ENERGY STORAGE SOLUTIONS TO DECARBONIZE ELECTRICITY

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THE ROLE OF ENERGY STORAGE IN DECARBONIZATION

Future	Challenge	Role of Storage
High wind and solar penetration	Weather dependent generation	Balance volatility and mitigate uncertainty
Resources with zero fuel costs	Extended periods of zero or negative prices	Price arbitrage
Sector electrification	Increasing and shifting load profiles	Move energy through time
Climate risks	Increasingly frequent extreme events	Resilience support

Levin, T. et al. Energy storage solutions to decarbonize electricity through enhanced capacity expansion modelling. Nature Energy (2023). https://doi.org/10.1038/s41560-023-01340-6

TECHNOLOGY REPRESENTATION

Heterogeneous technology characteristics	• Charge/discharge capacity, duration, losses, capacity degradation, lifetime etc.
State of charge management	• Must monitor and manage SOC in models and operations
Degradation	• Dependence on operational strategies
Independent power and capacity sizing	• Different costs and independent decision
Value dependence on other technologies	• E.g., VRE, price responsive loads, flexible nuclear, hydrogen

SYSTEM REPRESENTATION

Increased geographic fidelity	• Need for both increased resolution and expanded geographic scope
Increased temporal fidelity	• Granular time steps • Chronological representation • Extended representative periods
Improved weather data	• Dependent on weather profiles through both charging and generation
Improved climate data	• Long term projections, multiple weather years
Long-run uncertainty	• Future cost and performance characteristics • Deep uncertainty around new technologies, unknowable or entirely subjective
Short-run uncertainty	• Weather dependent volatility • Unforced outages

POLICY, MARKET AND SOCIETAL CONSIDERATIONS

Decarbonization targets

- Nearly 75% of Americans are served by an electric utility with a target to decarbonize fully

Heterogeneous policy landscape

- Technology specific incentives
- Jurisdictional issues within power systems

Competitive wholesale markets

- Emerging grid services
- Opportunity cost-drive price formation
- Strategic investment decisions

Energy equity and justice

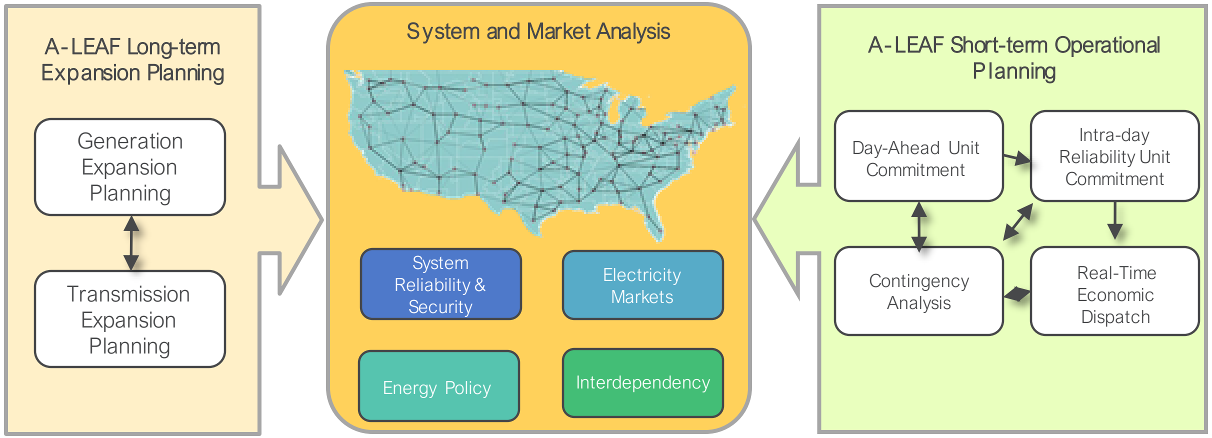
- Community impacts, distribution of costs and benefits, differentiated reliability

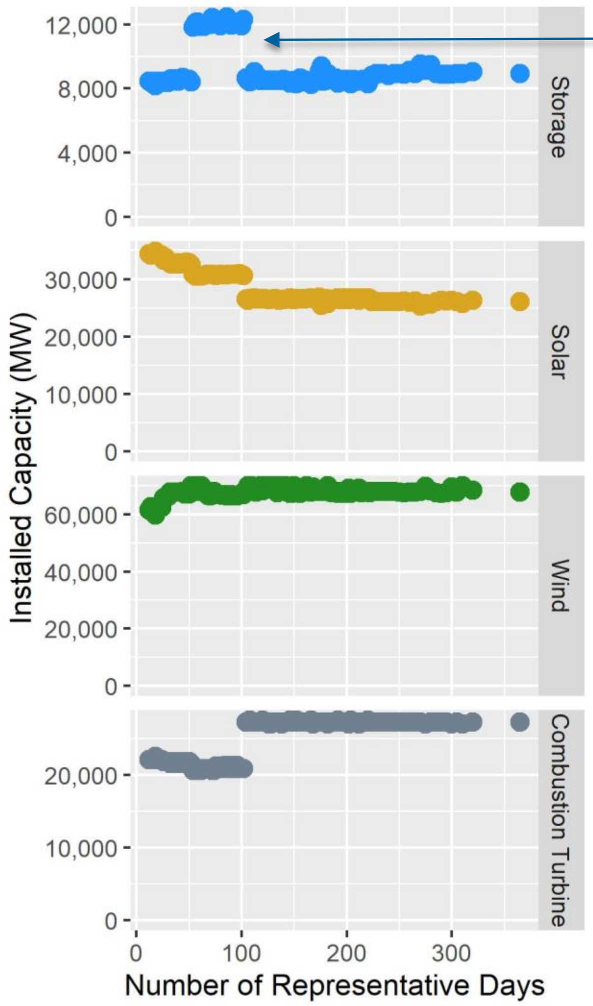
NATIONAL DECARBONIZATION PATHWAYS

ARGONNE LOW-CARBON ELECTRICITY ANALYSIS FRAMEWORK (A-LEAF)

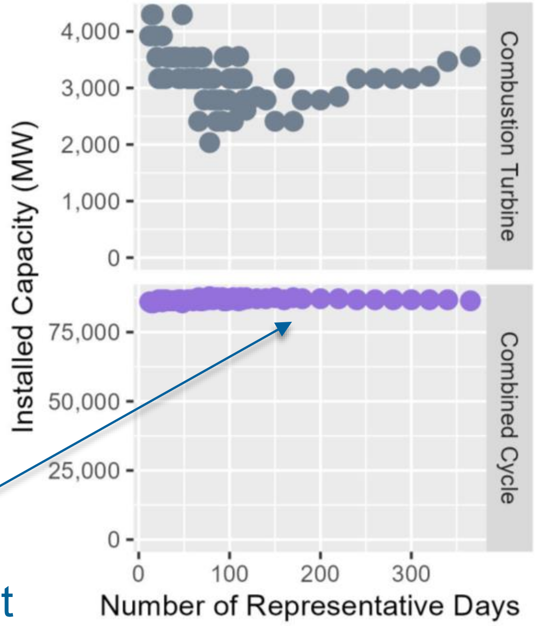
Applied to analyze national decarbonization pathways

- Integrated *national-scale* power system simulation framework developed at ANL that has been applied to analyze different issues related to power system evolution.
- Suite of least-cost generation & transmission expansion, unit commitment, and economic dispatch models
- Applied to several national scenarios to analyze storage and transmission expansion
  - Decarbonization targets, cost projections, land use and public acceptance

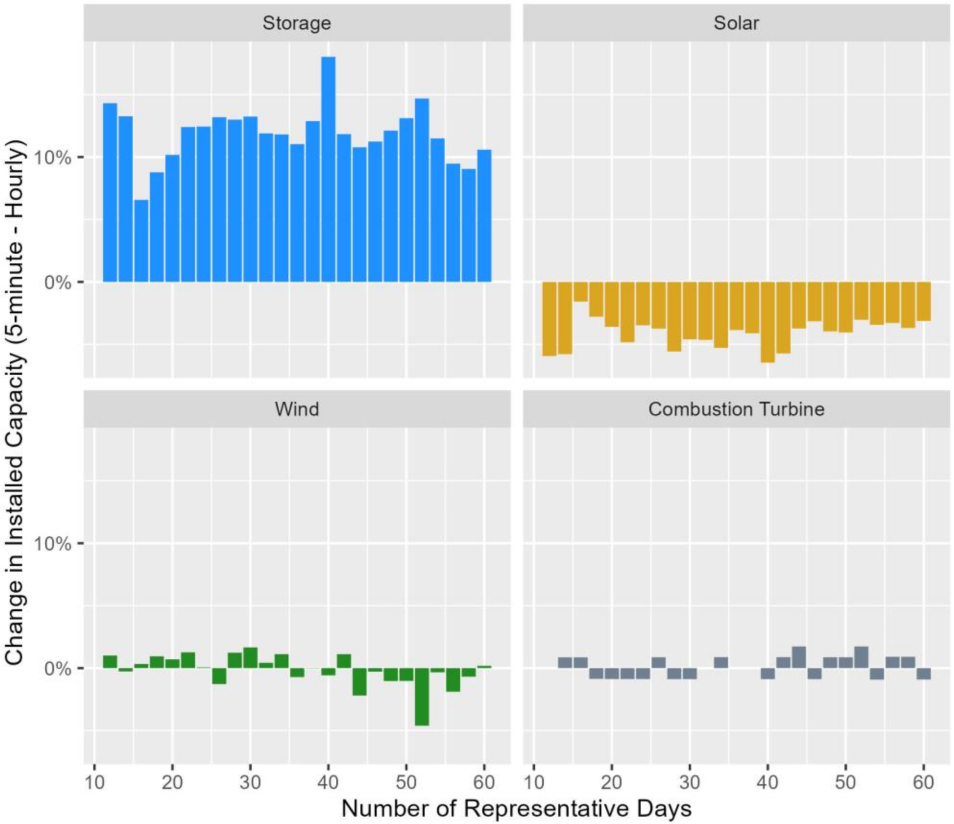




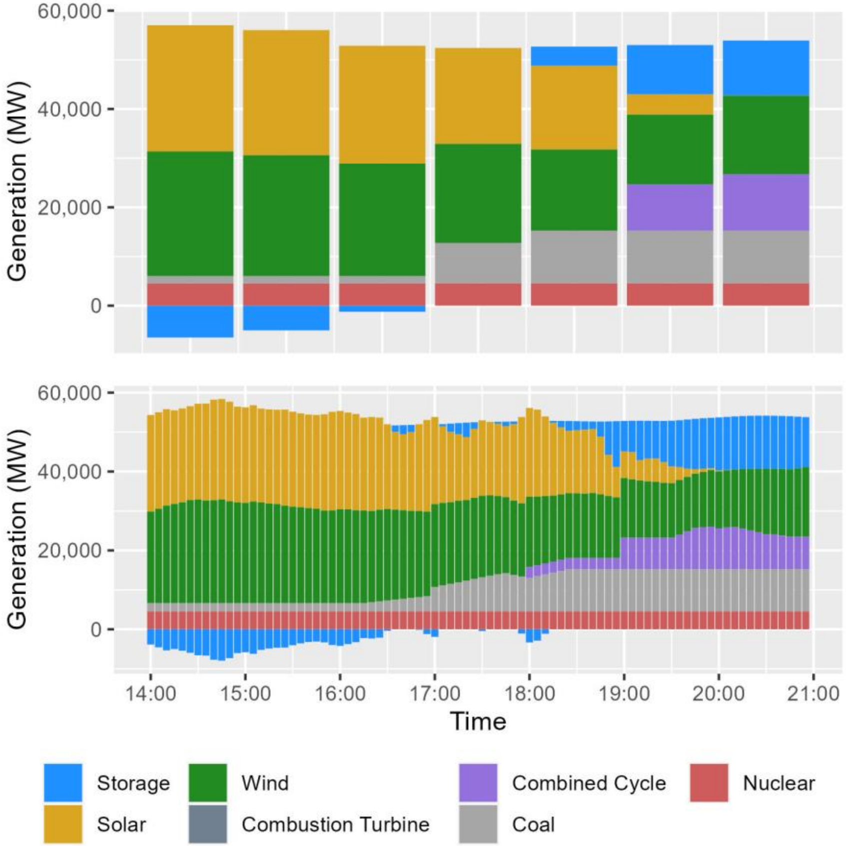
Small changes in the number of considered representative days can greatly impact expansion in low-carbon systems.



Impacts are much less significant in traditional thermal-dominated systems.



Representing 5-minute dispatch intervals in capacity expansion leads to less solar and more storage deployment.



Hourly dispatch overlooks sub-hourly charge/discharge opportunities

CLIMATE INFORMED CAPACITY EXPANSION

CLIMATE TO GRID MODELING: INCORPORATING FUTURE CLIMATE IMPACTS INTO GRID PLANNING

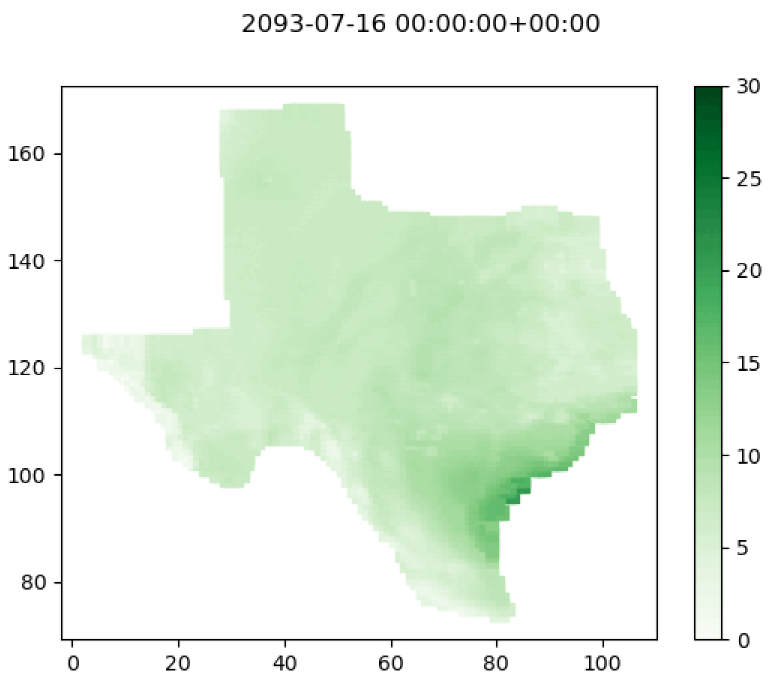
- Climate and weather are major drivers of *power system* investment and operation
- Extreme weather events are occurring more frequently, with more severity
- Climate datasets that are relevant to grid-related decision making are lacking
  - Especially with uncertainty representations
- Energy storage technologies can play an important role in mitigating event impacts
  - Particularly long duration energy storage

FUTURE CLIMATE DATA

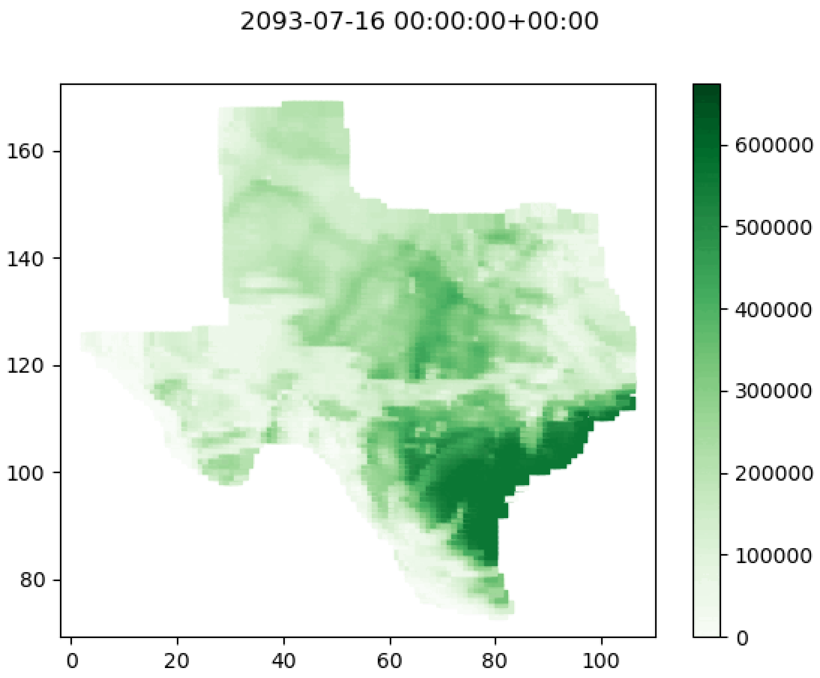
GCM Results Downscaled with WRF

- **Spatial Domain**
  - Most of North America: 309,600 points (600×516)
  - Grid spacing ≈ 12 km × 12 km
- **Temporal Domain**
  - Every three hours
  - Using cubic splines interpolation to hourly
- **Simulations**
  - **Periods**: 1995–2004, 2045–2054, 2085–2094
  - **RCP**: 8.5
  - **GCM**: CCSM4, GFDL, HadGEM
  - **WRF**: version 3.3.1
- **Geographic Variables (One for Each Cell)**
  - HGT: terrain height [m]
  - XLAND: land mask [N/A] (1=land, 2=water)
  - XLAT: latitude [decimal °]
  - XLONG: longitude [decimal °]
- **Weather Variables (Time Series for Each Cell)**
  - PSFC: Atmospheric pressure [atm] @ 0 m
  - Q2: Water vapor mixing ratio [N/A] @ 2m (from QVAPOR)
  - SWDOWN: Downward shortwave flux [W/m²] @ 0 m
  - T2: Dry bulb temperature [C] @ 2 m
  - U10: Wind velocity, x-component [m/s] @ 10 m
  - V10: Wind velocity, y-component [m/s] @ 10 m

HURRICANE: 2093 GFDL RCP8.5



Wind Speed [m/s]



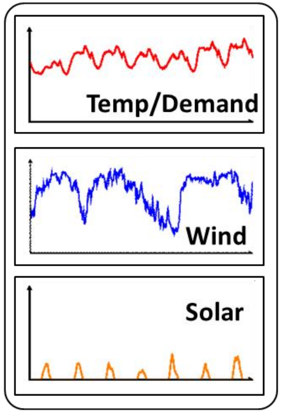
Wind Output [kW]

FUTURE STOCHASTIC OPTIMIZATION WORKFLOW

Identify and explicitly consider extreme events

Climate Inputs

3D



Temporal aspect

Time series
Cell by cell
(previous)

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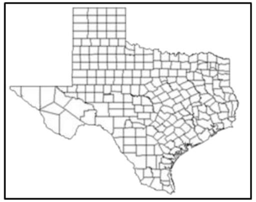
2D

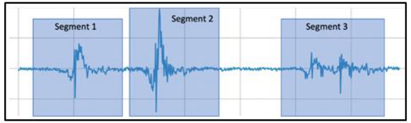


Spatial aspect

Machine Learning Based Grid Input Scenario Generation

Task 1: Representative period selection

- Clustering methods
- Machine learning methods (large size)



- The correlation between the different time series & regions.

Task 2: Extreme events identification
(fixed and irreducible scenario)

- Define threshold
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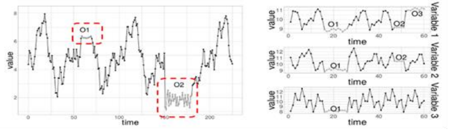
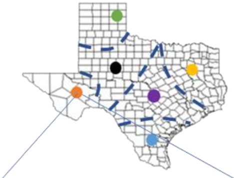


Task 3: Scenario reduction

- Clustering methods
- Importance sampling

Output Scenarios

Scenarios of Correlated Grid Inputs for Each Representative Periods and Regions



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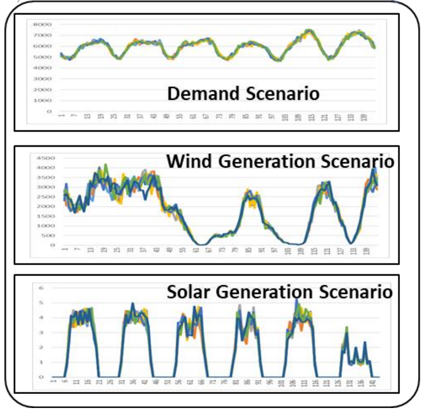

QUESTIONS?

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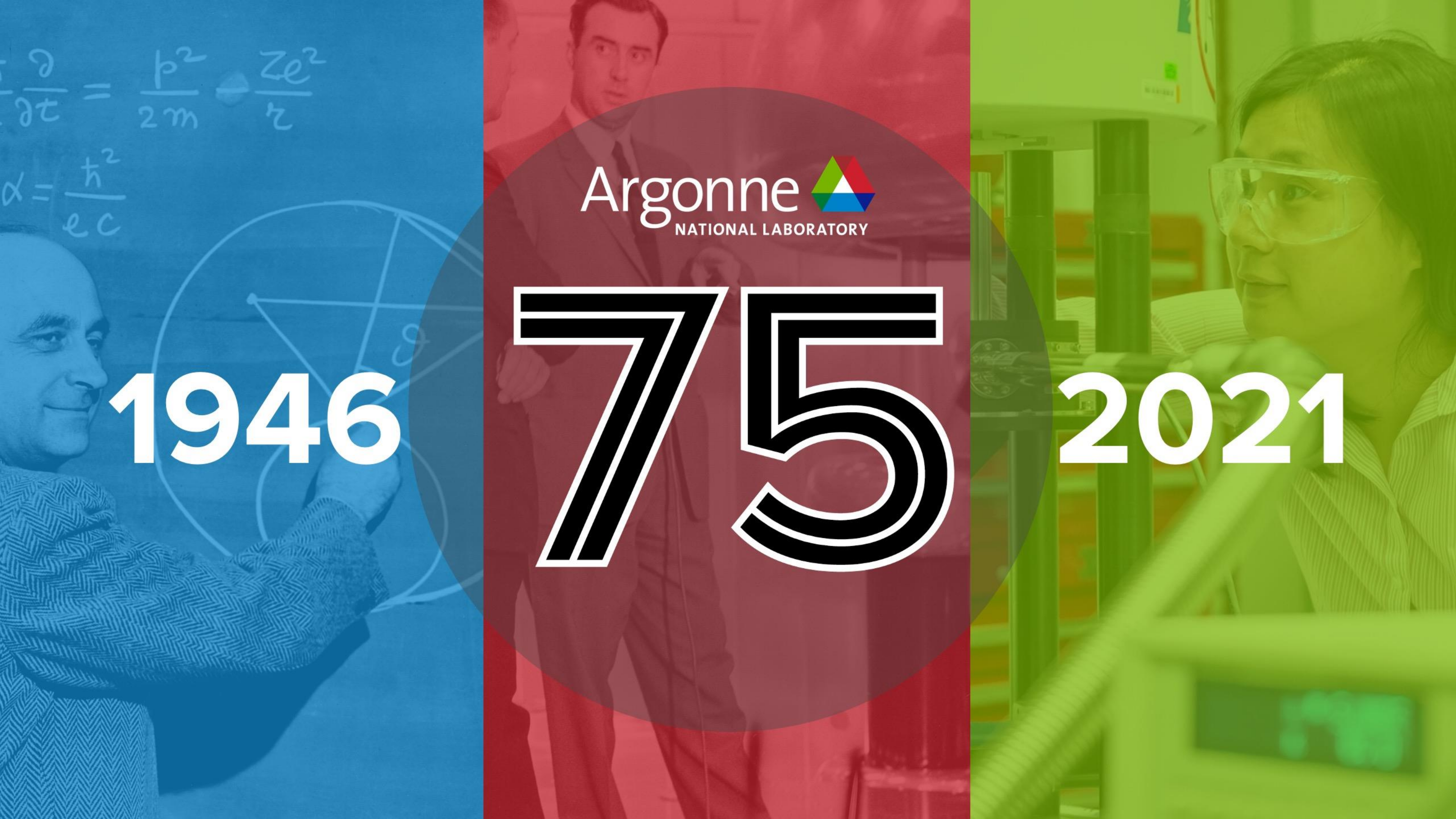
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