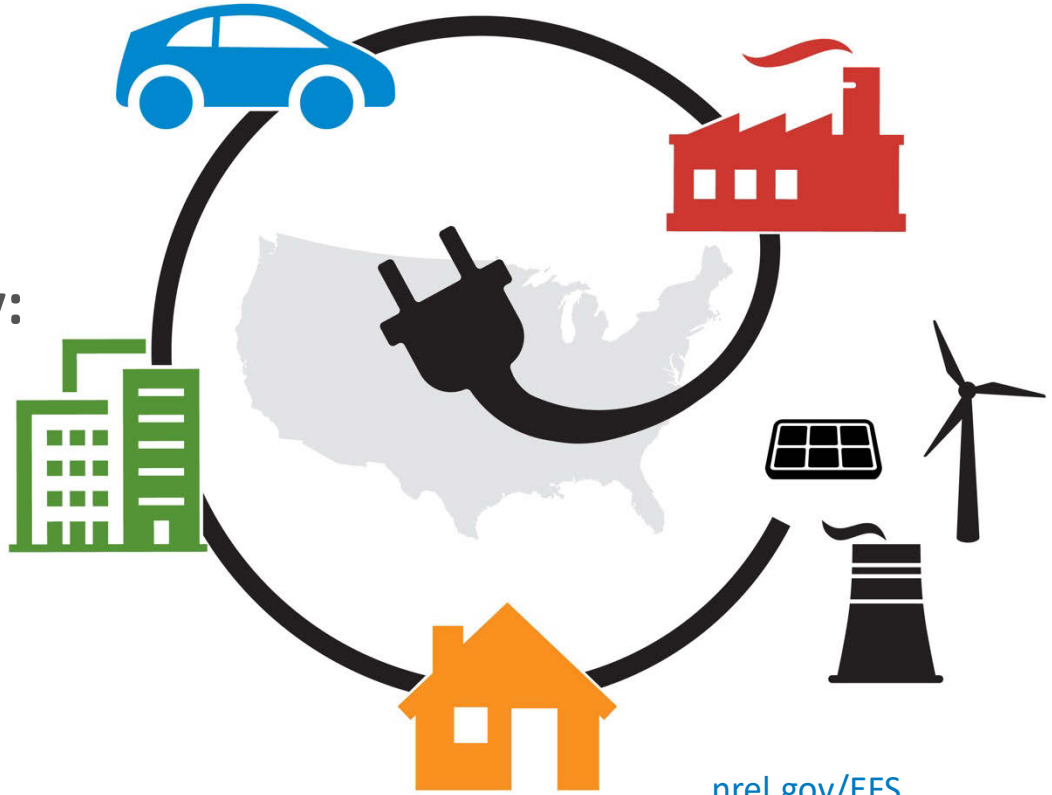
NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Electrification Futures Study: Scenarios of Power System Evolution

Caitlin Murphy and Trieu Mai

January 14, 2021



nrel.gov/EFS

Study sponsored by U.S. DOE-EERE Office of Strategic Programs

Answering crucial questions about:

Technologies

What electric technologies are available now, and how might they **advance**?

Consumption

How might electrification impact electricity **demand** and **use patterns**?

System Change

How would the electricity system need to **transform** to meet changes in demand?

Flexibility

What role might **demand-side flexibility** play to support reliable operations?

Impacts

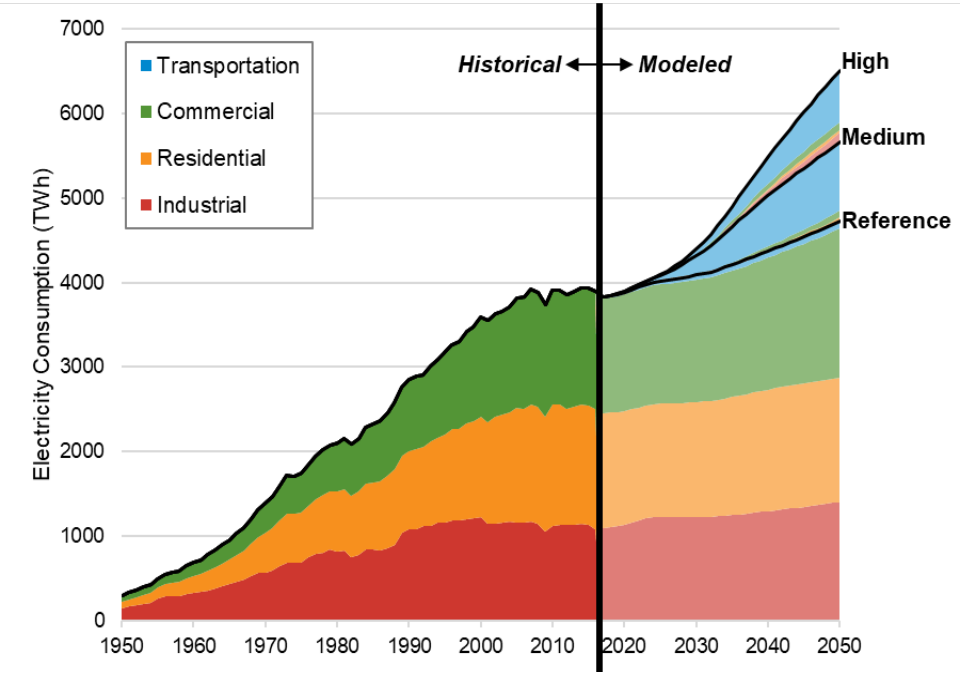
What are the potential **costs, benefits, and impacts** of widespread electrification?

NREL-led collaboration, multi-year study

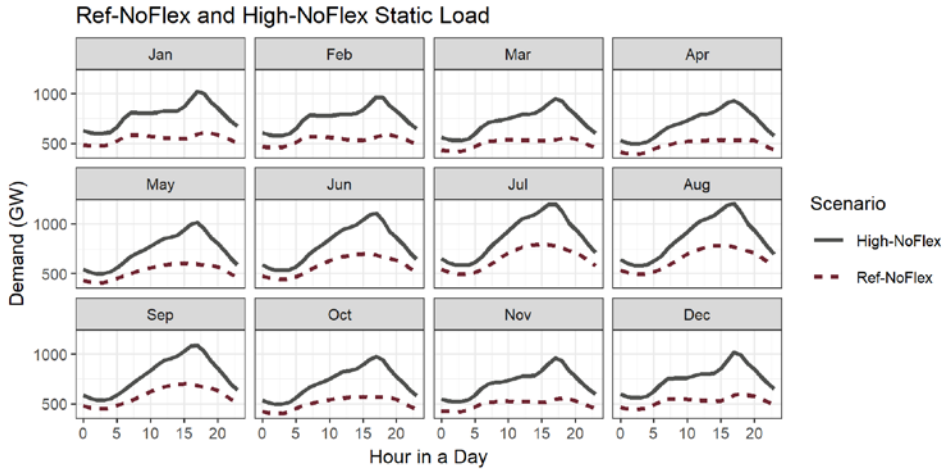
- Technology cost and performance (December 2017)
- Demand-side adoption scenarios (June 2018)
- dsgrid model documentation (August 2018)
- Methodological approaches (July 2020)
- **Supply-side evolution scenarios (January 2021)** — Today's focus
- Electricity system operations (2021, forthcoming)

Study sponsored by U.S. DOE-EERE Office of Strategic Programs

Vehicle electrification dominates incremental growth in *annual* electricity demand



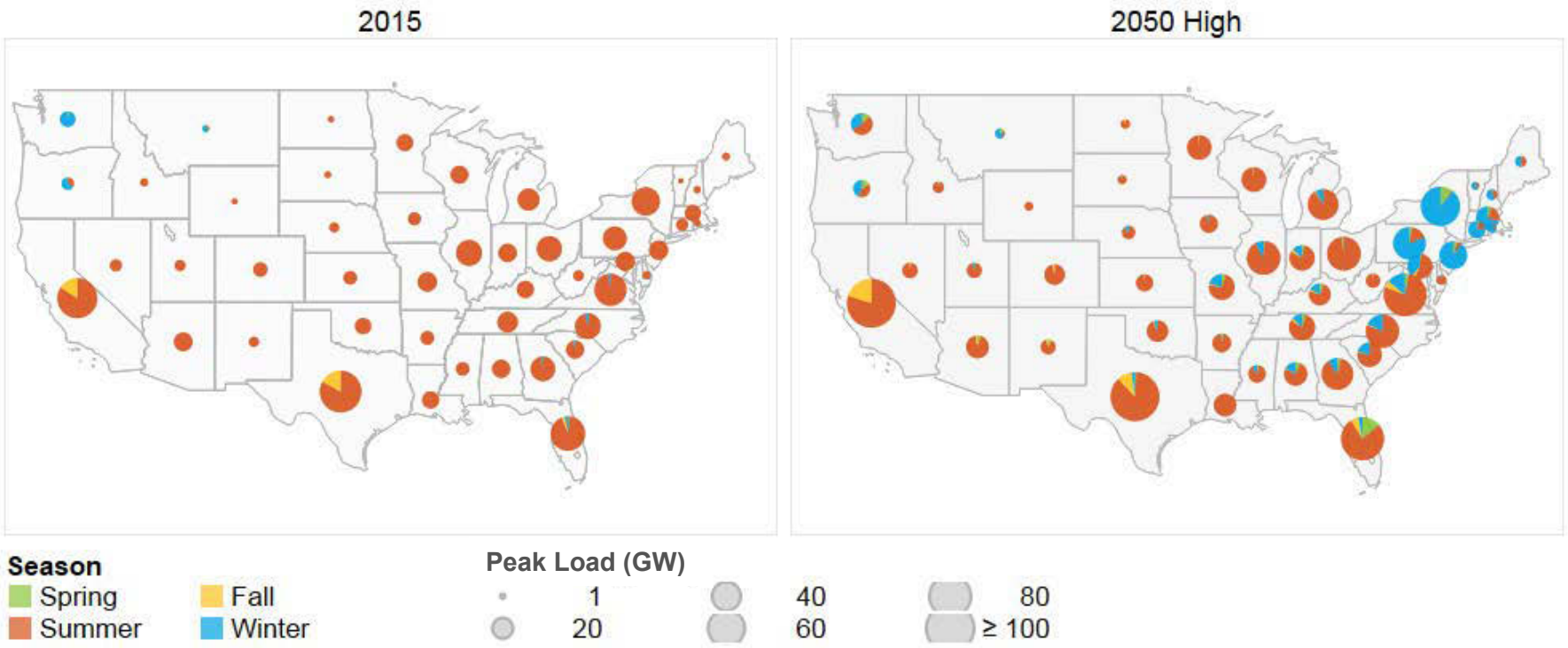
Greater electricity consumption



Possibly higher, sharper, and more-frequent peaks

Source: Mai et al. 2018 + (Murphy et al. 2021, Sun et al. 2020, Zhou and Mai forthcoming)

Electric space heating also impacts the timing and magnitude of peak demand



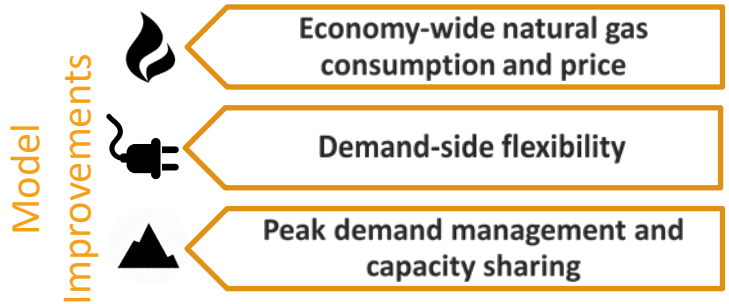
Note: Summer = June-August, Fall = September-November, Winter = December-February, Spring = March-May

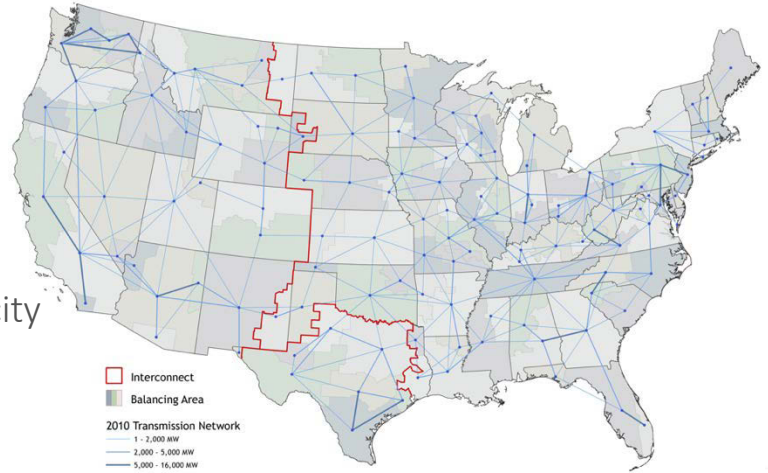
Power sector modeling methods

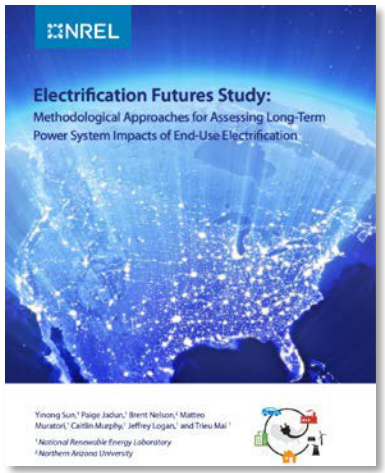
- Regional Energy Deployment System (ReEDS)
  - Long-term capacity expansion model of the electricity system in the contiguous United States

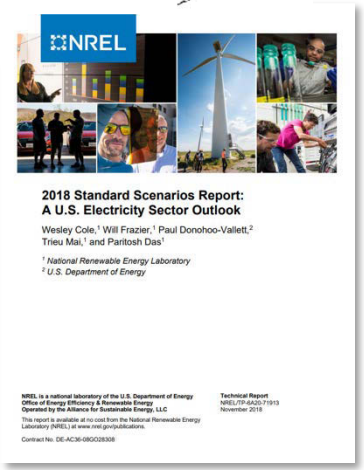
- Base model = 2018 final release version
  - Consistent with 2018 Standard Scenarios report
  - Key assumptions from ATB 2018 and AEO 2018

- New electrification-specific methodological improvements*









*Report available at https://www.nrel.gov/docs/fy20osti/73336.pdf

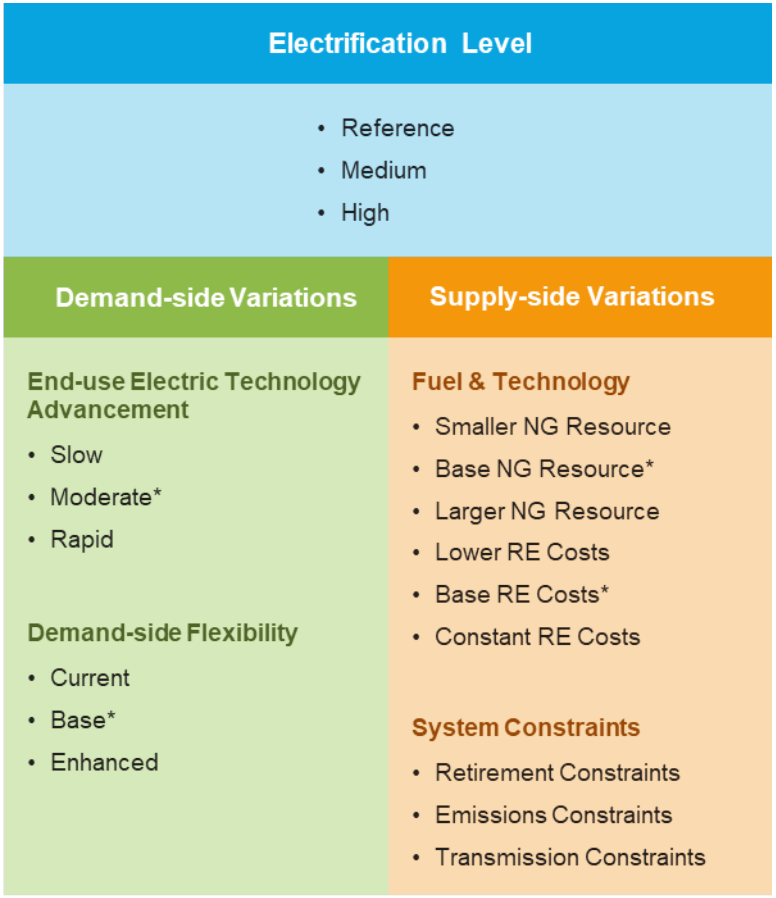
Research Questions

If widespread electrification occurs, how would the U.S. power system need to evolve, and what are some broader implications?

- What are the impacts of electrification on the mix, magnitude, location, and timing of **new bulk power system infrastructure development** in the United States?
- How could widespread end-use electrification impact the **generation mix and utilization** of different classes of generators and transmission assets?
- What are the impacts of electrification on **costs, energy consumption, and air emissions** for the electric and broader energy systems?

A wide range of supply-side scenarios

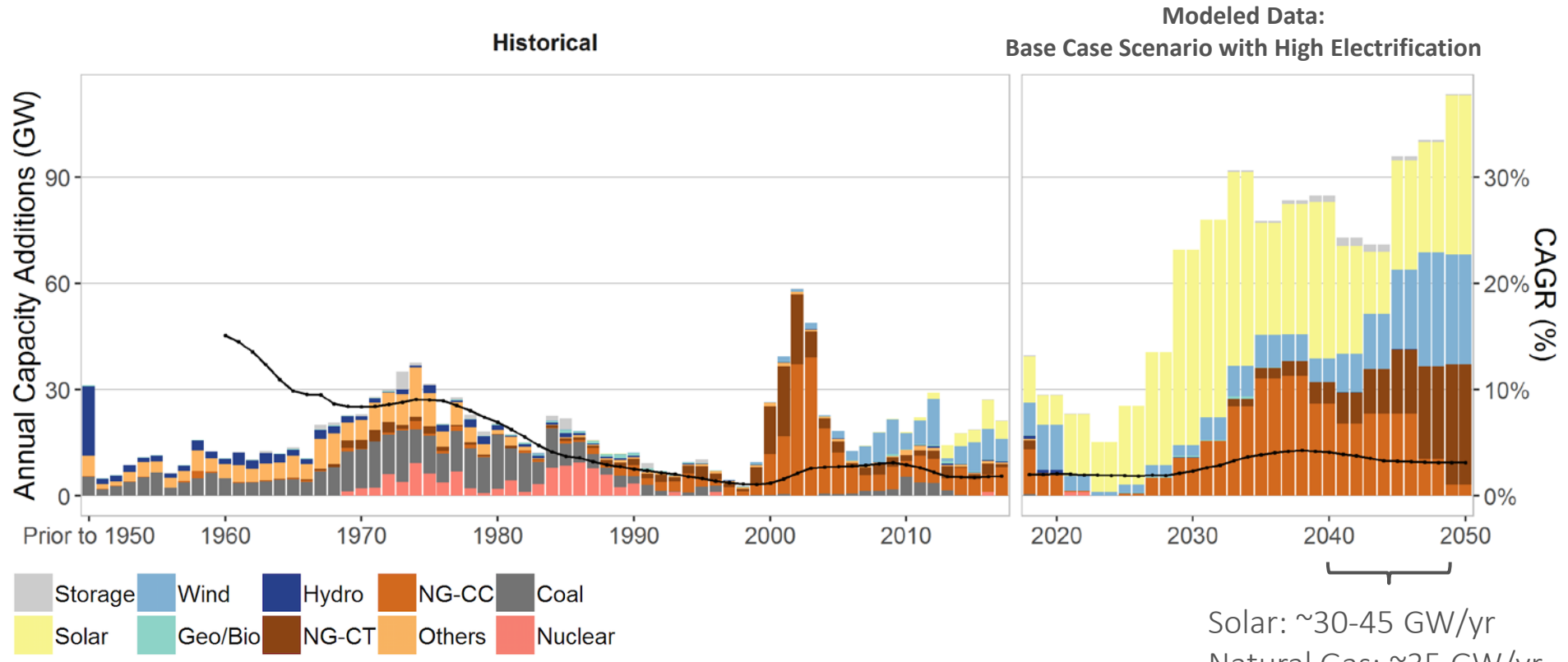
- Designed to **isolate the impacts** of electrification
  - Impacts = High minus Reference electrification
- **Sensitivities across multiple dimensions** in demand sectors and future supply uncertainties
- Presents **power system impacts** (when appropriate) and **broader energy system impacts** (whenever possible)



Murphy et al. (2021), https://www.nrel.gov/docs/fy21osti/72330.pdf

Finding 1

Electrification drives the sustained deployment of renewable energy and natural gas generators in all regions and, in turn, increases generation from these sources

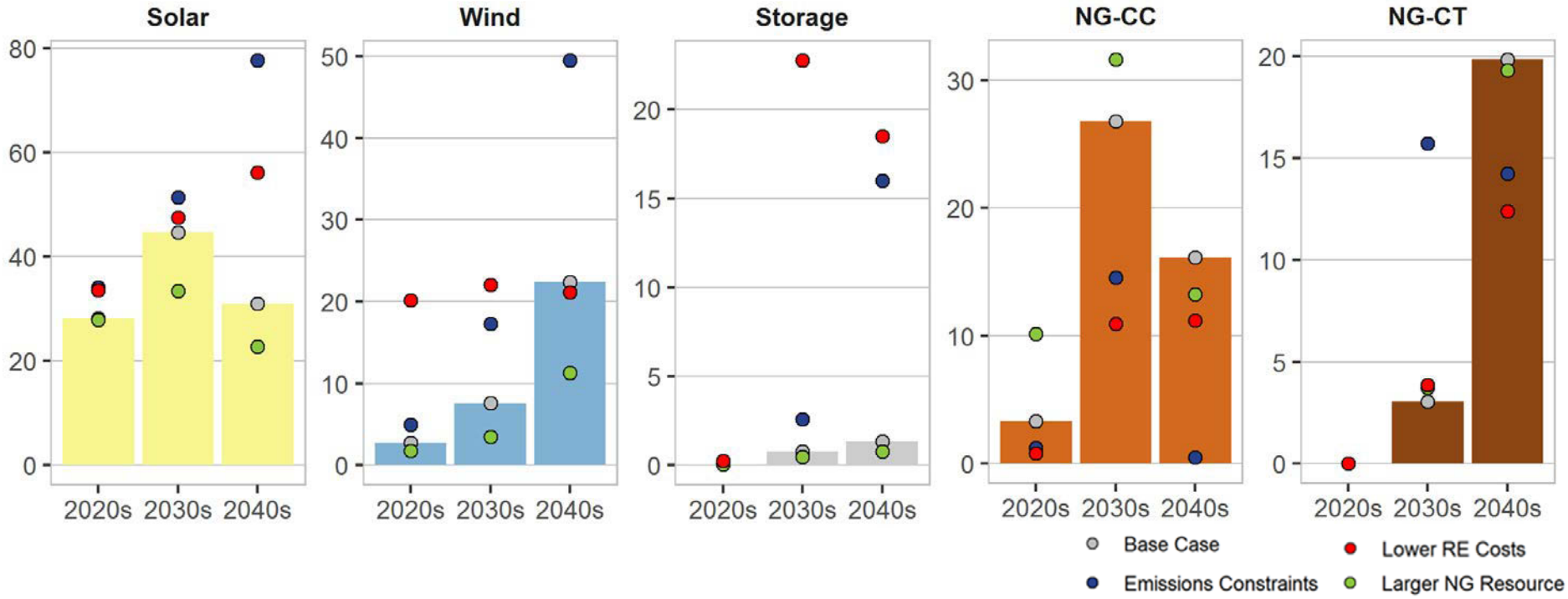


Solar: ~30-45 GW/yr
Natural Gas: ~35 GW/yr
Wind: ~20 GW/yr

+ even higher rates in some scenarios

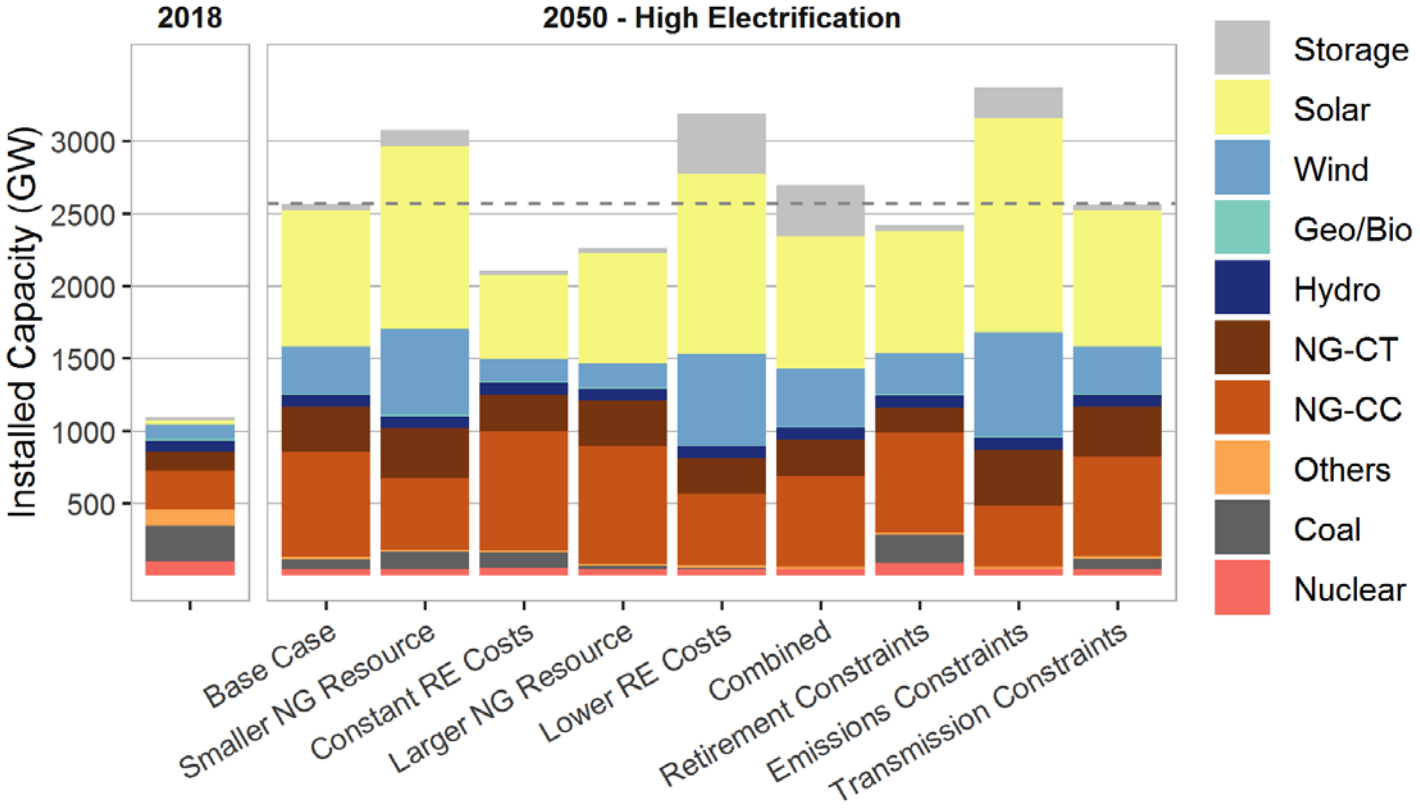
Murphy et al. (2021), https://www.nrel.gov/docs/fy21osti/72330.pdf

Annual Capacity Additions (GW)



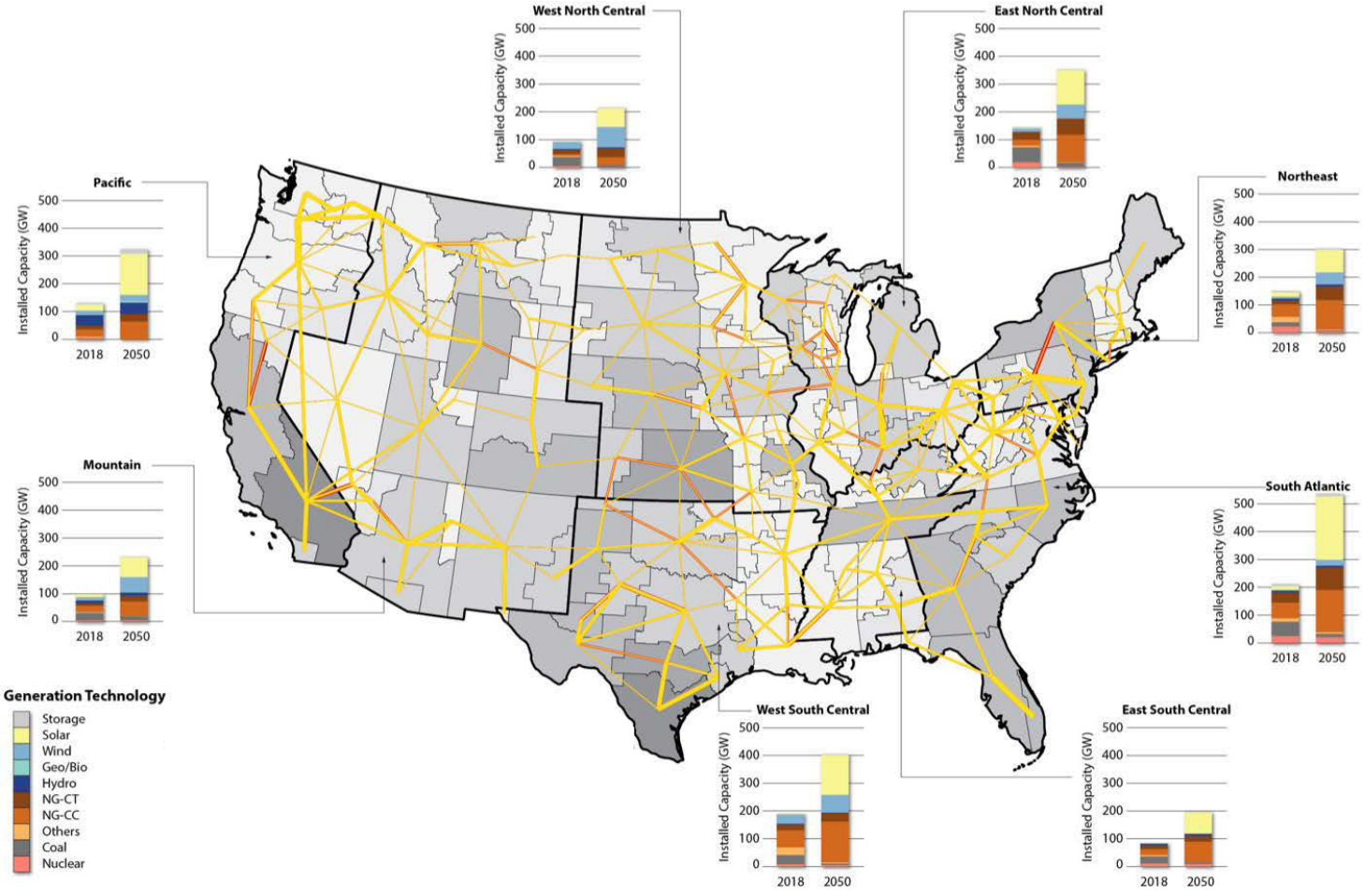
The future electricity supply mix depends on uncertain technology, market, and policy conditions

Murphy et al. (2020), *Electricity Journal,* https://doi.org/10.1016/j.tej.2020.106878

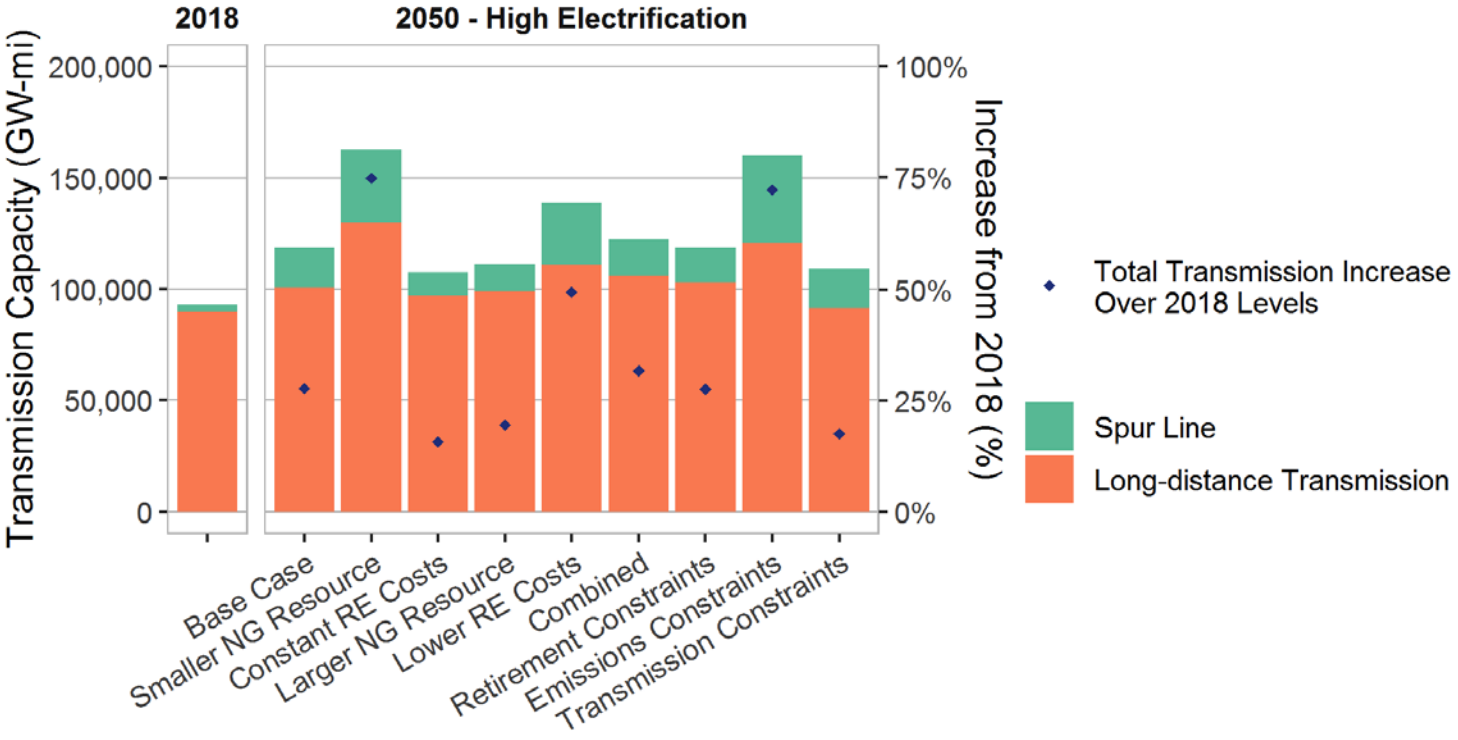


The future electricity supply mix depends on uncertain technology, market, and policy conditions

Murphy et al. (2020), *Electricity Journal,* https://doi.org/10.1016/j.tej.2020.106878



Murphy et al. (2021), https://www.nrel.gov/docs/fy21osti/72330.pdf



The corresponding expansion of long-distance transmission capacity is correlated with growth in renewable energy sources

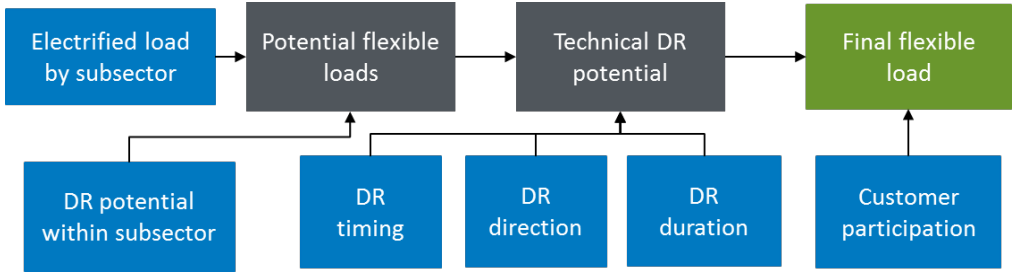
Murphy et al. (2021), https://www.nrel.gov/docs/fy21osti/72330.pdf

Finding 2

Electrification inherently increases the reliance of demand sectors on electricity and could offer enhanced opportunities for more-active participation from flexible loads in planning and operations

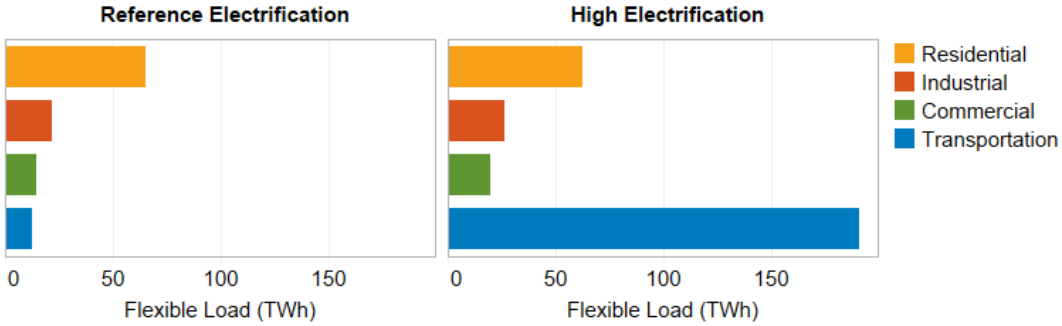
Modeling demand-side flexibility

- Demand-side flexibility modeled as shiftable load and parameterized by **timing, duration, direction, and participation**
- Three levels of demand-side flexibility modeled: *Current, Base,* and *Enhanced*
- Amount and nature of flexibility depends on electrification, with greater potential for flexibility primarily from **optimized EV charging** but also **managed building and industrial loads**



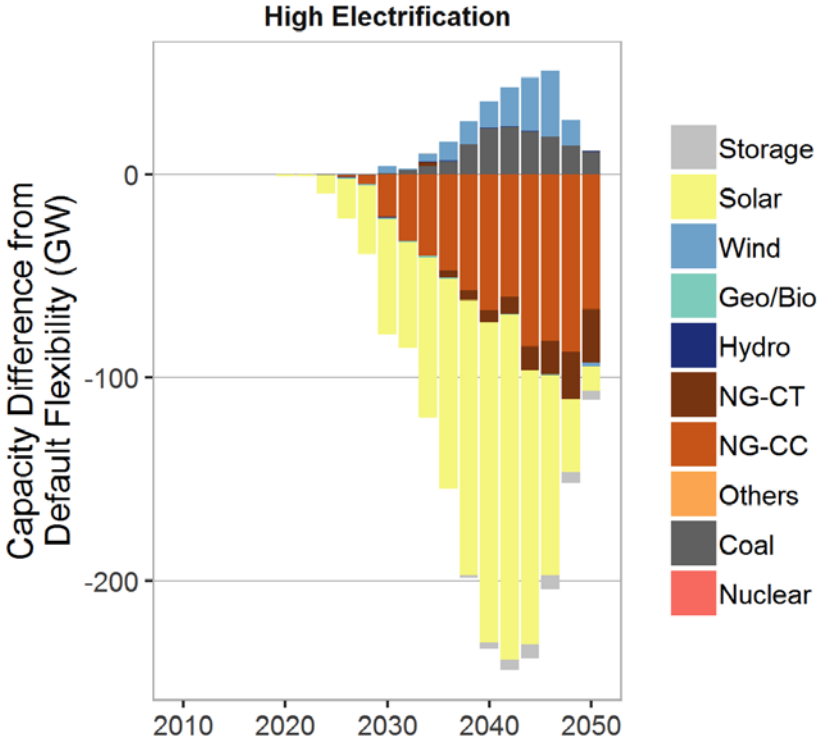
% of total 2050 load that is flexible:

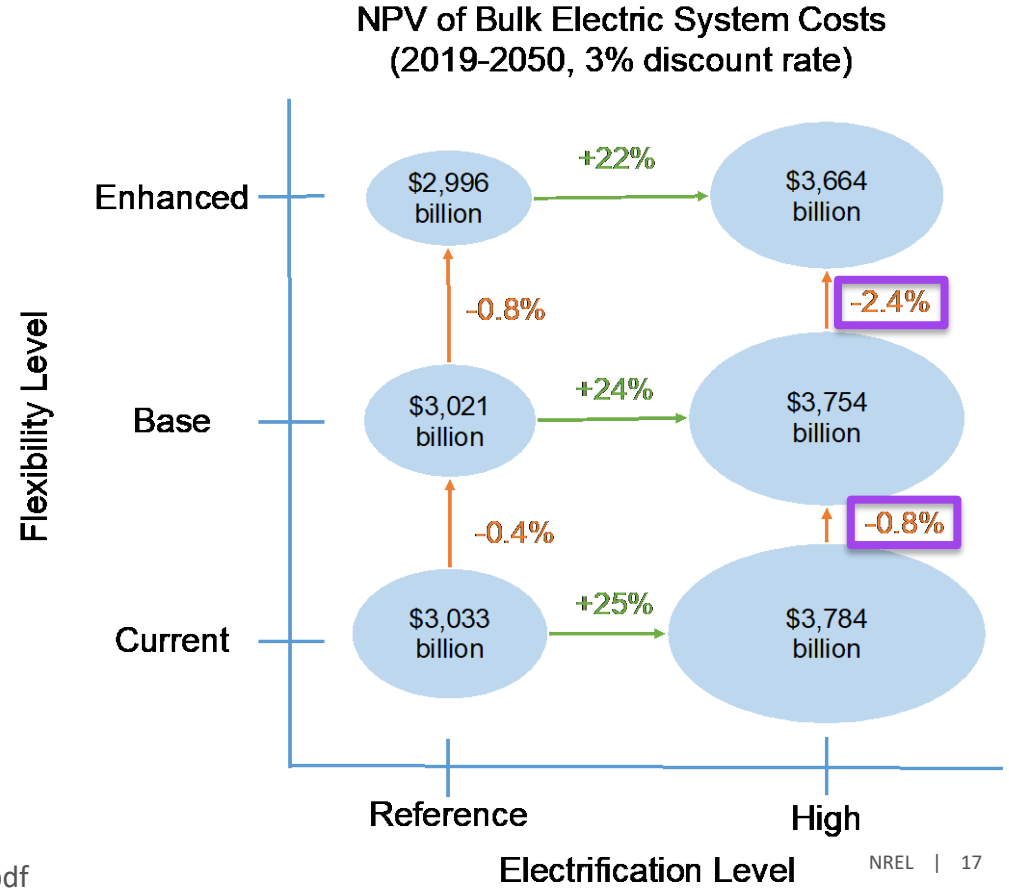
1% Current	1% Current
2% Base	4% Base
7% Enhanced	17% Enhanced



Murphy et al. (2021), https://www.nrel.gov/docs/fy21osti/72330.pdf

Flexible loads can mitigate some of the power sector infrastructure needs and associated costs from electrification

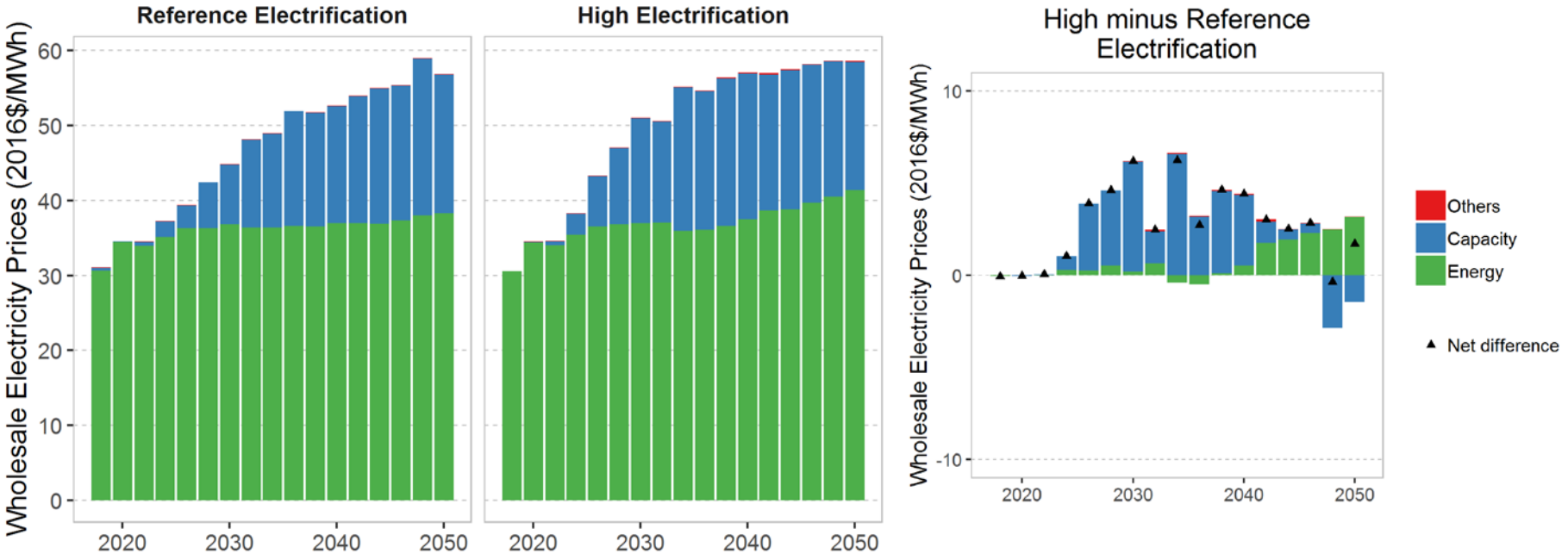




Murphy et al. (2021), https://www.nrel.gov/docs/fy21osti/72330.pdf

Finding 3

There are abundant resources in the United States with similar costs to meet potential electrification-driven growth in electricity demand

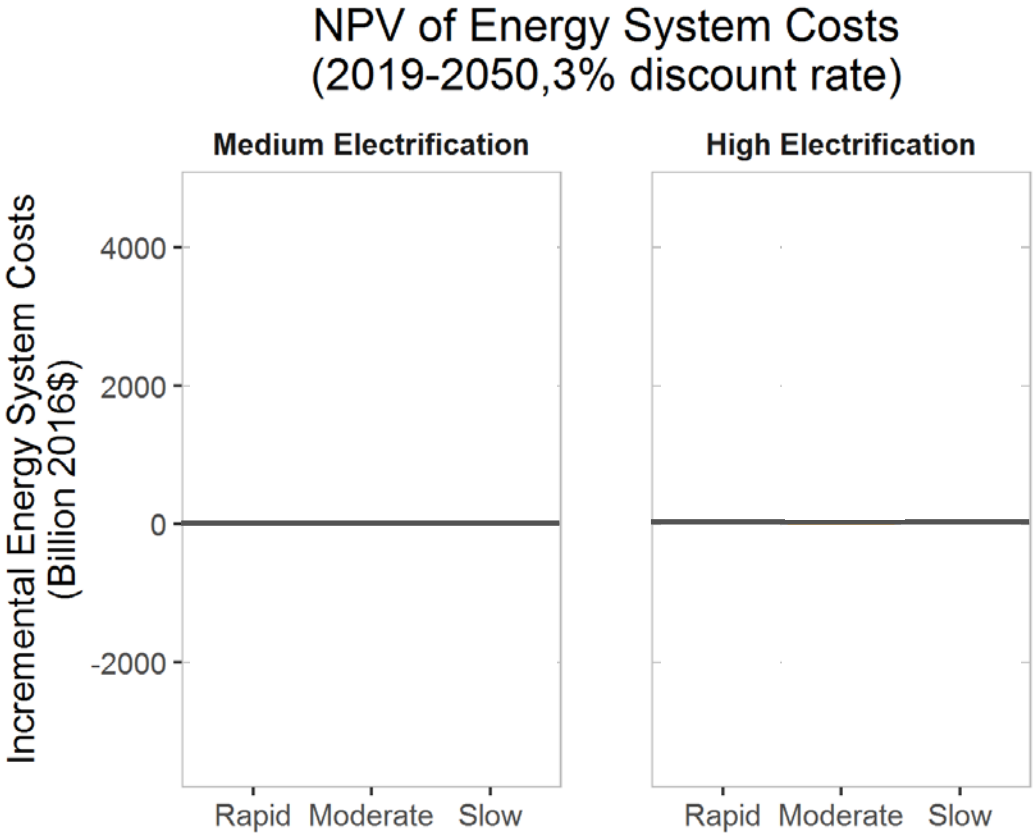


- Future electricity prices can be highly **sensitive** to future technology, market, and policy conditions
- But *incremental* 2050 prices are **<$5/MWh** under all conditions modeled

Murphy et al. (2021), https://www.nrel.gov/docs/fy21osti/72330.pdf

Finding 4

Considering system costs across the energy sector, the net effect of electrification depends most significantly on future advancements in the cost and efficiency of electric end-use technologies

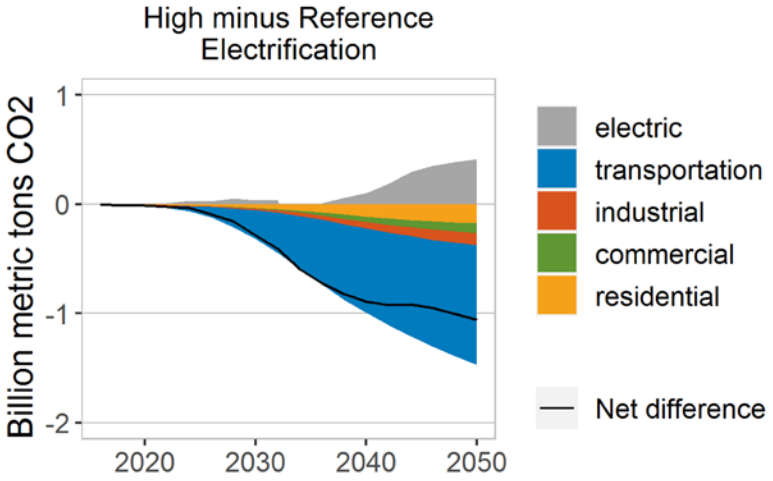


Murphy et al. (2021), https://www.nrel.gov/docs/fy21osti/72330.pdf

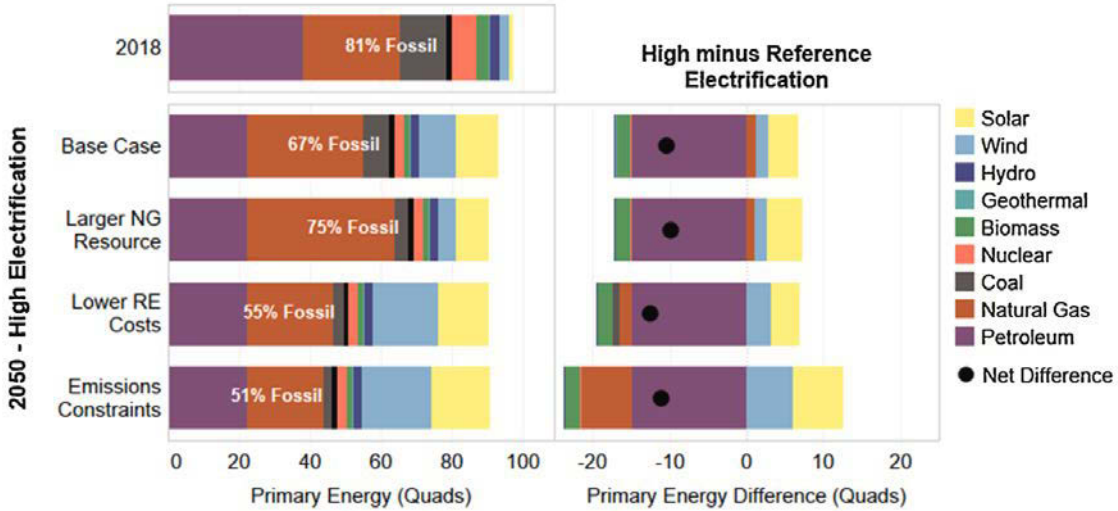
Finding 5

Electrification shifts energy consumption and emissions from the demand sectors into the power sector, the net effect of which is energy system-wide reductions in both

CO_2 Emissions

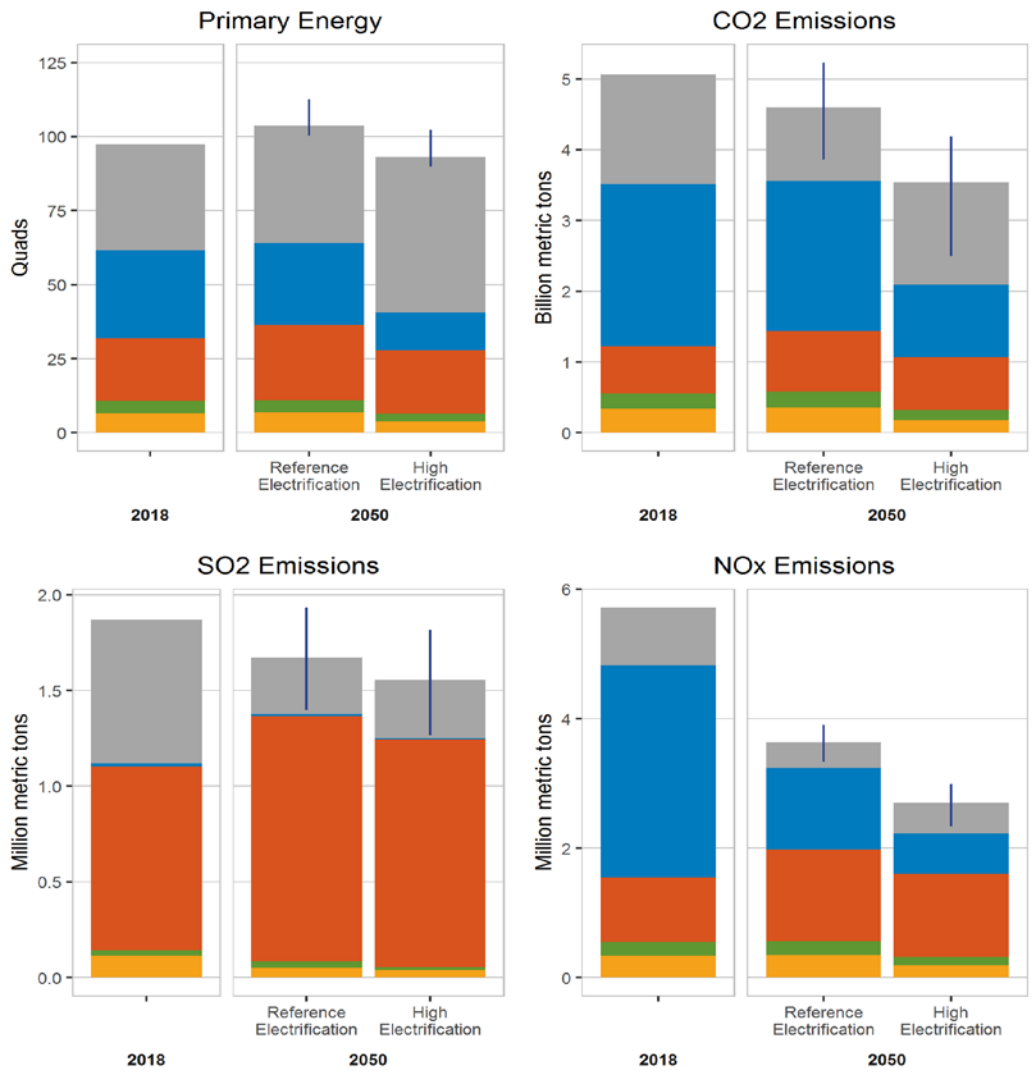


Primary Energy



Murphy et al. (2020), *Electricity Journal,* https://doi.org/10.1016/j.tej.2020.106878

Murphy et al. (2021), https://www.nrel.gov/docs/fy21osti/72330.pdf



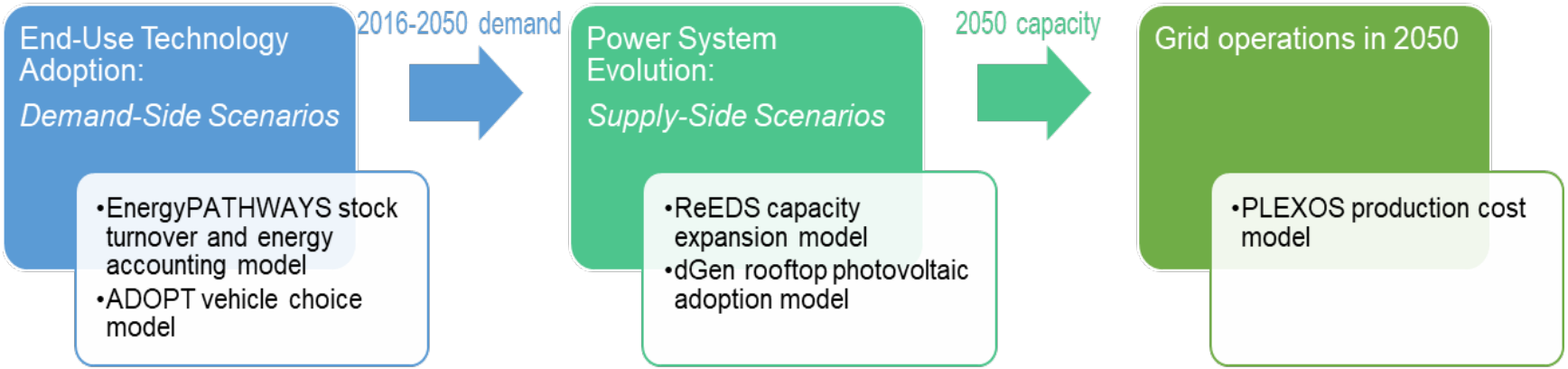
Explore the data for yourself!

EFS Scenario Viewer

Murphy et al. (2021),
https://www.nrel.gov/docs/fy21osti/72330.pdf

Looking forward

EFS Workflow



EFS Workflow

End-Use Technology Adoption:
Demand-Side Scenarios

- EnergyPATHWAYS stock turnover and energy accounting model
- ADOPT vehicle choice model

2016-2050 demand

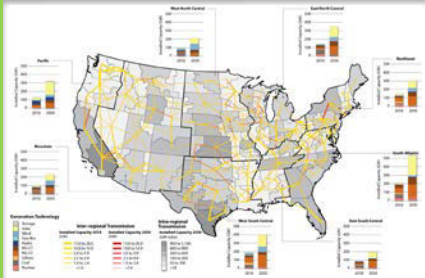
Power System Evolution:
Supply-Side Scenarios

- ReEDS capacity expansion model
- dGen rooftop photovoltaic adoption model

2050 capacity

Grid operations in 2050

- PLEXOS production cost model



PLEXOS BY ENERGY EXEMPLAR

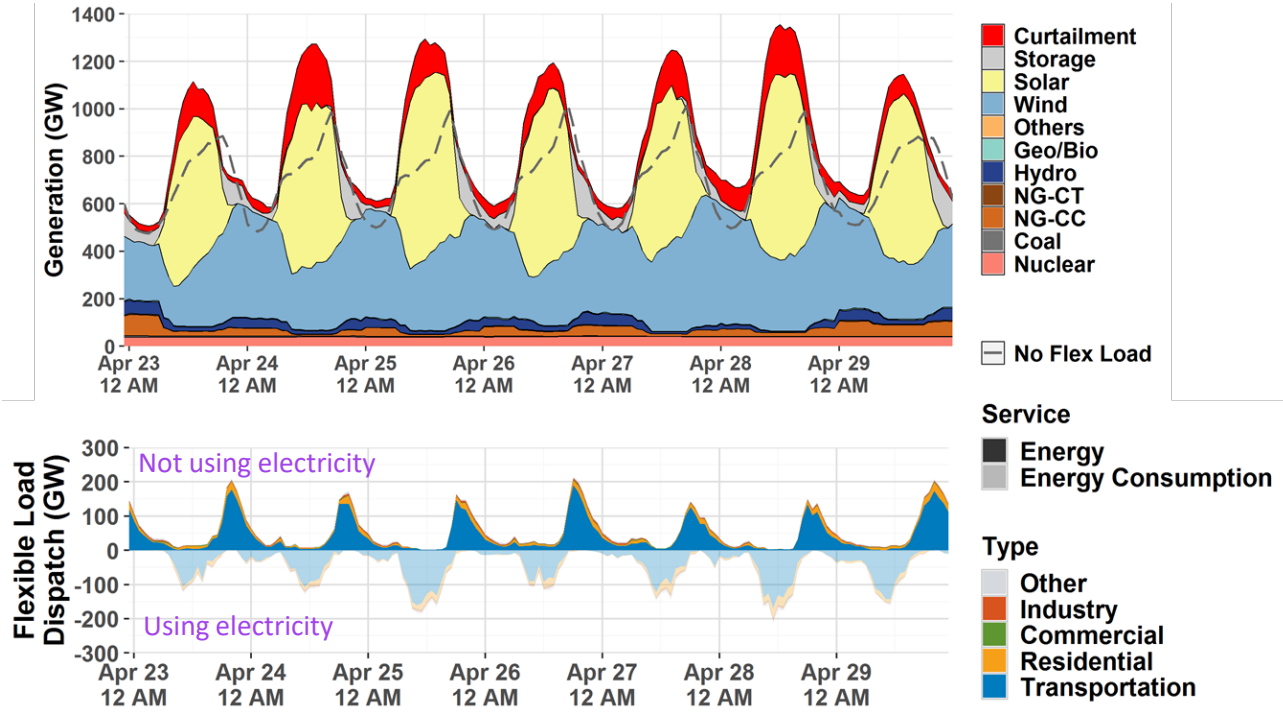
- Individual units for thermal generators
- Operating reserves represented
- 14 demand-side flexibility objects per BA

Select Metrics for PLEXOS Analysis	
Model Formulation	Hourly, Zonal, MIP
Year of Analysis	2050
VRE Penetration	40%-66%
Electrification	Reference-High
Flexibility	No-Moderate-High

Scope and Preliminary Results for PLEXOS Analysis

Topics to be discussed:

1. Feasibility of power system operations under high electrification and high-VRE penetration, considering resource adequacy and economics
2. The role(s) that demand-side flexibility could play to support adequate operations of the bulk power system under a highly electrified future



Recent and ongoing related research at NREL

- See the www.nrel.gov/efs for more information
  - Hourly demand data
  - Scenario data viewer
- Standard Scenarios - www.nrel.gov/analysis/standard-scenarios.html
- Annual Technology Baseline – Electricity and Transportation – atb.nrel.gov
- Demand-side grid (dsgrid) - www.nrel.gov/analysis/dsgrid.html
- Transportation Energy & Mobility Pathway Options (TEMPO) - www.nrel.gov/transportation/tempo-model.html

Thank you from the EFS Team!


Elaine Hale


Kelsey Horowitz


Ry Horsey


Paige Jadun


Jeff Logan


Trieu Mai


Colin McMillan


Matteo Muratori


Caitlin Murphy


Dan Steinberg


Yinong Sun


Laura Vimmerstedt


Eric Wilson


Ella Zhou


Devonie McCamey


Mike Meshek

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

EVOLVED ENERGY RESEARCH

OAK RIDGE National Laboratory

U.S. DEPARTMENT OF ENERGY

NORTHERN ARIZONA UNIVERSITY

EPRI

Questions? Thank you.

caitlin.murphy@nrel.gov

trieu.mai@nrel.gov

+ EFS team

www.nrel.gov/efs

NREL/PR-6A20-78783

This work was authored by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by the U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Office of Strategic Programs. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government. The U.S. Government retains and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for U.S. Government purposes.

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Electrification: Scope and Definitions

- **Electrification**: the shift from any non-electric source of energy to electricity at the point of final consumption
  - Direct electric technologies only
  - Not exploring new sources of demand

- **Contiguous U.S. energy system**, including transportation, residential and commercial buildings, industry
  - Sectors cover **74% of primary energy in 2015**
  - Excludes air transport, petroleum refining and mining, CHP, outdoor cooking