Electricity is integral to our daily lives—and increasingly so.
Yet total growth in electricity demand has slowed

While U.S. population, GDP, and end-use services have all increased and changed in complex ways
• Development of **advanced electric technologies** has driven adoption in key sectors—especially in vehicles, but also for businesses and homes
• Local policies and economic incentives support electrification to **reduce emissions**, **improve air quality**, and **increase energy security**
• Electric utilities are carefully watching to see if electrification has the potential to **increase sales and revenues**
So how do we plan for widespread electrification?
EFS: The Electrification Futures Study

nrel.gov/EFS
NREL-led collaboration, multi-year study

Collaborators from:

- EPRI
- Evolved Energy Research
- Northern Arizona University
- Oak Ridge National Laboratory
- Lawrence Berkeley National Laboratory
- U.S. Department of Energy

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

- Strategic Energy Analysis
- Transportation and Hydrogen Systems
- Buildings and Thermal Systems

+ Technical Review Committee of 19 experts from industry and consultants, labs, government, NGOs
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?
Progress to date

- Technology cost and performance (December 2017)
- Demand-side adoption scenarios (June 2018)
- dsgrid model documentation (coming soon)
- Supply-side evolution scenarios (2019)
- Impacts of electrification (2019)
- Electricity system operations (~2020)
- Value of demand-side flexibility (~2020)

Note: Future work scope is tentative
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
  - Isolating electrification from other changes

- **Contiguous U.S. energy system**, including transportation, residential and commercial buildings, industry
  - Sectors cover **74% of primary energy in 2015** (79% of energy-related CO₂)
  - Excludes air, petroleum refining and mining, CHP, outdoor cooking

- **Focus on 2050**, but transition modeled as well
Technology Cost and Performance Data Report (December 2017)

https://www.nrel.gov/docs/fy18osti/70485.pdf
Foundational technology data

- Three technology advancement trajectories (slow, moderate, rapid) for **buildings** and **transportation** technologies
- Literature-based summary of **industrial** electrotechnologies

**Key Technologies:**
- Light-duty and heavy-duty vehicles, buses (multiple range PHEVs and BEVs)
- Air-source heat pumps (including cold-climate ASHPs)
- Heat pump water heaters
Commercial ASHPs installed cost and efficiency projections

Levelized cost of driving (2020 Moderate)
Looking at the demand side

OBJECTIVES
Characterize changes to end-use sectors under futures with increasing levels of electrification
Quantify how electrification impacts total electricity demand and consumption profiles

APPROACH
Expert judgment adoption projections and consumer choice modeling
Bottom-up stock and energy accounting model (EnergyPATHWAYS)

USES
Provides data for evaluating future electricity supply scenarios
Gives researchers and decision-makers data and context to plan for an electrified energy system
Technology adoption and energy transitions generally follow characteristic **S-curve shape**

- **Invention** → **Innovation** → **Niche Market** → **Pervasive Diffusion** → **Saturation** → **Senescence**
Method in brief:  
Electrification follows a similar trend

Example for light-duty vehicles

Sales shares determined from a combination of expert judgment based on current trends & consumer choice models (e.g., NREL ADOPT model for LDVs)

EnergyPATHWAYS model used for stock rollover and detailed energy accounting

Principles: technology-rich assessment, bottom-up accounting, cross-sectoral breadth, national scope with state-level detail
Scenarios

- **Reference**: Least incremental change (~AEO2017)
- **Medium**: Widespread electrification among low-hanging fruit opportunities
- **High**: Transformational electrification
  - *focus of this presentation*
- + end-use technology advancement sensitivities

Scenarios designed for assessment of isolated impacts of electrification
Scenarios are not forecasts or predictions
What we found:

Key takeaways by sector
Transportation sector

• Significant opportunities exist for electric vehicles, in part because electricity currently provides <1% of total transportation energy needs
• Light-duty plug-in electric cars and trucks drive the greatest overall electrification impact in all scenarios
• But electric freight trucks can play a major role, particularly for short-haul applications and in more transformational scenarios
• Transit buses are prime candidates for electrification
Transportation sector details

- 2050 U.S. transportation fleet (High scenario):
  - **240 million** light-duty plug-in electric vehicles
  - **7 million** medium- and heavy-duty plug-in electric trucks
  - **80 thousand** battery electric transit buses
- Together these deliver up to **76%** of miles traveled from electricity in 2050
- 138,000 DCFC stations (447,000 plugs) and 10 million non-residential L2 plugs for light-duty vehicles
Key questions in transportation electrification

• Will battery costs continue to decline, and will battery performance continue to improve?
• How might consumer preference—range anxiety, acceleration, automation—and technology development evolve?
• Will EVSE infrastructure enable or impede electrification?
• How will ownership models—for vehicles and chargers—evolve and impact utility planning? How might utility-controlled charging and vehicle-to-grid services affect energy use and adoption?
Buildings sector

• Electricity already powers a significant share of buildings end-use services
• Electrification opportunities in buildings are most significant for space and water heating
• Air-source heat pumps are the key buildings electrification technologies
• Electric equipment provides up to **61% of space heating**, **52% of water heating**, and **94% of cooking services** in the combined commercial and residential building sectors by 2050 *(High scenario)*

• Would require dramatic change in appliance manufacturing and installations (170 million heat pumps in 2050*)

*Heat pumps include ASHPs and geothermal heat pumps (sales shares of geothermal heat pumps reach 3% by 2050 for commercial space heating in the High scenario)
Key questions in buildings electrification

- Will advancements in **cold-climate** heat pumps be sufficient to enable widespread adoption?
- Will new technologies facilitate electrification in **retrofits** and new buildings?
- How might **challenges** to buildings electrification—cultural acceptance, familiarity, landlord-tenant issues—be overcome?
- How might **value streams** through “smart” and “grid-connected” appliances affect consumer adoption?

Non-uniform adoption of ASHPs in commercial buildings (2012)
Industrial sector

• Industry experienced early electrification and sustained growth, but electricity consumption has been flat since ~1990
• Heterogeneity of industries prevents broad generalizations
• Limited industrial data create challenges for assessing electrification opportunities
• We focus on industrial process heating
Industrial sector details

- Industrial electrification is more muted compared to other sectors

- Most-significant growth for electrotechnologies with **productivity benefits**: improved product quality, higher throughput, reduced scrap and labor costs

- In the **High** scenario, electrotechnologies provide **63% of curing** needs, **32% of drying** services, **56% of other process heating**
Key questions in industrial electrification

• Will **productivity benefits** from electrotechnologies overcome potentially higher costs and other adoption barriers, especially when energy costs comprise a small share of total costs?

• Can cost-effective technologies for **high-temperature** applications be developed?

• How might the interplay between **long equipment lifetimes** and manufacturers’ profit-driven decisions impact the technology transition rate?

    **More data and research are needed!**
What we found:
Overall power system takeaways
Vehicle electrification dominates incremental growth in annual consumption

2050 U.S. electricity consumption increases
• Medium +932 TWh (20%)
• High +1,782 TWh (38%)
However, electric space heating more significantly changes the timing and magnitude of peak demand.
Electrification in **Medium** scenario is loosely consistent with that from favorable “economic” conditions; **High** is closer to transformational scenarios.
Electricity share of final energy **doubles** from 2016 to 2050 under the High scenario

*Note: Sector definitions and scope differ slightly between Historical and Modeled data*
Electrification leads to energy savings

- Greater efficiency of electric technologies yields reductions in final energy consumption by up to 21% (High scenario), relative to the Reference
- Technology improvements could lead to even greater savings
- Impacts to primary energy will depend on generation mix

Note: Does not include all activities, e.g., petroleum refining and extraction excluded
Estimated **fuel use** reductions

- Domestic onsite fuel use reductions: **74% gasoline, 35% diesel, 37% natural gas** in 2050 (High scenario)
- Expands opportunities for greater fuel use for power generation, fuel exports
Next steps
Forthcoming EFS reports

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Thank you

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