MODELING OF CRITICAL MATERIAL SUPPLY CHAINS

ALLISON BENNETT IRION
Director, Supply Chain Research

19 JULY 2022

U.S. DEPARTMENT OF ENERGY
Argonne National Laboratory is a U.S. Department of Energy laboratory managed by UChicago Argonne, LLC.

Argonne NATIONAL LABORATORY

U.S. DECARBONIZATION GOALS

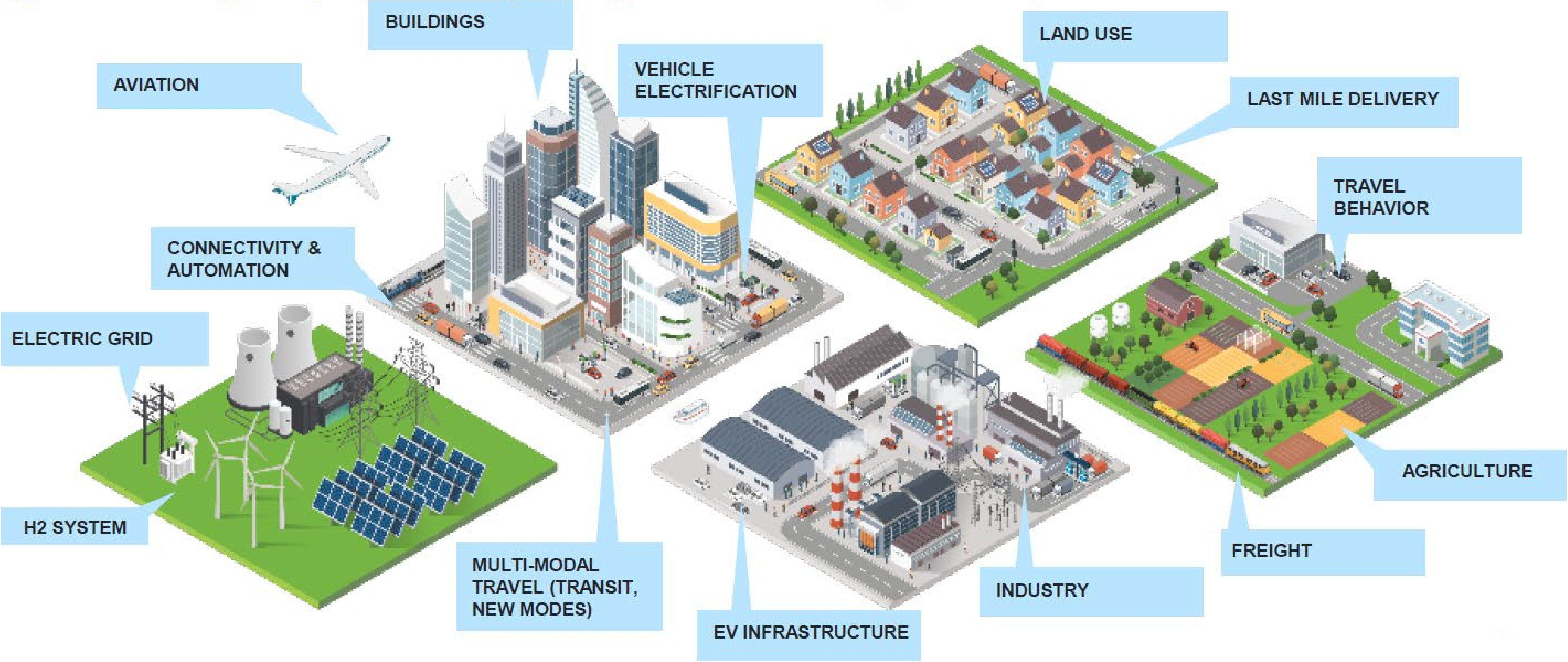
50% reduction GHG emissions from grid by **2030**

Fully decarbonized grid by **2035**

Net-zero economy by **2050**

A HOLISTIC APPROACH IS REQUIRED TO ACHIEVE AGGRESSIVE DECARBONIZATION GOALS

Multi-level, Multi-fidelity Framework Inclusive of all Metrics (e.g., energy, emission, greenhouse gases, economics, equity, environmental justice…)



CLEAN ENERGY SUPPLY CHAINS BROADLY

DOE's "Supply Chain Deep Dive" reports in response to E.O. 14017

- Identified vulnerabilities and opportunities for **11 energy industrial base technology supply chains** to decarbonize U.S. Economy
  - Widespread reliance on foreign countries for refined materials and intermediate products, not isolated to raw materials (*e.g. separation and refining of rare earth elements for magnets*)
  - Limited availability of certain materials to achieve climate goals under existing scenarios (*e.g. iridium in catalysts for electrolyzers*)
- **Need for dynamic market modeling** of decarbonization supply chains from mining to finished products that accounts for competing uses and market signals

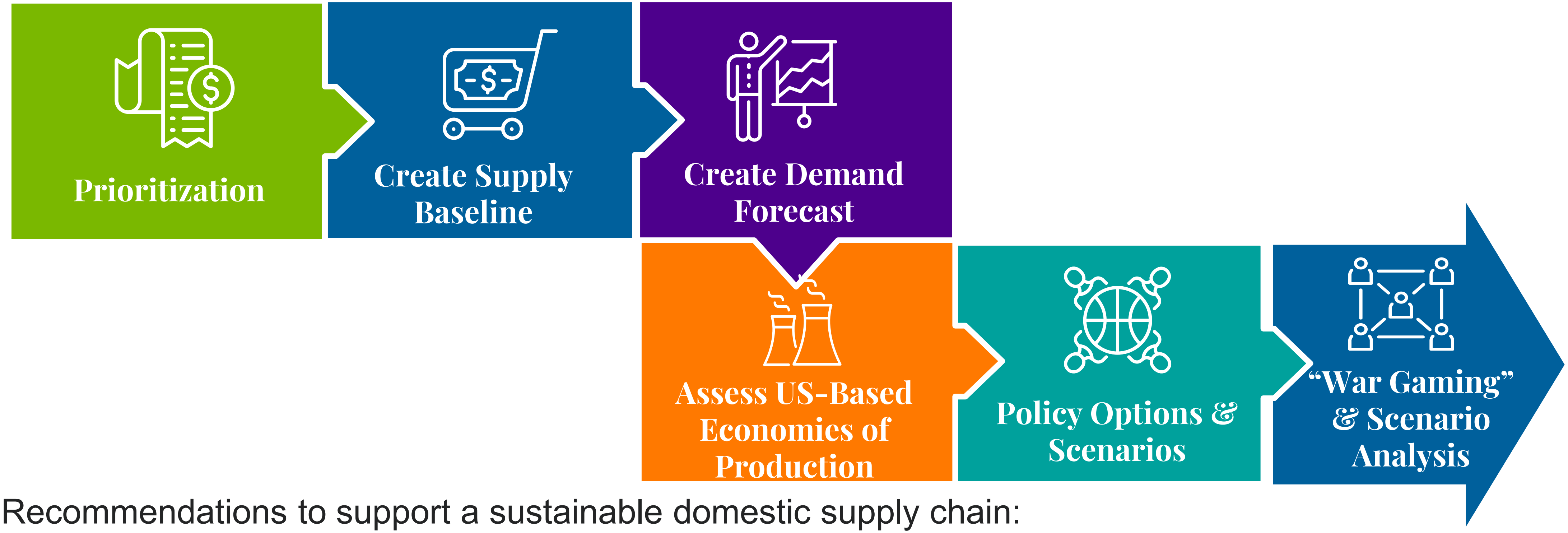
NEED FOR SUPPLY CHAIN MODELING AND INFORMATION

Modeling and information to address vulnerabilities

- Common vulnerabilities and challenges
  - Opaque markets with sparse data availability across the supply chain (proprietary information)
  - Demand uncertainty for specific (sometimes nascent) technologies
  - Global market instability of critical materials (REEs, PGMs, battery materials, etc.)
- Call for DOE to **provide informational support** to domestic industry and **compile qualitative and quantitative data** on various supply chains to close information gap
- **Supply chain modeling** plays central role in providing informational support to address these challenges
  - Demand scenarios (sufficient to support domestic industry, supply constraints, etc.)
  - Competitiveness of domestic industry
  - Viability of specific strategies
  - Impact of global events and disruptions

EO. 14017: COMPETITIVENESS & COMMERCIALIZATION

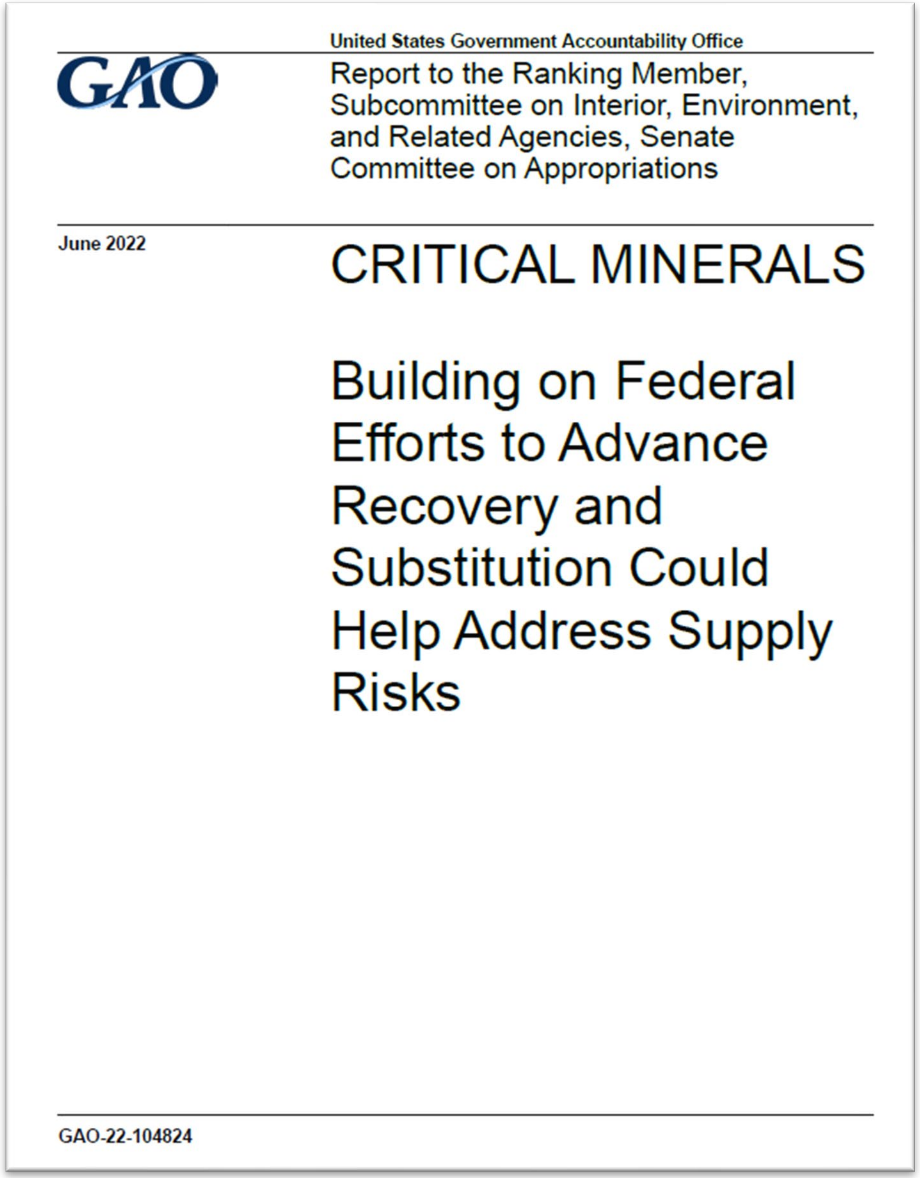
One-year cross-cutting report supporting analytically informed decisions to address supply chain issues



- Recommendations to support a sustainable domestic supply chain:
  - Significantly augment the analytical horsepower needed
  - Conduct systematic analysis for the most at risk supply chains to guide decision-making
  - Develop integrated commercialization roadmaps for priority technologies, industries, and markets
  - Use economic analysis and roadmaps with interagency partners to develop integrated commercialization strategies

KNOWN CHALLENGES

- U.S. desire for secure, ethical and economic access to critical and strategic materials needed for the clean energy transition
- GAO:
  - Limited data and analytical tools to support decision-making,
  - Insufficient research and development
  - Minimal domestic infrastructure and capacity
  - Potential adverse effects on the environment and worker safety
  - Limited economic viability of recovery and substitution methods


GAO

United States Government Accountability Office

Report to the Ranking Member, Subcommittee on Interior, Environment, and Related Agencies, Senate Committee on Appropriations

June 2022

CRITICAL MINERALS

Building on Federal Efforts to Advance Recovery and Substitution Could Help Address Supply Risks

GAO-22-104824

EXAMPLES OF DOE/NL MODELS (*LIST NOT EXHAUSTIVE)

Integrated Systems Planning and Analysis (Sectoral and Whole-Economy Models)

TIMES, GCAM, MESSAGE, NEMS/MARKAL, TEMOA, OSeMOSys, Scout, DREAM, FINITO, AMBER, ...

Ancillary Models/Tools

Grid Integration Analysis

ReOPT, REEDS, ALEAF, PLEXOS, APEX, ...

Life Cycle Assessment

GREET, MFI, USLCI, AWARE, BEIOM, ...

Material Flow Analysis

MFI, LightenUP, ...

Technology, Fuel, or Feedstock Analysis

GREET, BioSTAR, TEEM, HDSAM, TEMPO, ...

Adoption, and Market Analysis

Hanes et al., JEDI, ...

Efficiency Analysis Incl. CHP

IGATE-E, Rao et al., WESyS, ...

Logistics & Supply Chain Analysis

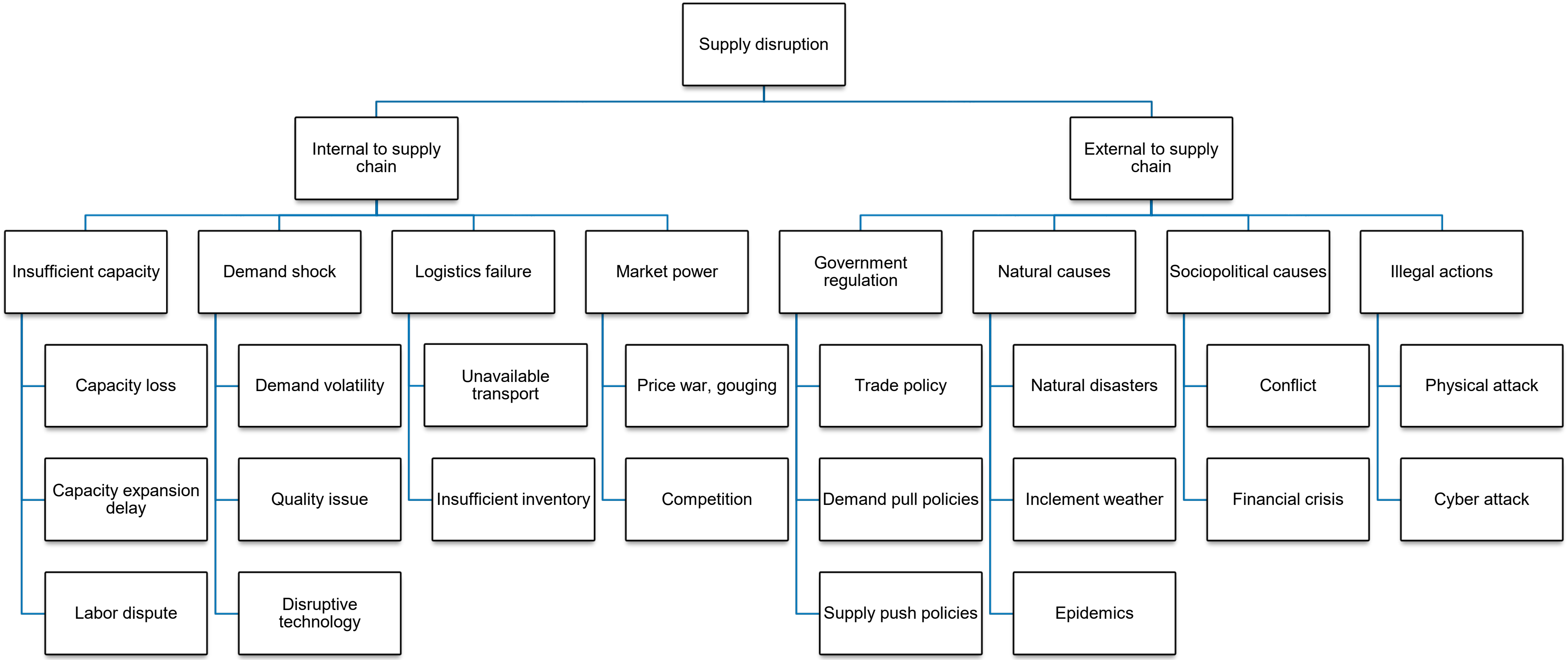
MFI, BEIOM, GCMAT, RELOG, BLM, SCM, ...

Input/Output Analysis

USEEIO, LightenUP, EIO-LCA, ...

RELIANCE ON IMPORTS FROM SENSITIVE NATIONS CREATES SUPPLY VULNERABILITIES

Causes U.S. exposure to price fluctuations and supply disruptions



Types of Supply Disruptions

Source: Matthew E. Riddle, Eric Tatara,Chuck Olson, Braeton J. Smith, Allison Bennett Irion, Braden Harken, David Pineaut, Elisa Alonso, Diane J. Graziano, *Resources, Conservation and Recycling*. Volume 164, (2021).

UNCERTAINTIES THAT ANALYTICAL APPROACHES CAN ADDRESS

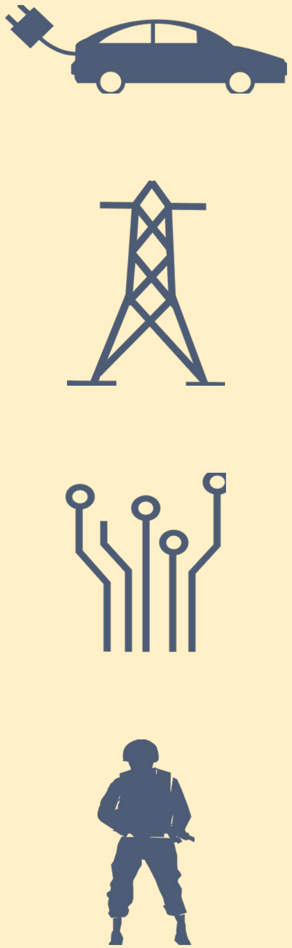
- Evaluate the market viability of different strategies for building out domestic supply chains from mines to materials
- Enhance understanding of the economic viability of domestic recycling and how recycling could affect markets, foster domestic demand, and mitigate supply disruptions
- Explore how different types of supply disruption could affect attainment of U.S. decarbonization goals
- Study the market impact and supply chain vulnerability of evolving decarbonization technologies, including those that substitute away from CMs
- Assess the effectiveness of supply chain resiliency measures (post-pandemic, geopolitical, etc.)
- Examine longer-term material supply issues
- Assessing Competitiveness

DIVERSE EXPERTISE TO LINK SCIENCE TO APPLICATION

ADVANCED PHOTON SOURCE

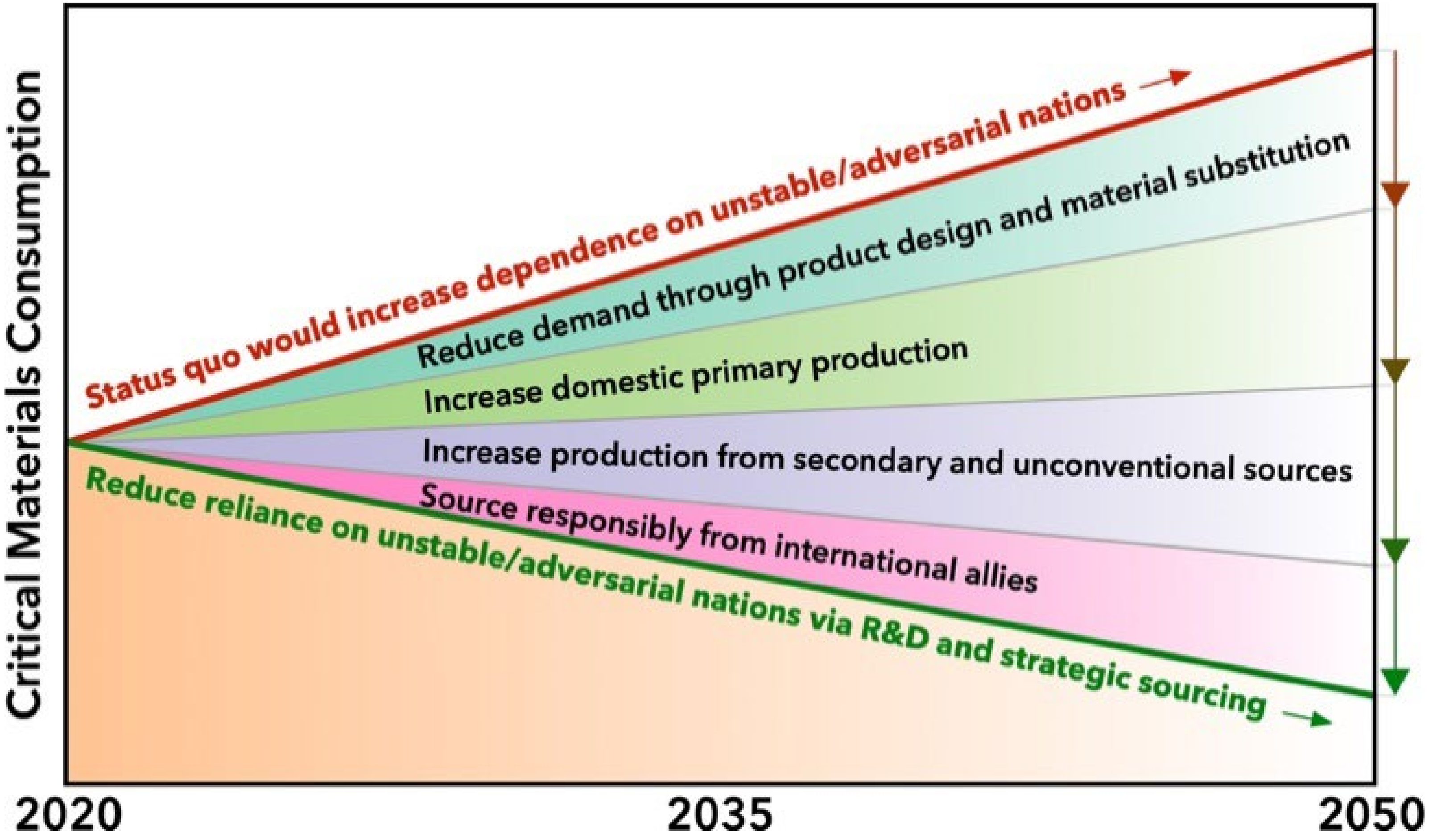
CENTER FOR NANOSCALE MATERIALS

ARGONNE LEADERSHIP COMPUTING FACILITY



SOLUTIONS ARE COMPLEX AND INTERDEPENDENT

Substitution: manipulate the chemistries of earth-abundant elements
Extraction: efficiently extract CMs from conventional and unconventional domestic sources
Processing: increase the flexibility of processing to tolerate mixing primary and recycled feedstock
Analytics: decision-support grounded in understanding risk and dependencies to assure our CM supply and avoid future material criticality



A cohesive approach to secure stable domestic critical material supply chains.

DOE'S RECELL CENTER

Purpose

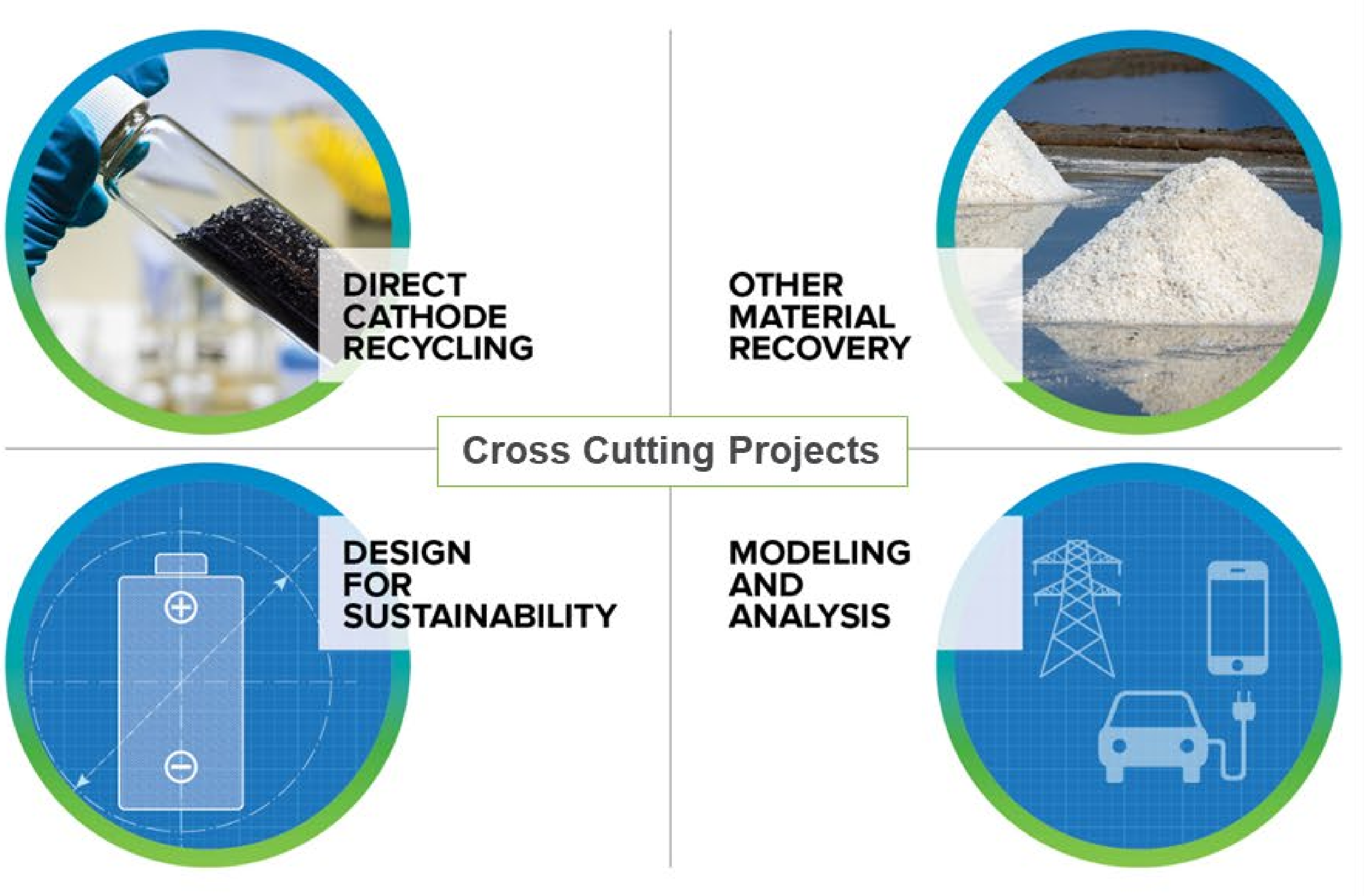
- Foster the continued improvement of cost-effective, environmentally sound processes to recycle lithium-ion batteries
- Bring together experts from all battery recycling areas and bridge the gaps
- Efficiently address the many challenges that face a successful advanced battery recycling infrastructure

Outcome

- Minimize use of the earth's limited resources, reduce energy consumption and increase our national security
- Provide stability to the battery supply chain
- Drive battery pack costs down to DOE's $80/kWh usable energy goal

RECELL HAS FOUR FOCUS AREAS

- Binder Removal
- Cathode/ Cathode Separation
- Relithiation
- Cathode Upcycling
- Impurity Impact



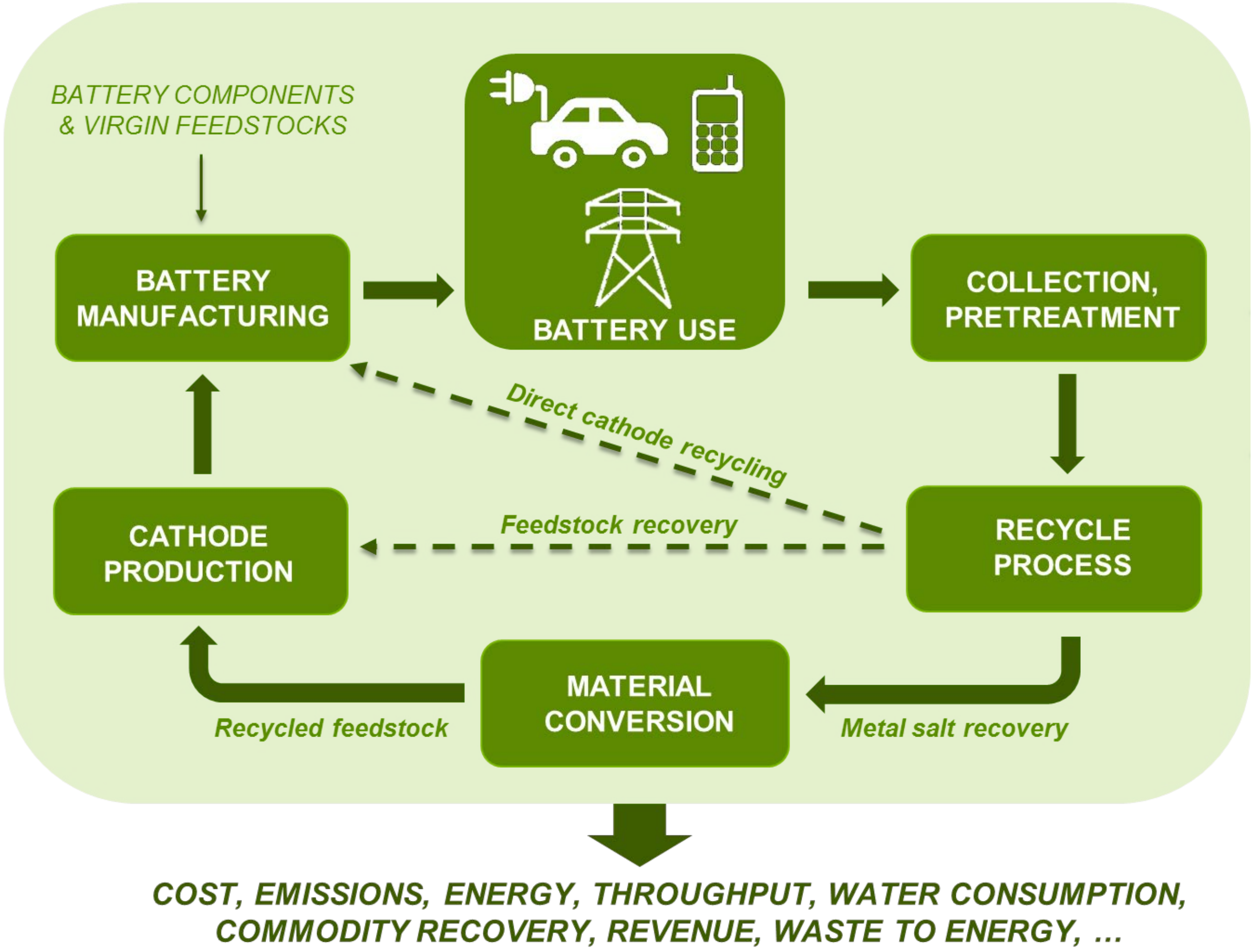
- Cell Shredding
- Electrode Delamination
- Anode/ Cathode Separation
- Electrolyte Component Recovery

- Cell Design for Rejuvenation

- EverBatt (TEA/LCA)
- LIBRA (Supply Chain Modeling)

EVERBATT MODEL FLOW

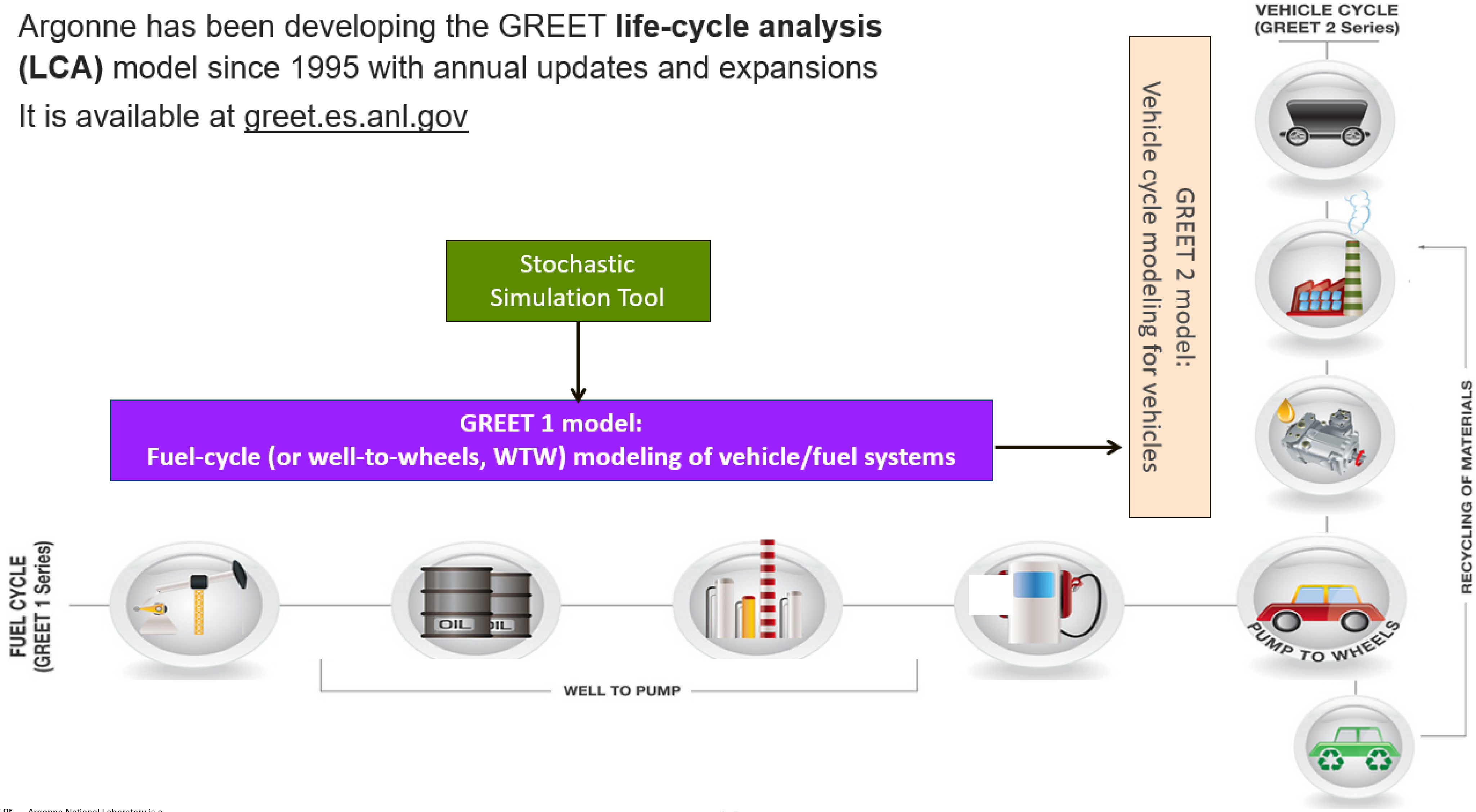
EverBatt breaks down and evaluates each stage of the battery's lifecycle providing the opportunity to compare each stage's cost and environmental impact to the overall impacts



Courtesy Argonne

The GREET (Greenhouse gases, Regulated Emissions and Energy use in Technologies) model Framework

- Argonne has been developing the GREET **life-cycle analysis (LCA)** model since 1995 with annual updates and expansions
- It is available at greet.es.anl.gov



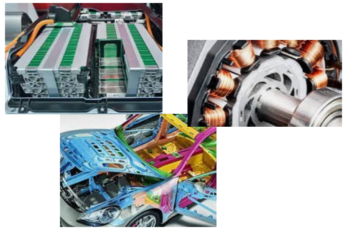
BEnefit ANalysis (BEAN)

Newly released techno-economic analysis and data visualization tool

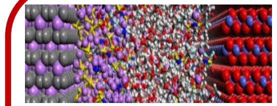
Supply chain development | **Market development** | **Infrastructure development**

High-Fidelity Tools, Studies

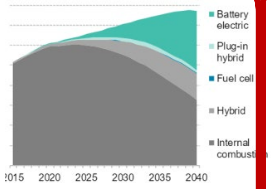
- AUTONOMIE — Vehicle design, energy consumption



- Component Costs



- BatPaC, ReCell — Battery Material, Recycling
- TCO, CCM…
- GREET LIFE-CYCLE MODEL — GHG, LCA



- Market Penetration
- H2FAST — Infrastructure Cost

Individual Databases

BEAN

Users' Selection

Timeframe, technology level, fuel pathways, market penetration uncertainty, …

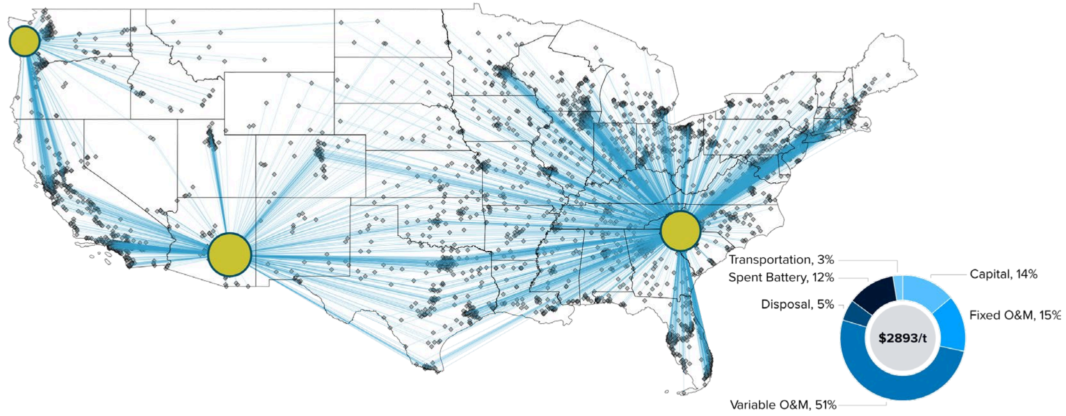
Insights

- DOE Vehicle Technology Office R&D benefits
- **Technology impacts on energy, cost, GHG**
- Critical material needs
- Technical targets for cost parity
- Uncertainties (e.g., energy cost, market penetration)
- **Requirements to meet targets (e.g., GHG % reduction)**

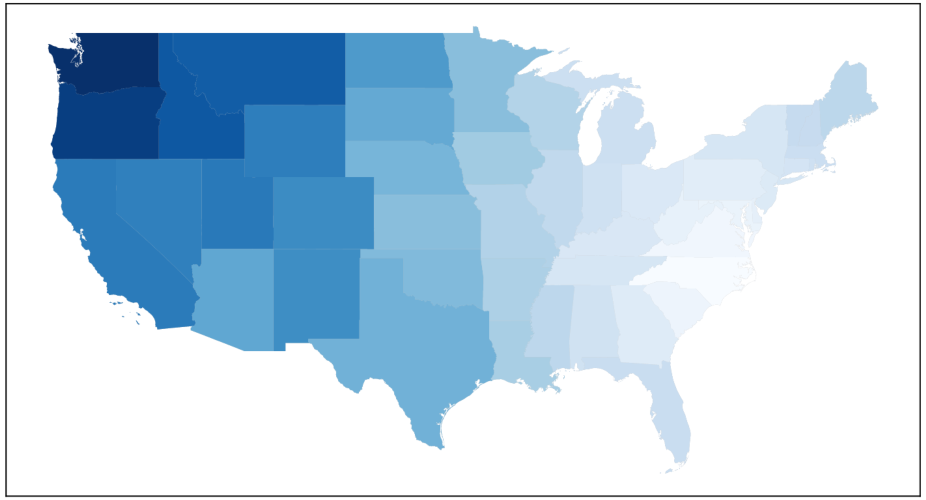
https://vms.es.anl.gov/tools/bean/

RELOG: REVERSE LOGISTICS OPTIMIZATION MODEL

- **Open-source package for design and analysis of optimal reverse logistics networks:**
  - Recycling plant location and sizing
  - Customer allocation
  - Optimal material flow



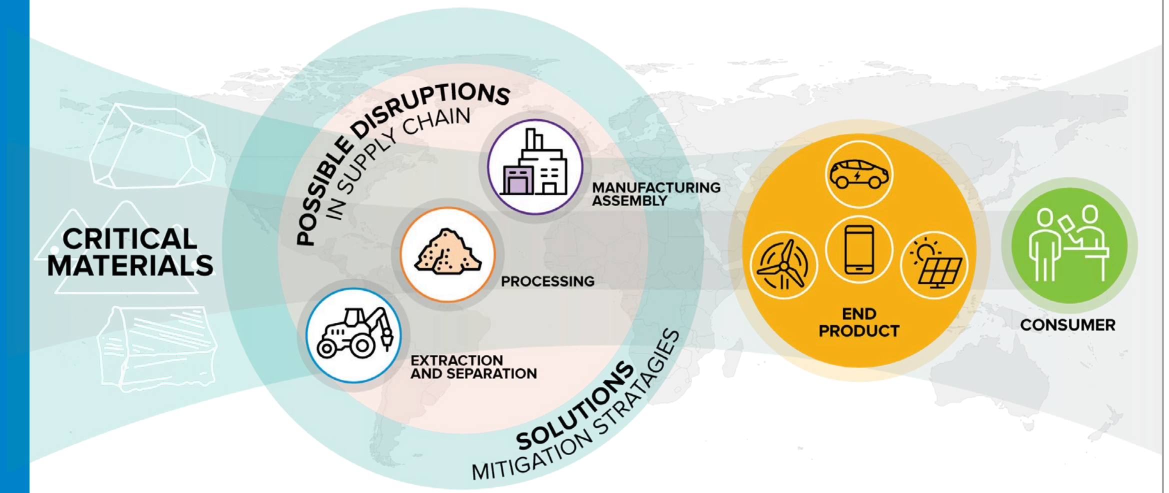
- **Insights from RELOG**
  - Facility location, sizing & upgrade:
  - Economic / marginal cost analysis:
  - What happens as supply, demand or costs change?



RELOG: Available at https://anl-ceeesa.github.io/RELOG

Global Critical Materials (GCMat) Model

- ***Objective:*** Utilize agent-based modeling as an analytical tool to assess supply disruption, dependencies, substitutions and trade policies to strengthen material supply chains critical to decarbonization technologies



- ***Project Background/Details:***

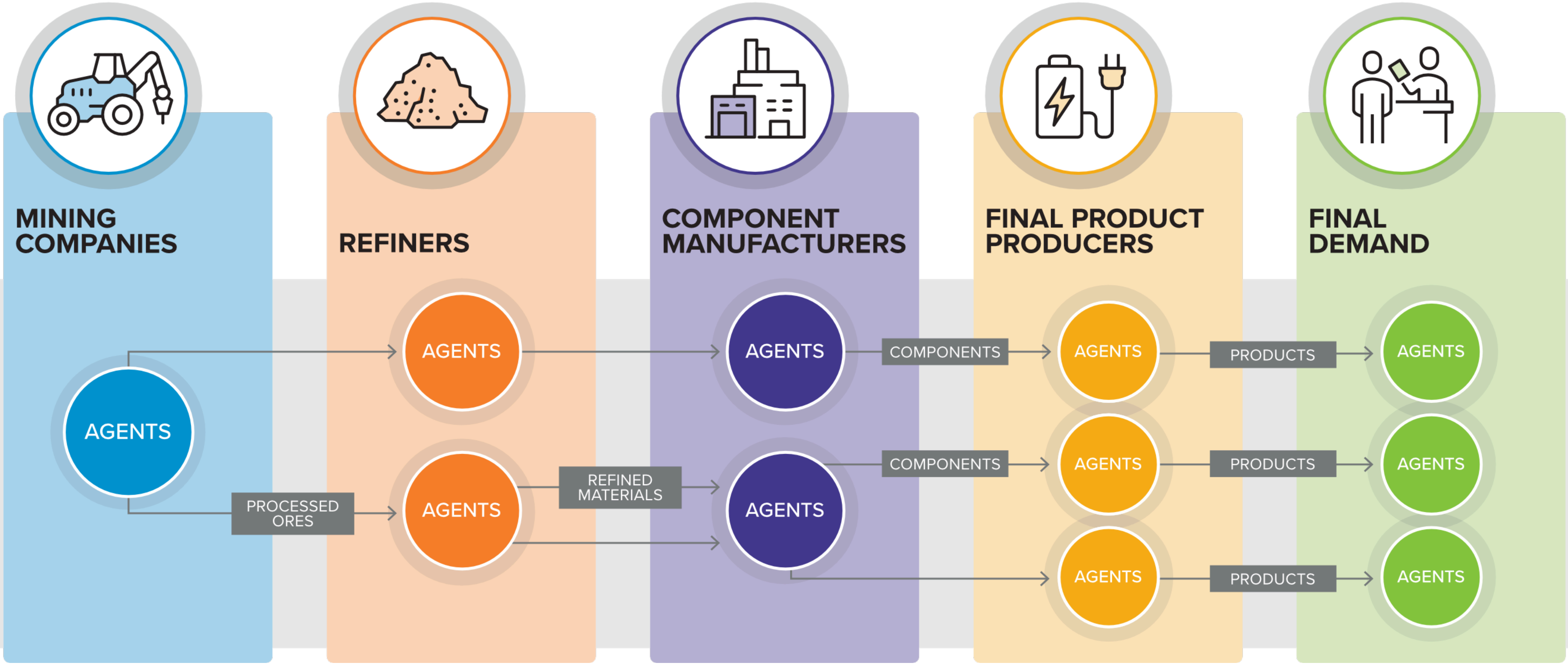
Capture supply and demand dynamics

Identify exposure from market disruptions

Evaluate risk mitigation strategies

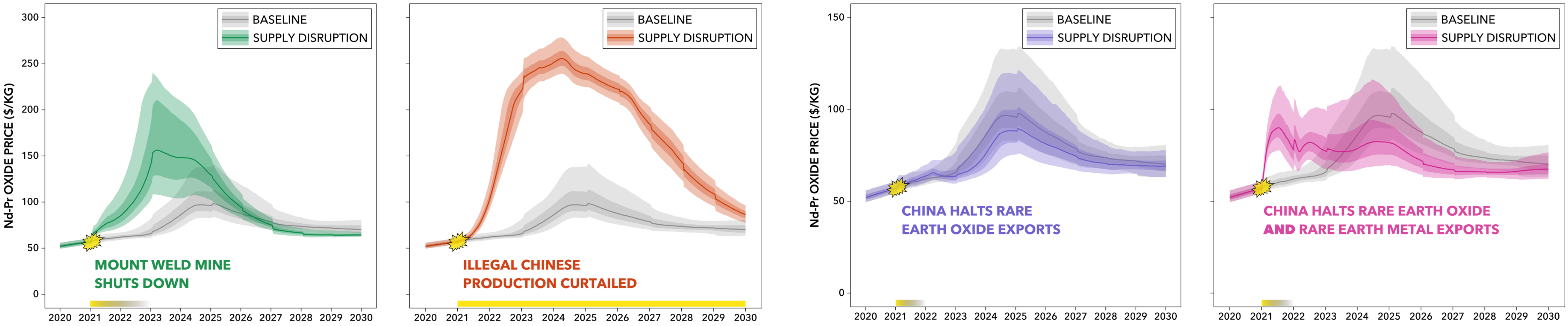
SPONSORS: U.S. DEPARTMENT OF ENERGY, U.S. DEPT OF DEFENSE, Argonne NATIONAL LABORATORY

AN AGENT-BASED VIEW OF
MODELING CRITICAL MATERIALS



HIGHLIGHTS OF RECENT SUPPLY CHAIN DISRUPTION PUBLICATION WITH DOD-DLA

- Study of impacts of three types of supply disruptions on rare earth markets
  - Shut-down of production from Mt Weld mine in Australia
  - Reduction in illegal rare earth oxide production in China
  - Restriction of rare earth exports from China
- Large and lasting impacts found on rare earth prices
- Analysis of model results improves intuition on how different rare earths might be affected differently depending on type of disruption



Argonne
NATIONAL LABORATORY

CONTACT US

Allison Bennett Irion
Director, Supply Chain Research
Email: abi@anl.gov