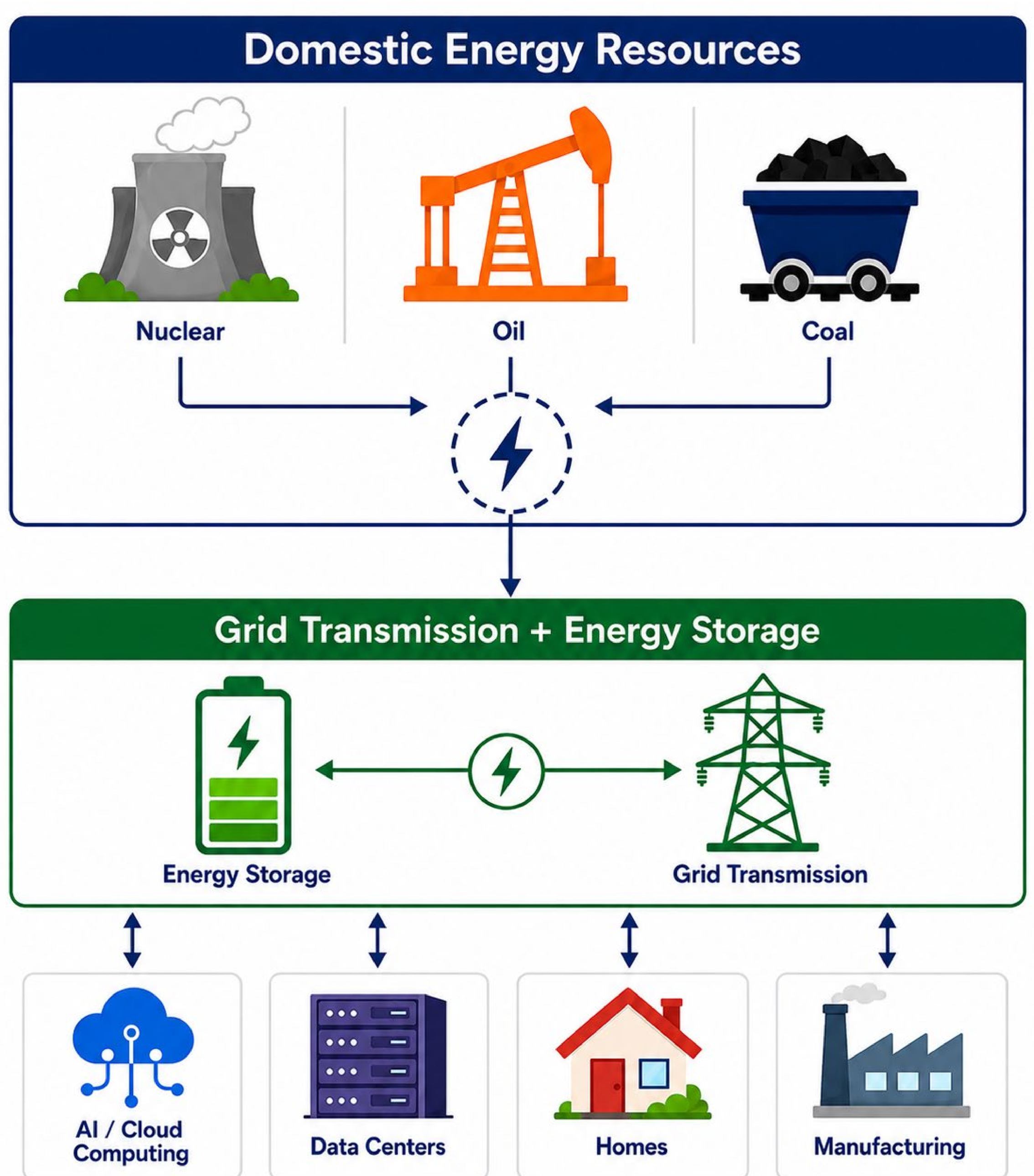


Fig. 1. Schematic diagram showing how energy storage connects domestic energy generation, grid transmission, and end-use demand in a distributed energy system

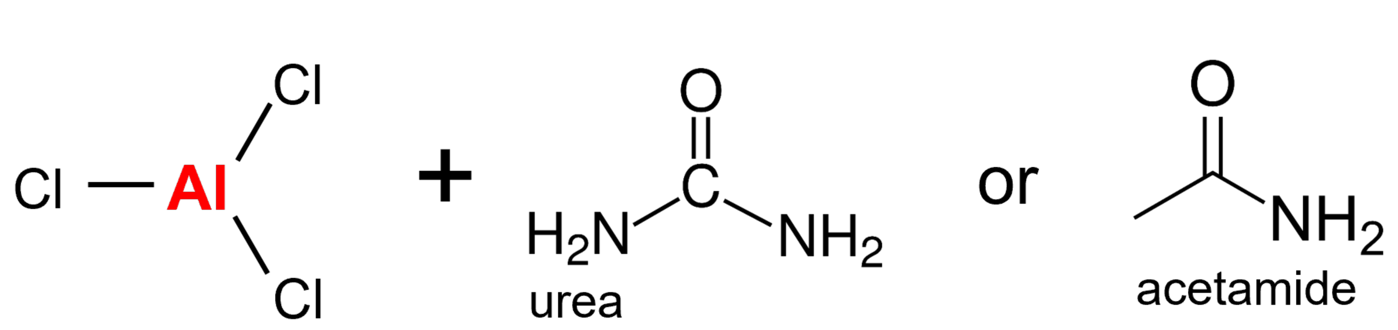
- Al-based batteries leverage low-cost domestic materials and U.S. manufacturing/recycling infrastructure

Limitations on State-of-Art Commercialized Battery Technologies

- Li-ion batteries rely on flammable electrolytes and critical materials, creating safety and domestic supply-chain concerns, respectively
- Redox flow batteries provide long-duration storage, but require large system footprints and costly active materials
- ZEBRA batteries (Na-$NiCl_2$) use chemically stable molten salt chemistry but require high temperature (~250 °C) and subject to supply-chain volatility

Approach

- Develop moderate-temperature Al-based molten salt electrolyte chemistry for all-duration grid storage
- Demonstrate a safe and cost-effective pathway toward durable grid storage



$$xAlCl_3 + n[\text{base}] \rightarrow [AlCl_2\text{-(base)}_n]^+ + [Al_xCl_{3x+1}]^-$$

Fig. 2. Molecular structures of the Al-based electrolyte constituents and representative reaction scheme to form chloroaluminate anions and $AlCl_2$-base cationic complexes

Conclusions & Impact

- Al-based molten-salt electrolytes provide a pathway to diversify grid-storage chemistries using low-cost, domestically abundant materials
- Coupling spectroscopy and modeling enables the design of safer, lower-cost, and more reliable batteries

Results: Electrochemistry

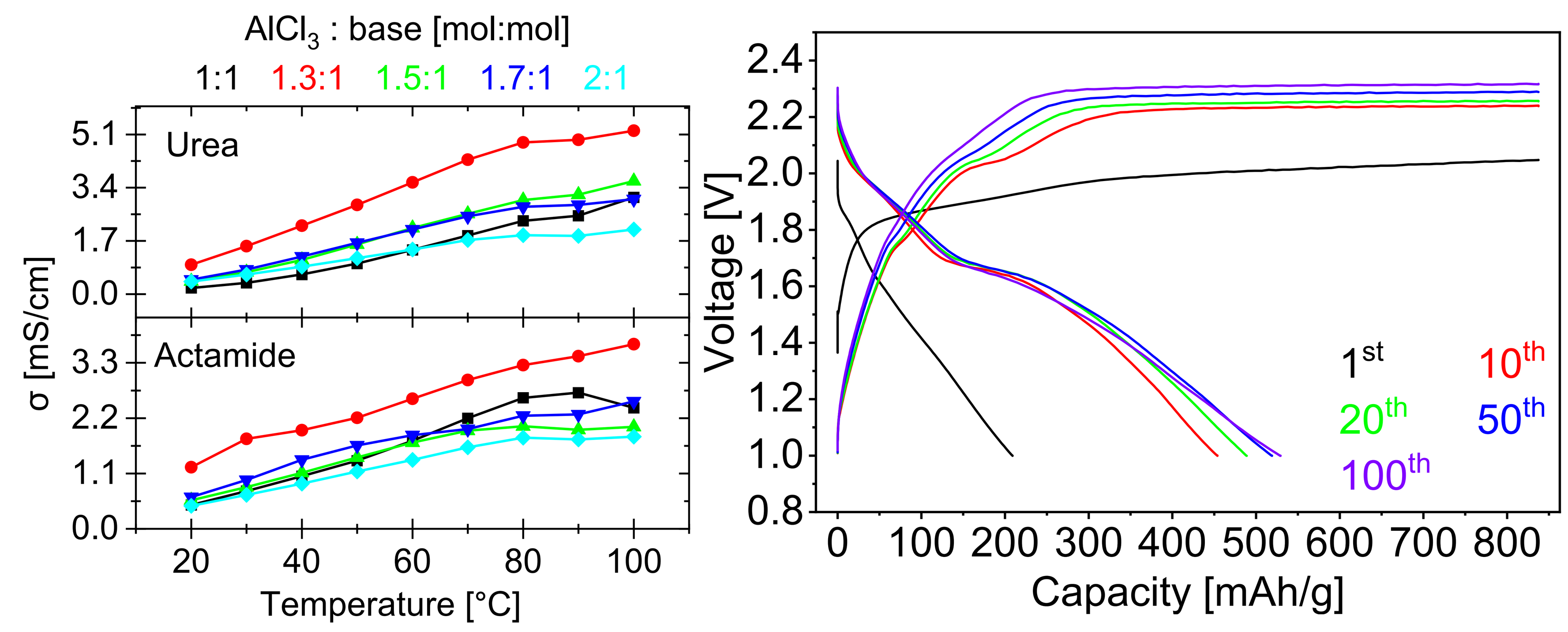


Fig. 3. (left) Ionic conductivity of two Al-based molten-salt electrolyte candidates (right) Prototype molten-salt Al–S cells using $AlCl_3$:urea = 1.3:1 electrolyte and sulfur oxidation pathways in development

- Moderate-temperature Al-based molten-salt batteries show promise for all-duration grid storage

Results: Advanced Characterization

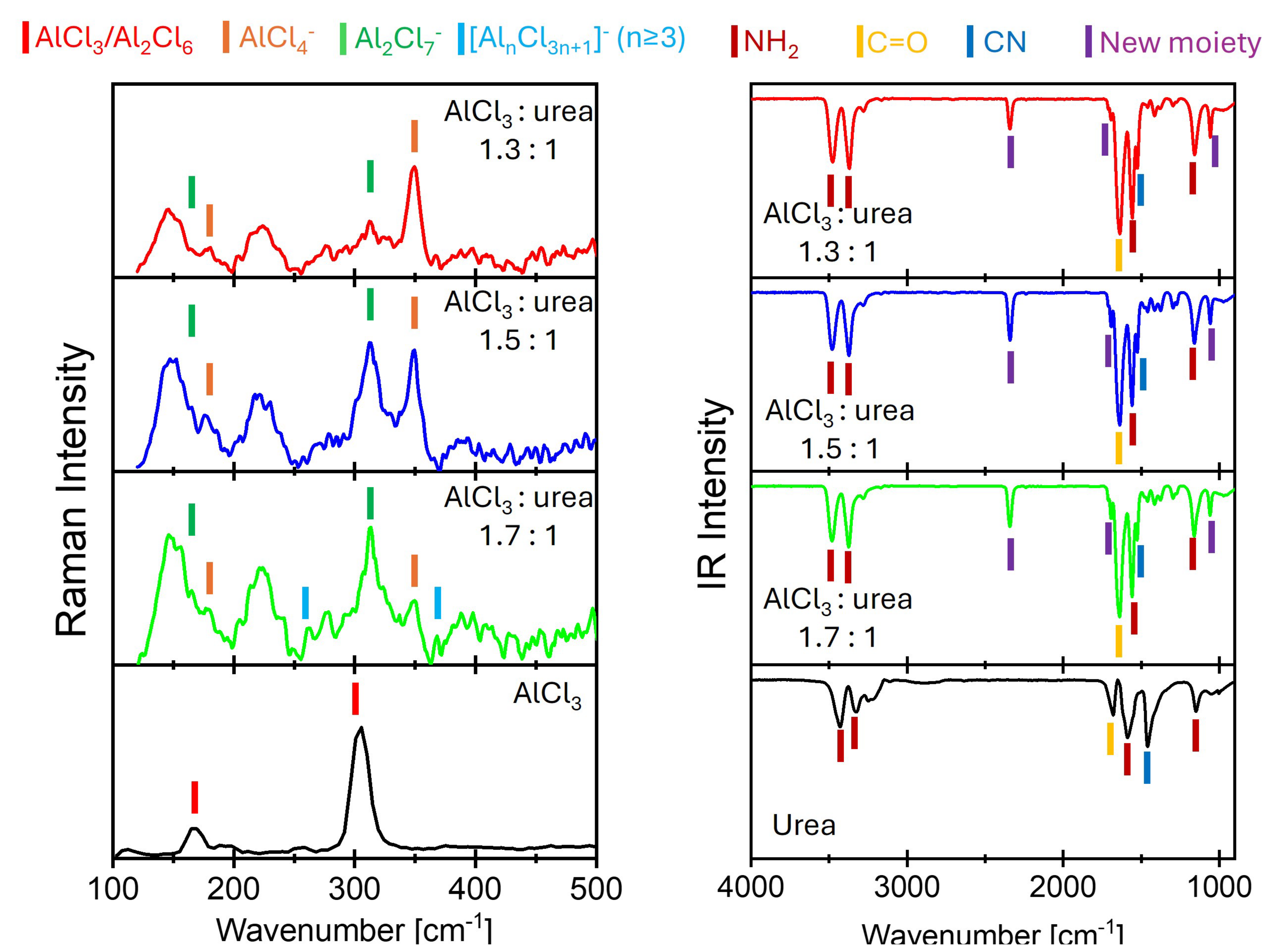


Fig. 4. Raman (left) and FTIR (right) spectra of $AlCl_3$-urea electrolytes identifying chloroaluminate transport species, $AlCl_3$-urea interactions, and possible $AlCl_3$-urea-derived species

- Electrolyte speciation and molecular interactions were identified using Raman and FTIR methods

Results: Computational Modeling

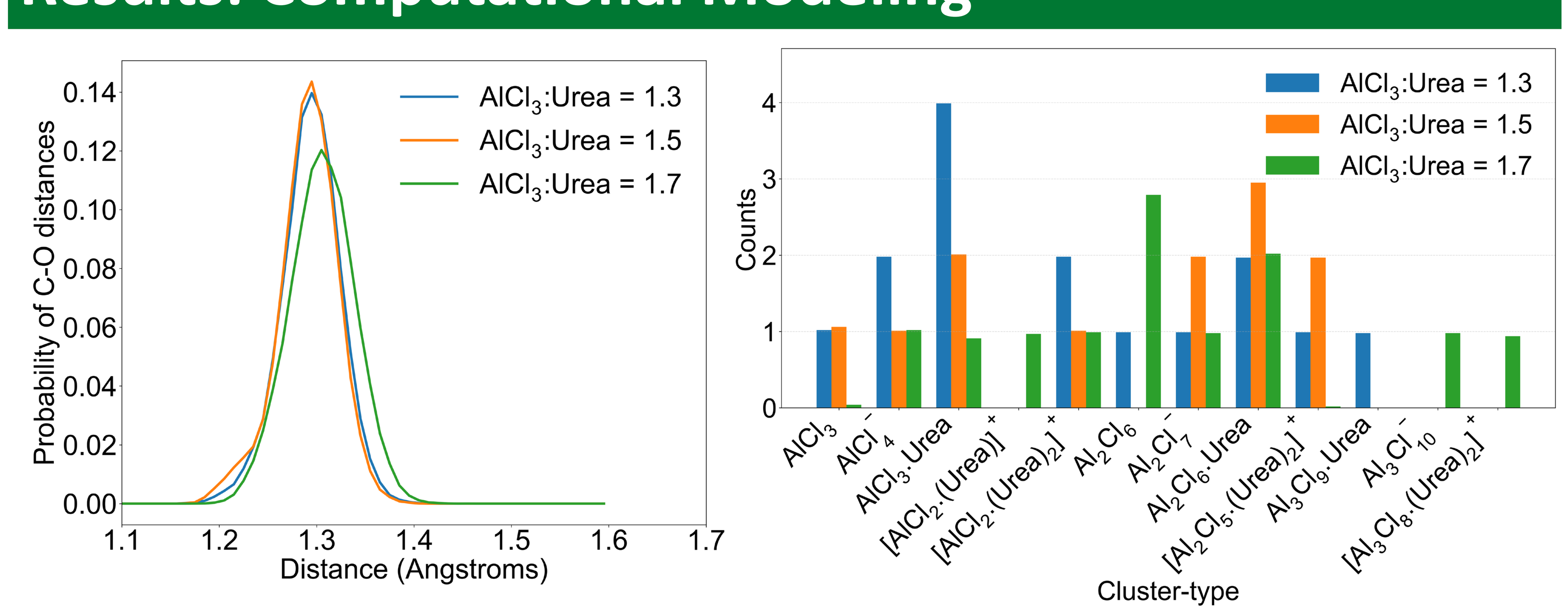


Fig. 5. AIMD analysis of $AlCl_3$-urea electrolytes showing carbonyl-related distance distributions, $AlCl_x$ speciation, and composition-dependent cluster formation

- Computational modeling and advanced characterization jointly reveal electrolyte speciation and coordination

Future Directions

- Improve cycling stability and reversibility toward durable Al-based energy storage devices for all-duration grid storage
- Advance Al-based molten-salt chemistry using low-cost, domestically abundant materials
- Scale electrolyte and cell designs toward safer, more cost-effective all-duration storage

This material is based upon work supported by the U.S. Department of Energy, Office of Electricity (OE), Energy Storage Division