NREL
Transforming ENERGY

An Electrified Future

Kelly Eurek, Trieu Mai, Dan Steinberg, Jeff Logan, Dave Bielen, and Collin McMillan

ARUP Electrical Skills Network
Friday April 12, 2019

NREL at a Glance

2,050

Employees,
plus more than
400
early-career researchers and visiting scientists

World-class
facilities, renowned technology experts

nearly
820

Partnerships
with industry, academia, and government

Campus
operates as a living laboratory

Source: NREL (2019).

South Table Mountain Campus
Golden, CO

Source: NREL (2019).

Research Support Facility
Golden, CO

Photo by Dennis Schroeder, NREL 17820

Mesa Top Facility
Golden, CO

Photo by Dennis Schroeder, NREL 30719

Flatirons Campus
Boulder, CO

Photo by Pat Corkery, NREL 17706

Flatirons Campus
Boulder, CO

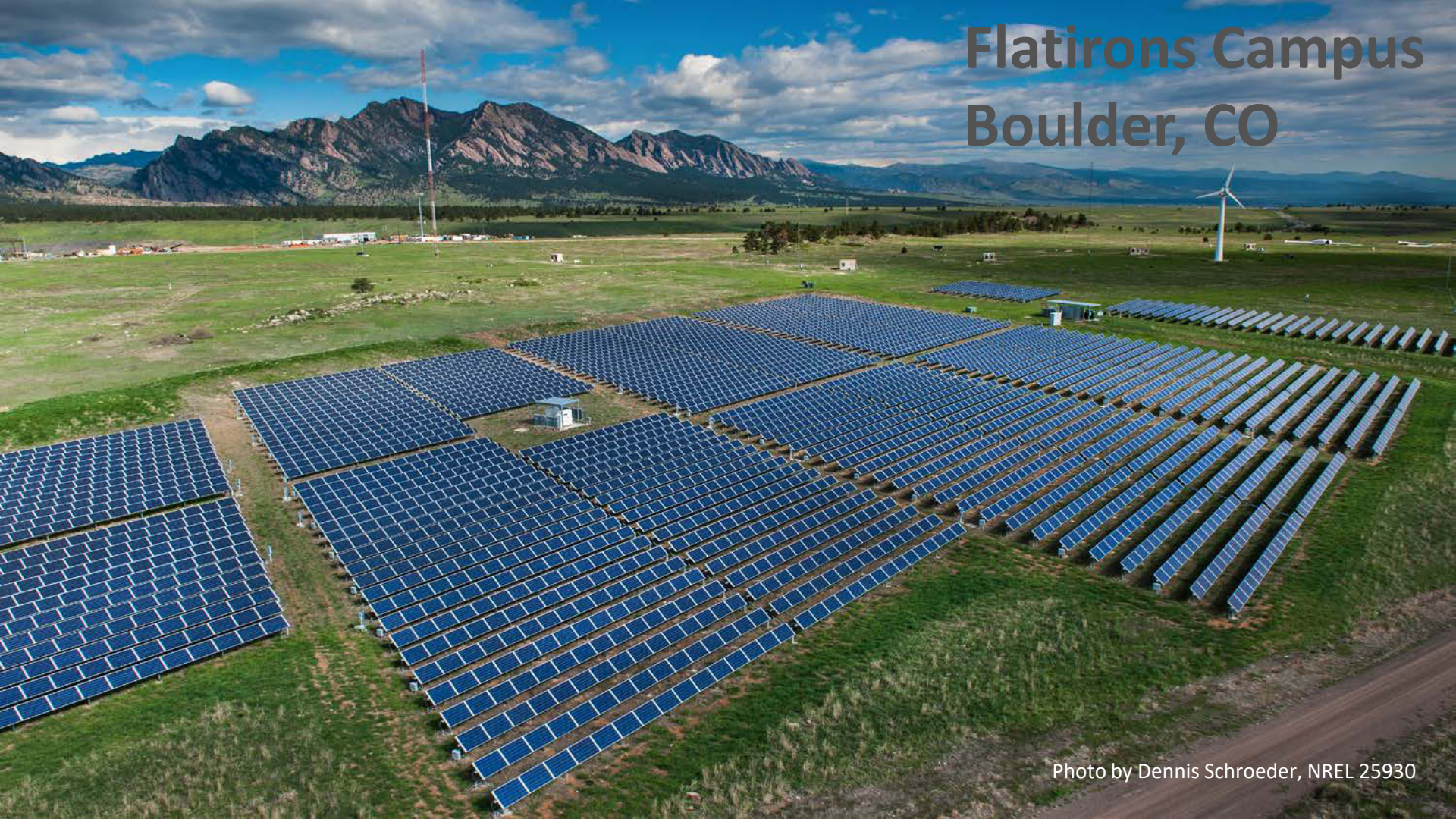


Photo by Dennis Schroeder, NREL 25930

Agenda

- Motivation for Examining Future Electrification
- An Electrified Future (past work)
- Electrification Futures Study (ongoing work)
- Questions and Discussion

Electricity is a versatile fuel

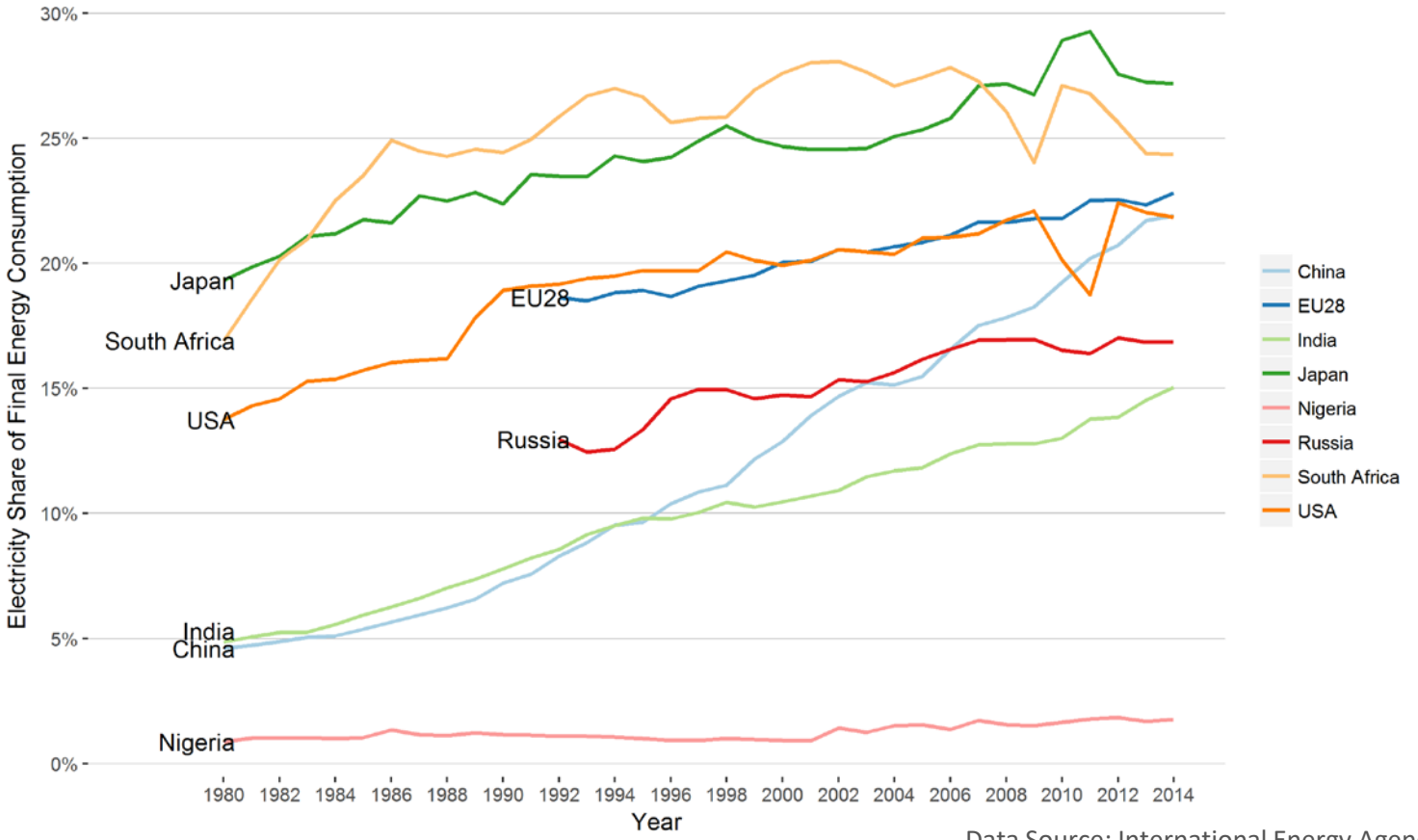
Transportability

Zero Point-of-use Emissions

Flexibility and Controllability

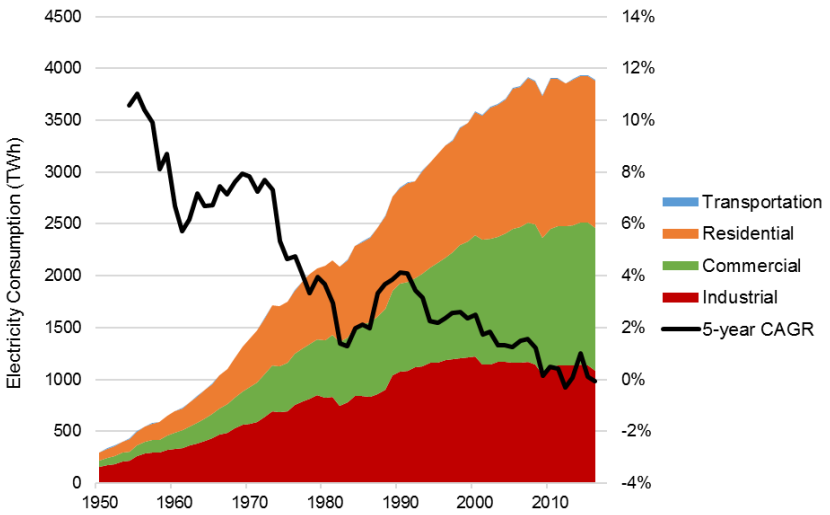
Storability (?)

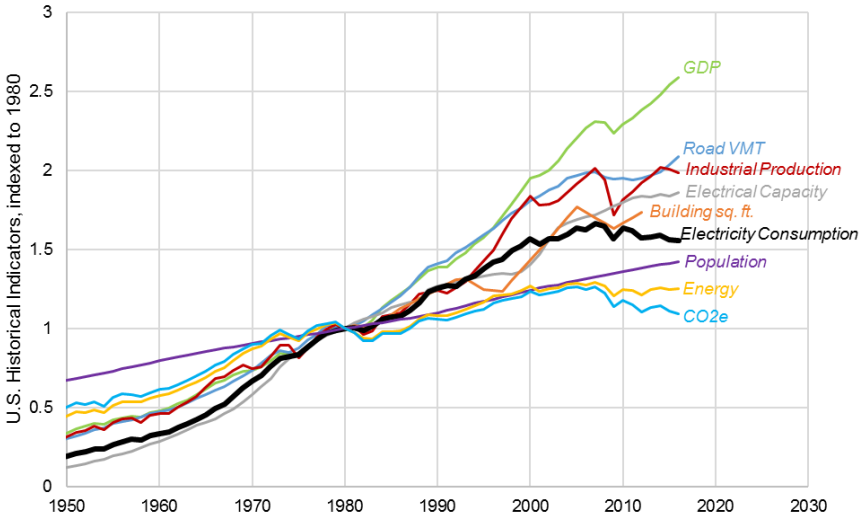
Global trends in electrification



Data Source: International Energy Agency

Yet total growth in US electricity demand has **slowed**





While U.S. population, GDP, and end-use services have all **increased** and changed in complex ways

Source: Mai (2018).

But **greater** electrification may be on the horizon

- 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**

Source: Mai (2018).

Past NREL work on electrification

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Electrification & Decarbonization: Exploring U.S. Energy Use and Greenhouse Gas Emissions in Scenarios with Widespread Electrification and Power Sector Decarbonization

Daniel Steinberg, Dave Bielen,
Josh Eichman, Kelly Eurek, Jeff Logan,
Trieu Mai, Colin McMillan, Andrew Parker,
Laura Vimmerstedt, and Eric Wilson
National Renewable Energy Laboratory

July 2017

NREL is a national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy
Operated by the Alliance for Sustainable Energy, LLC

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

Technical Report
NREL/TP-6A20-68214
July 2017

Contract No. DE-AC36-08GO28308

An Electrified Future

By Trieu Mai, Daniel Steinberg, Jeffrey Logan, David Bielen, Kelly Eurek, and Colin McMillan

July 2018

AS AN ENERGY SOURCE, ELECTRICITY benefits from a number of desirable characteristics: it can be transported at nearly the speed of light with transmission infrastructure, it has zero end-use emissions, it is highly flexible and controllable, it is now storable at rapidly declining costs, and it can offer improved service quality relative to conventional fuels. As such, electrification—the conversion of previously fossil-fueled end-use processes to electricity—has been identified as a key pathway to a clean, reliable, and secure energy future. Electric vehicles are the most widely cited application of electrification, but technology improvements in electrically driven devices for buildings and industrial end uses, including heat pumps for space and water heating needs, induction stoves for cooking, infrared or ultraviolet curing processes, and electric arc furnaces for process heating, could lead to more widespread electrification across these sectors.

In this article, we report results from a recently published initial analysis conducted by the National Renewable Energy Laboratory (NREL) that simulated widespread electrification from present day through 2050 in the United States. The study focused on 1) levels of technically achievable end-use electrification, 2) power-sector capacity expansion needs required to meet the growing demand for electricity

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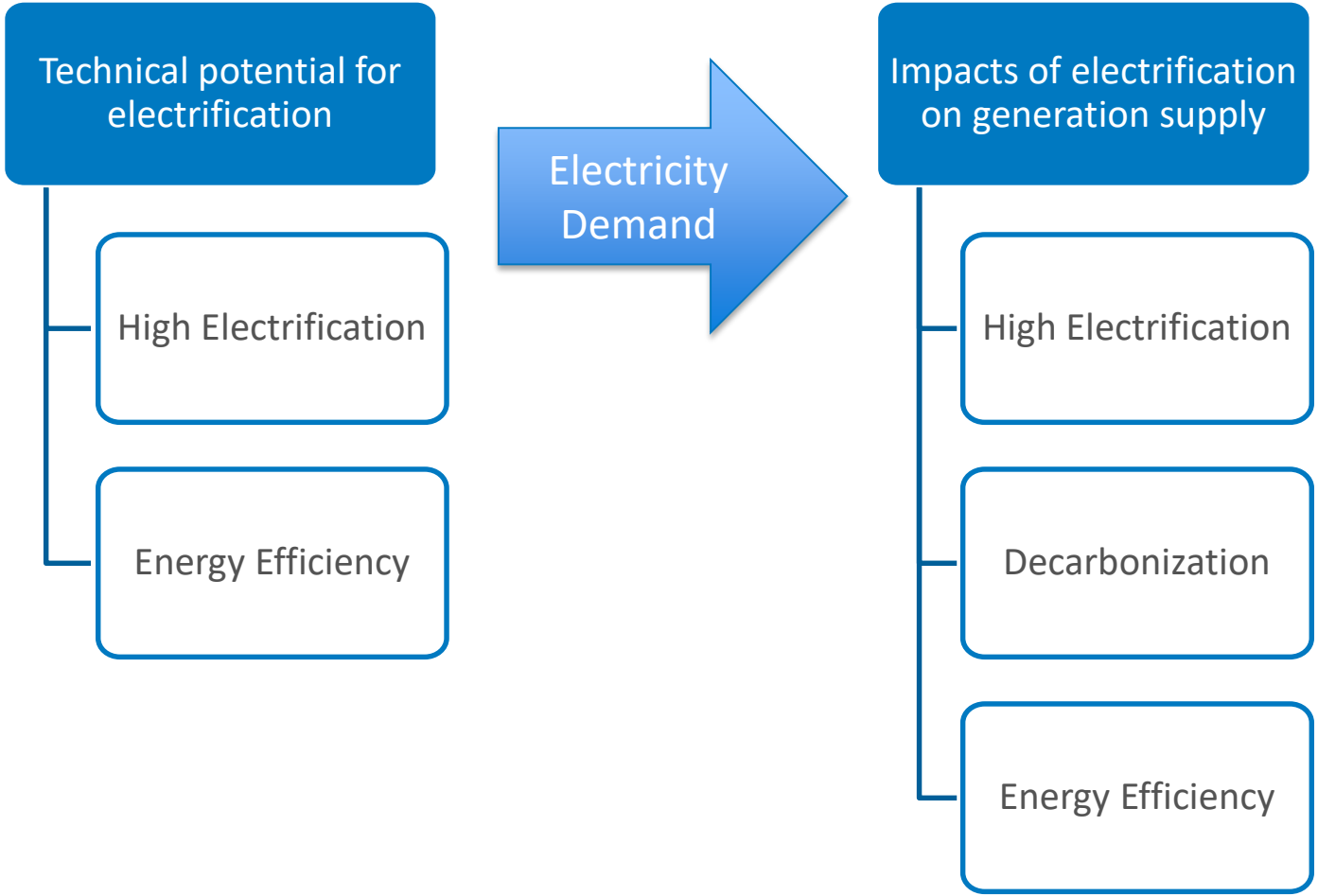
Date of publication: 18 June 2018


Technical potential for electrification
High Electrification
Energy Efficiency
Electricity Demand
Impacts of electrification on generation supply
High Electrification
Decarbonization
Energy Efficiency

Disclaimers

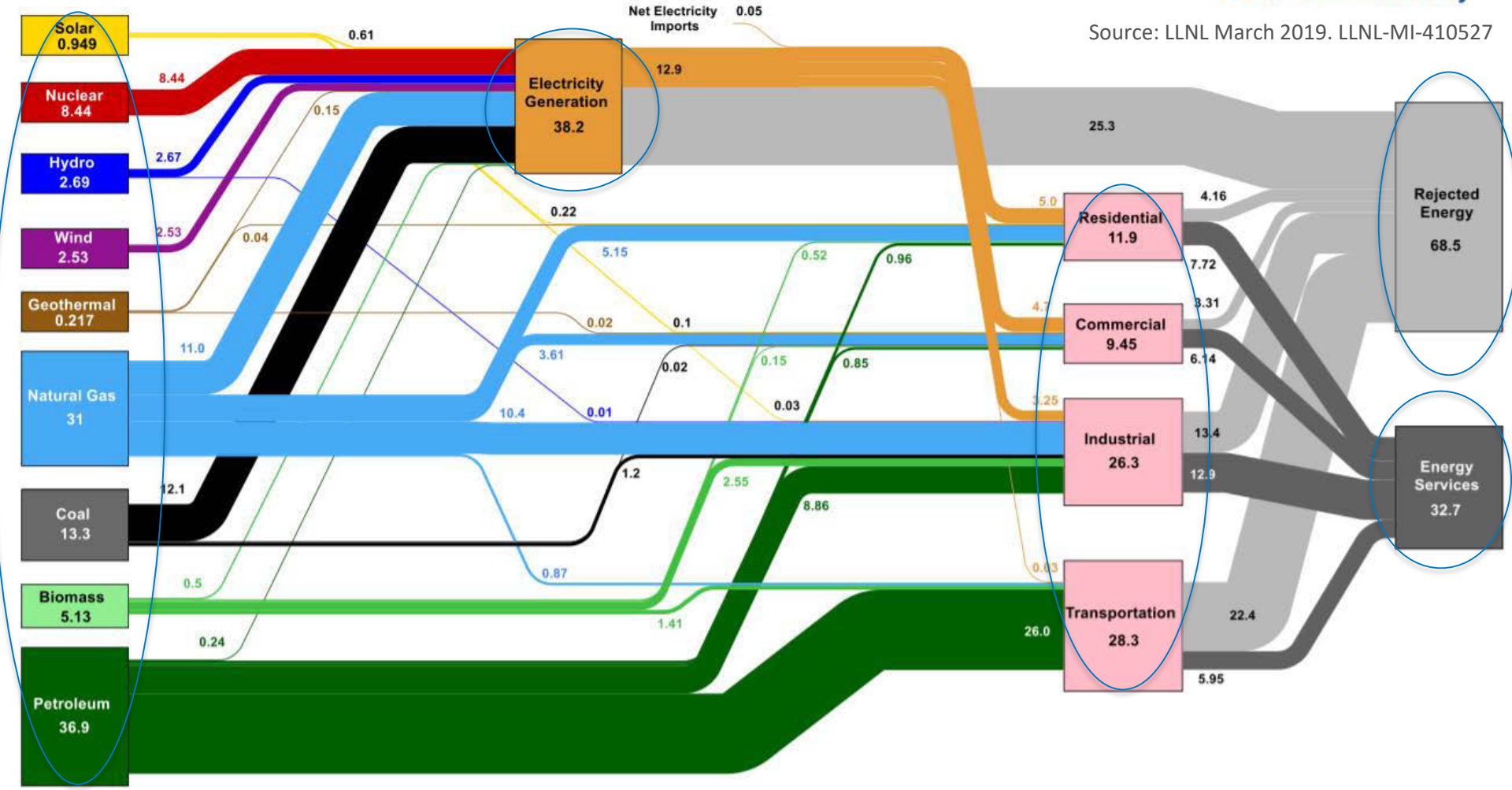
- The objective of this analysis is **not to predict** the specific deployment trajectories for the various technologies.

- **These scenarios are not forecasts,** and we make no claims that our scenarios have been or will be more indicative of actual future electrification or power sector evolution than projections made by others.

Estimated U.S. Energy Consumption in 2018: 101.2 Quads

Lawrence Livermore National Laboratory

Source: LLNL March 2019. LLNL-MI-410527



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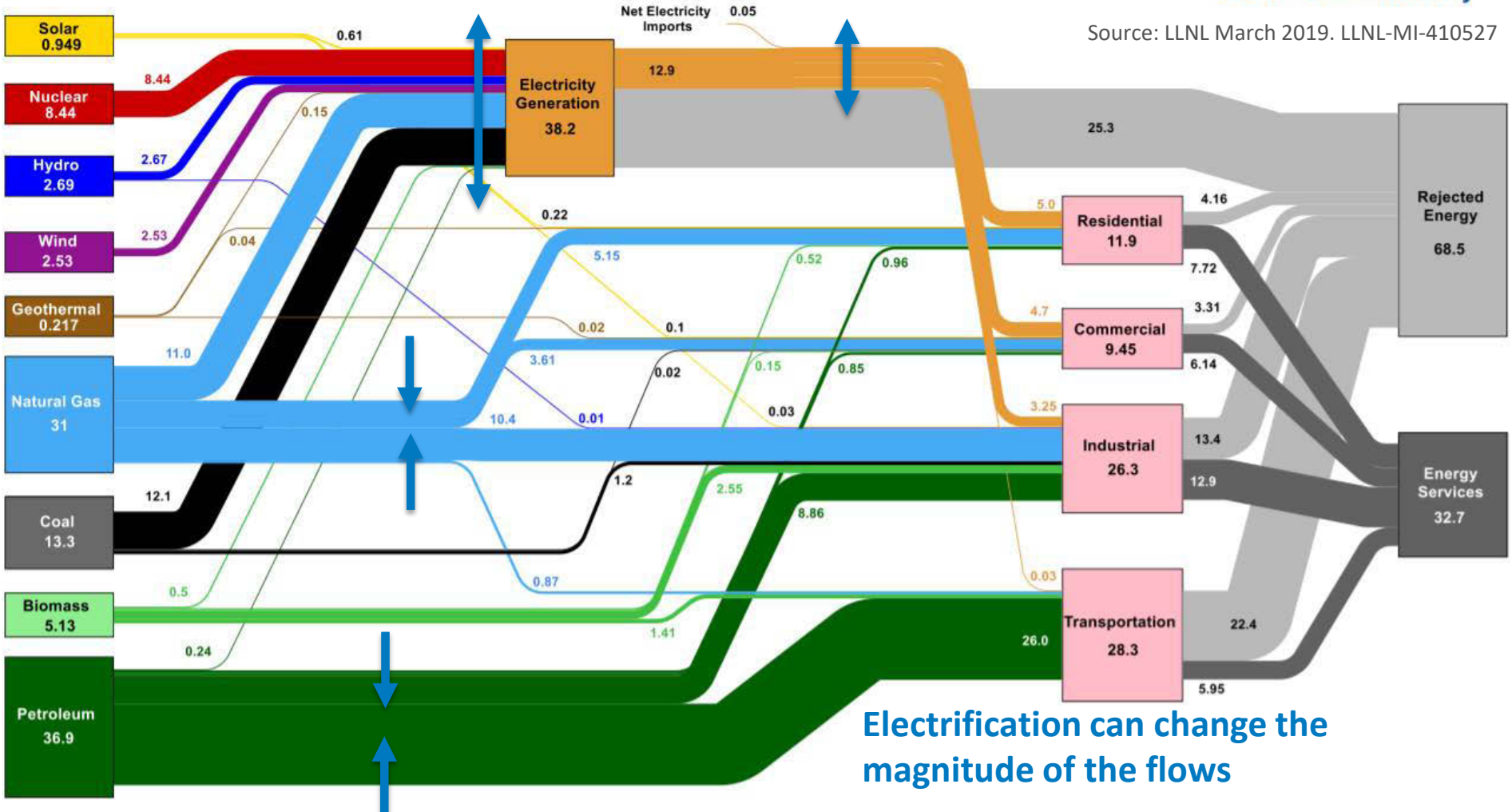


Electrification can change the magnitude of the flows

Residential buildings energy use

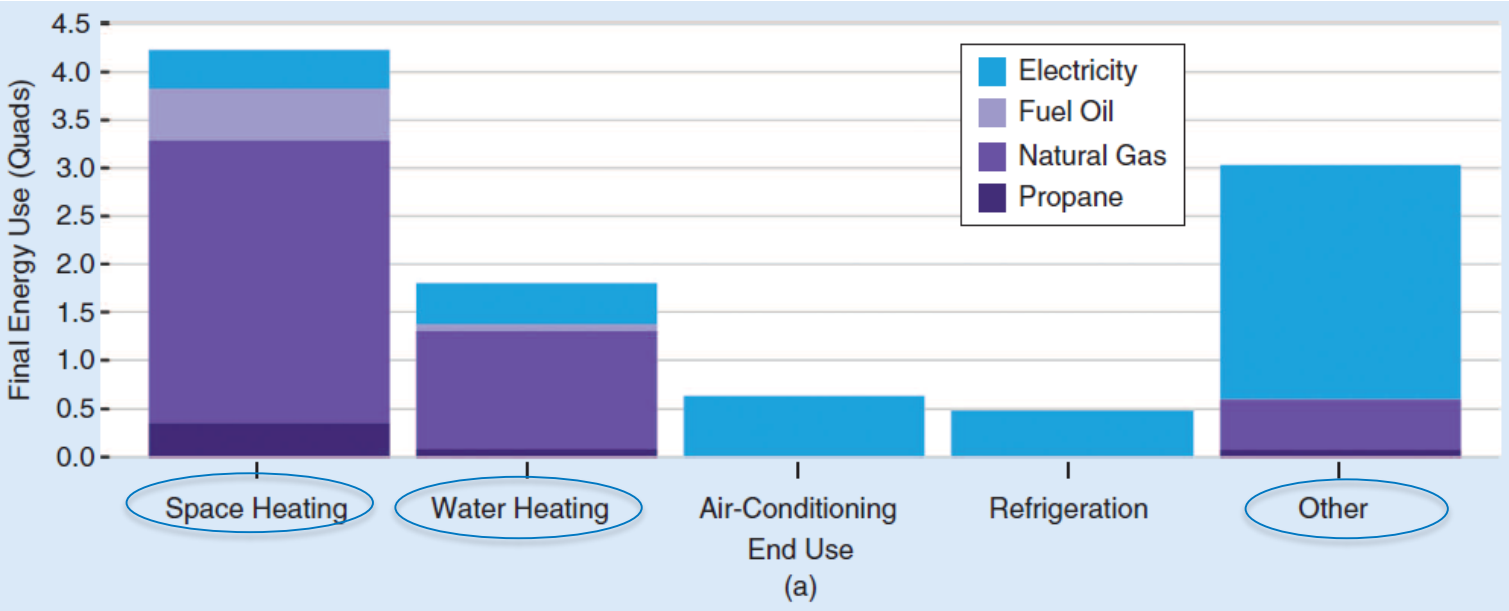
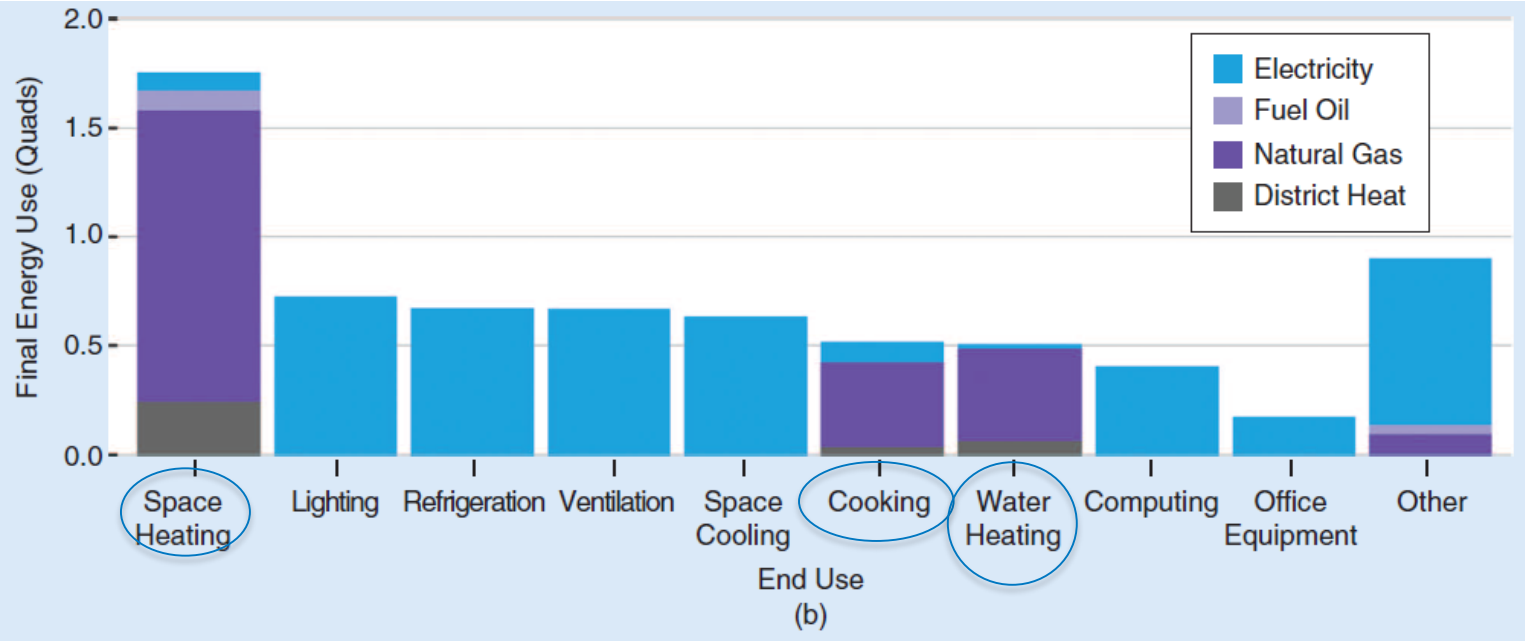


figure 2. Final energy consumption in (a) residential buildings, (b) commercial buildings, and (c) industry sectors by end use and fuel. The data for industry exclude energy consumption as a nonfuel (feedstock). (Data from the EIA 2009 Residential Energy Consumption Survey, EIA 2012 Commercial Buildings Energy Consumption Survey, and EIA 2010 Manufacturing Energy Consumption Survey.)

Source: Mai et al. (2018).

Commercial buildings energy use



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Source: Mai et al. (2018).

Total electricity consumption

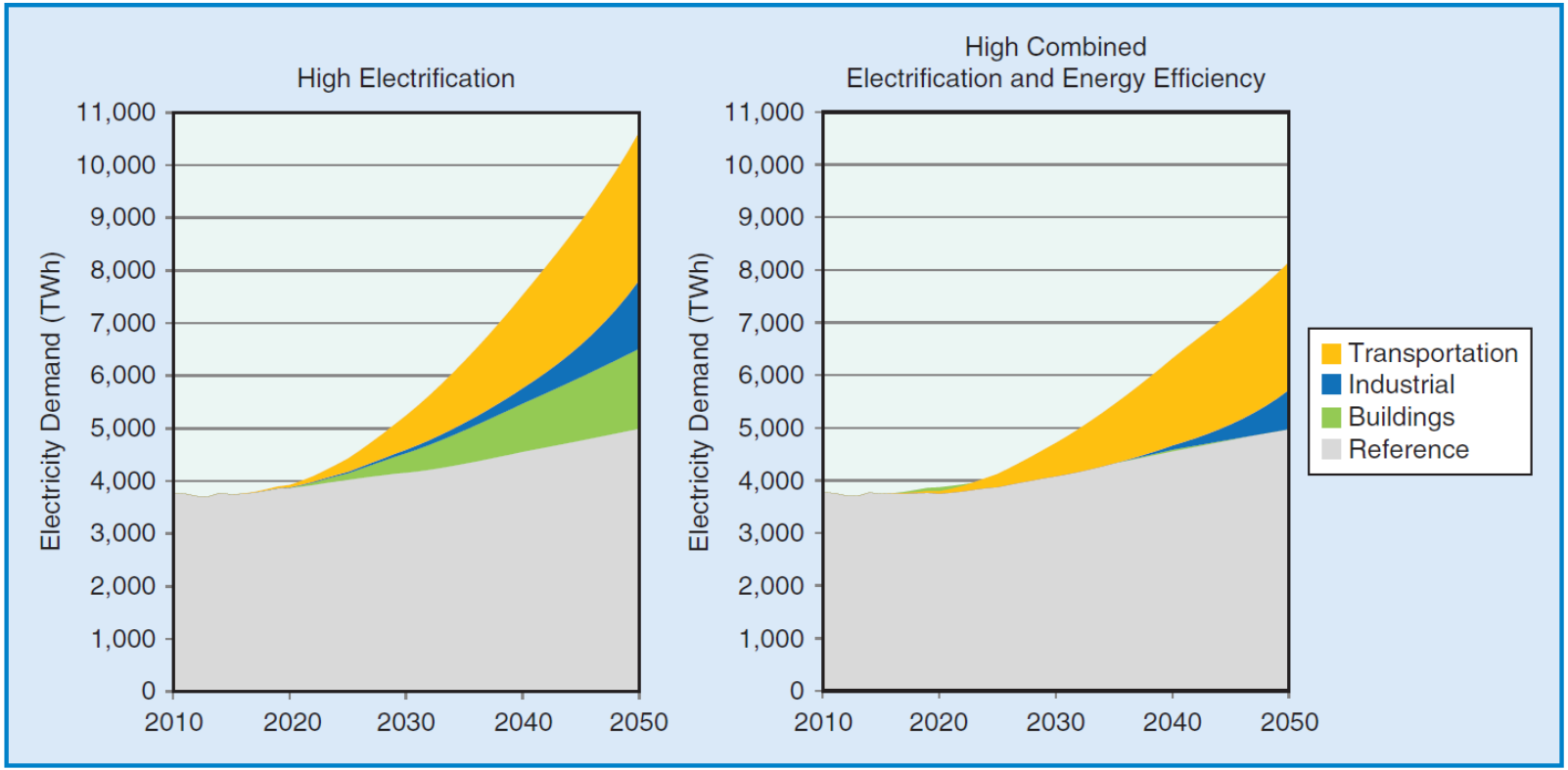


figure 4. The reference and incremental electricity consumption from electrification by sector, 2010–2050.

Source: Mai et al. (2018).

Peak-to-average demand ratio

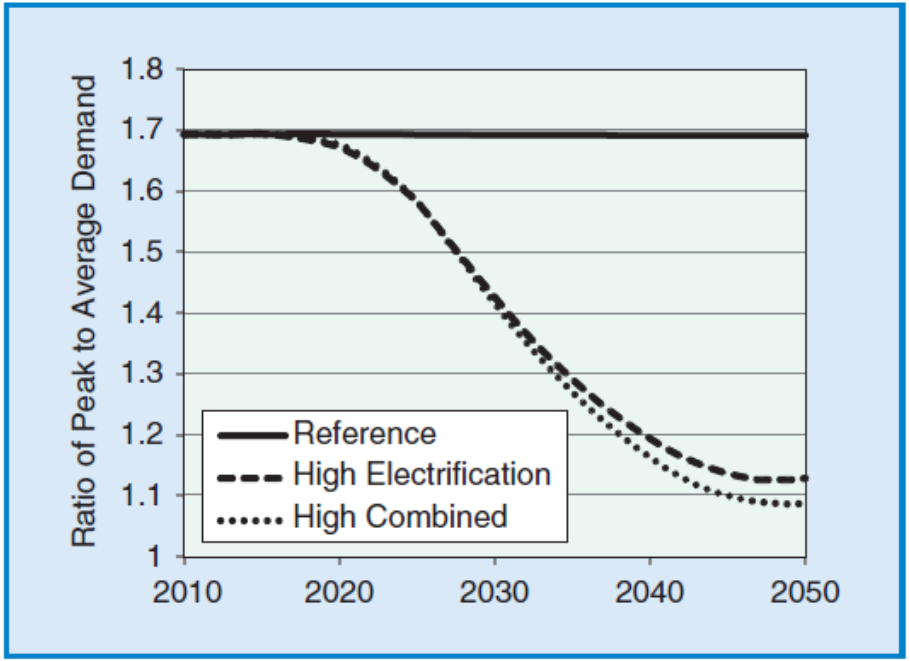
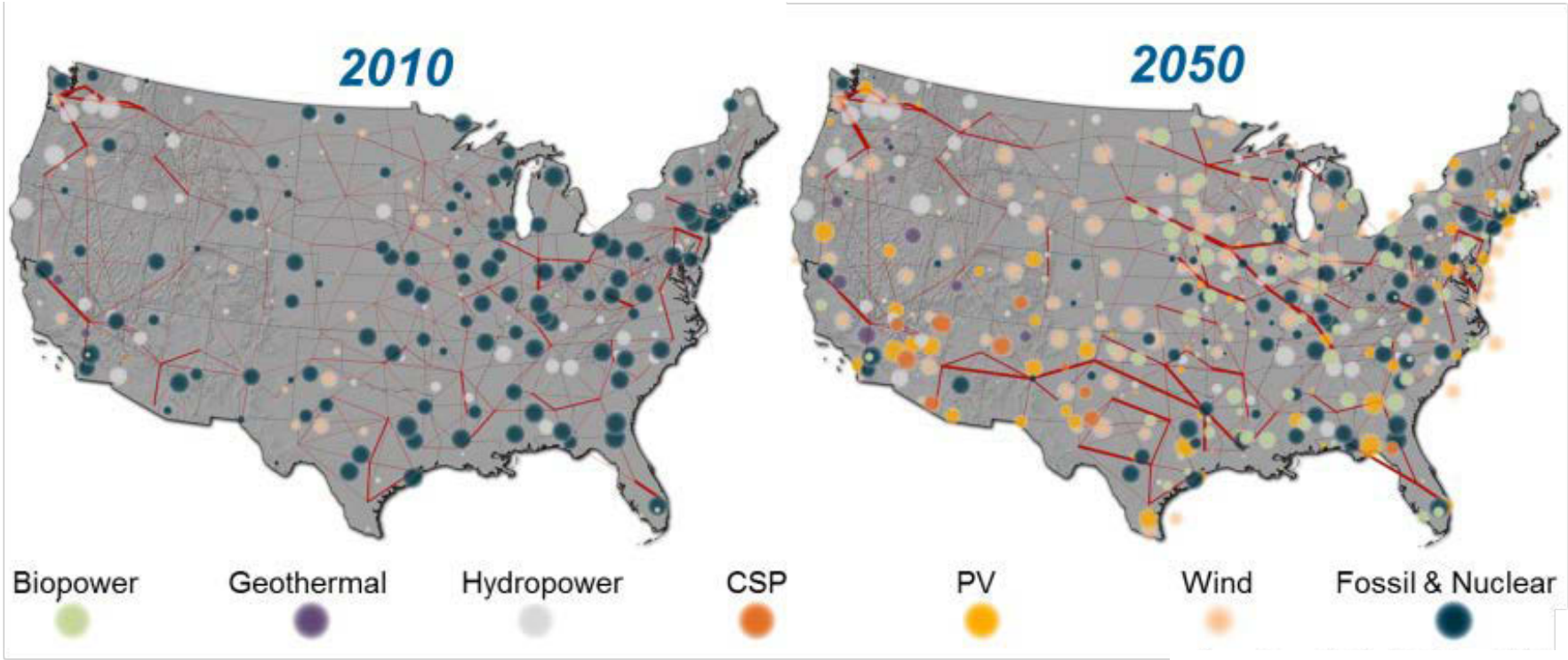


figure 5. The peak-to-average demand ratio for the reference, high-electrification, and high-combined scenarios.

Source: Mai et al. (2018).

Regional Energy Deployment System (ReEDS)



Source: NREL (2012).

Electricity generation mix

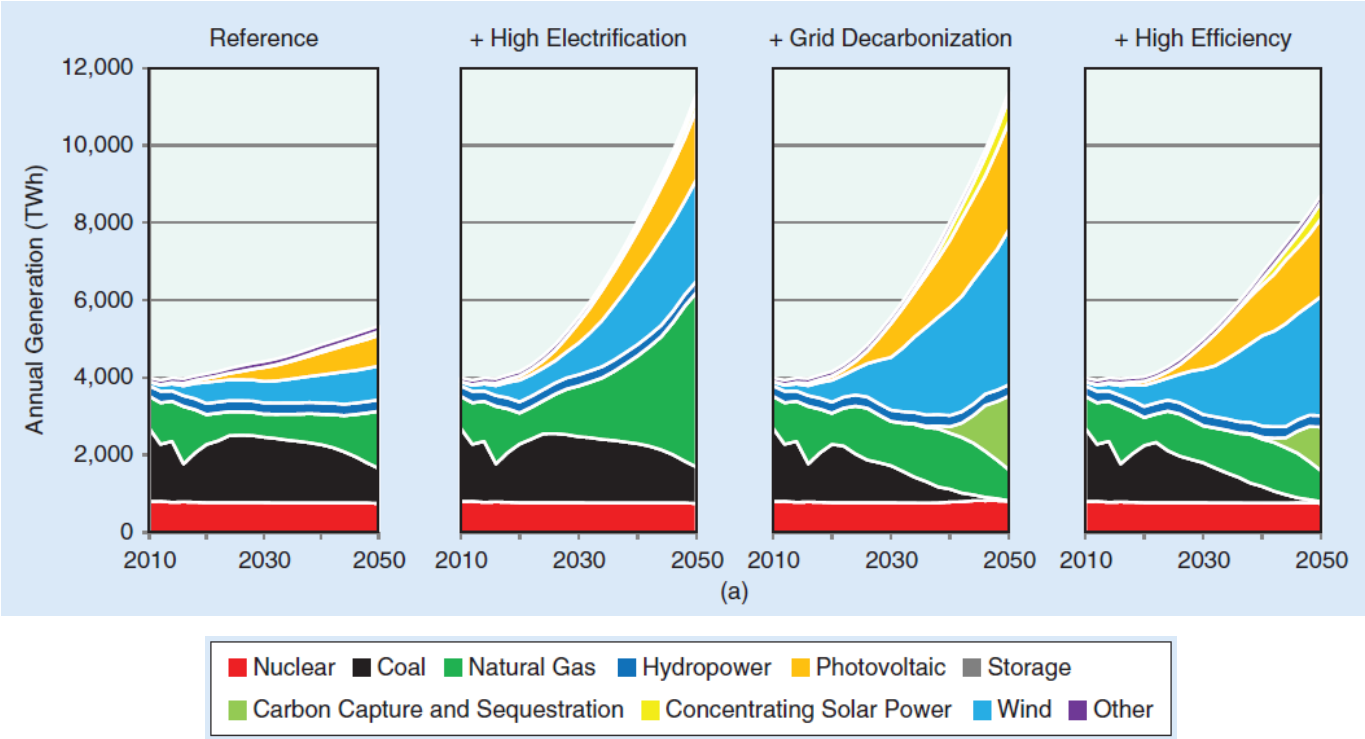


figure 6. The (a) generation and (b) capacity mix over time for various supply- and demand-side scenarios. The first (far left) panel includes both reference demand- and supply-side evolution. The second panel is end-use electrification only. The third panel includes electrification and grid decarbonization (an 83% reduction from 2005 levels in 2050), and the far-right panel combines electrification, grid decarbonization, and end-use energy efficiency.

Source: Mai et al. (2018).

CO2 Emissions – electric power sector

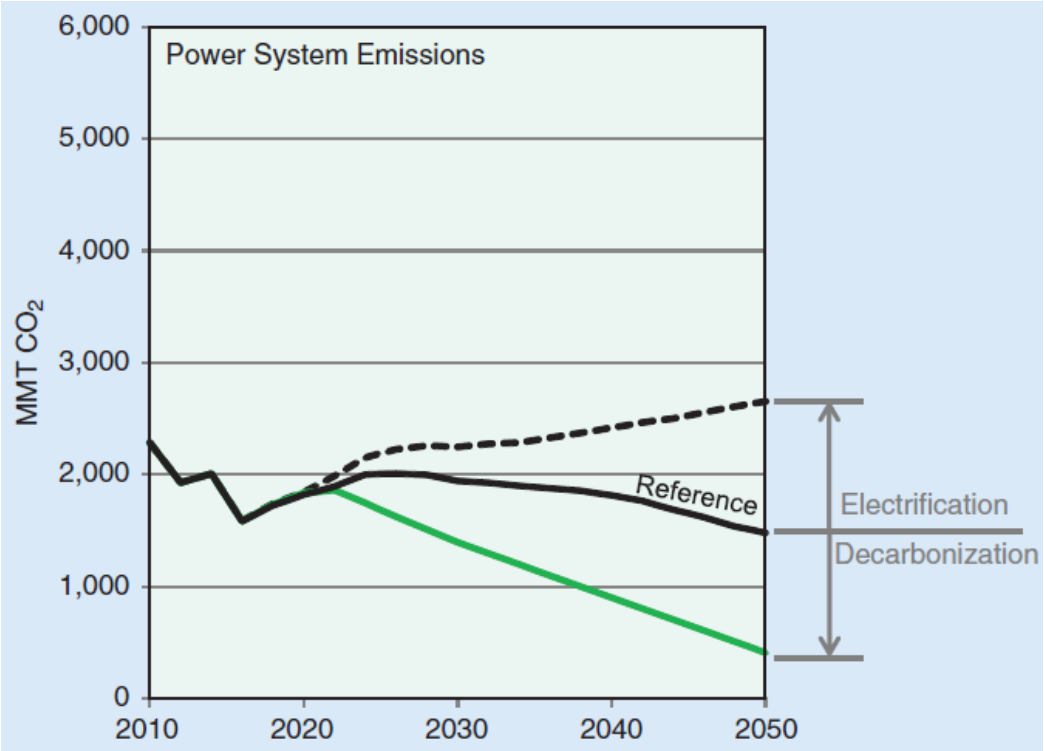


figure 7. Projected energy system and electricity system emissions.

Source: Mai et al. (2018).

CO2 Emissions – all sectors

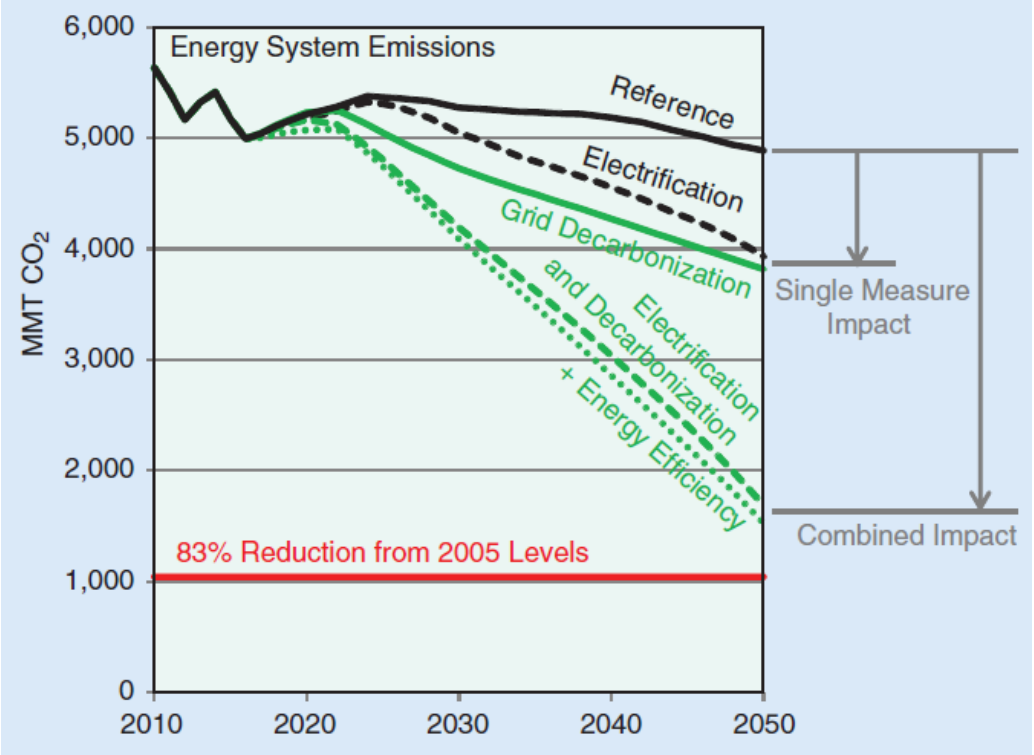


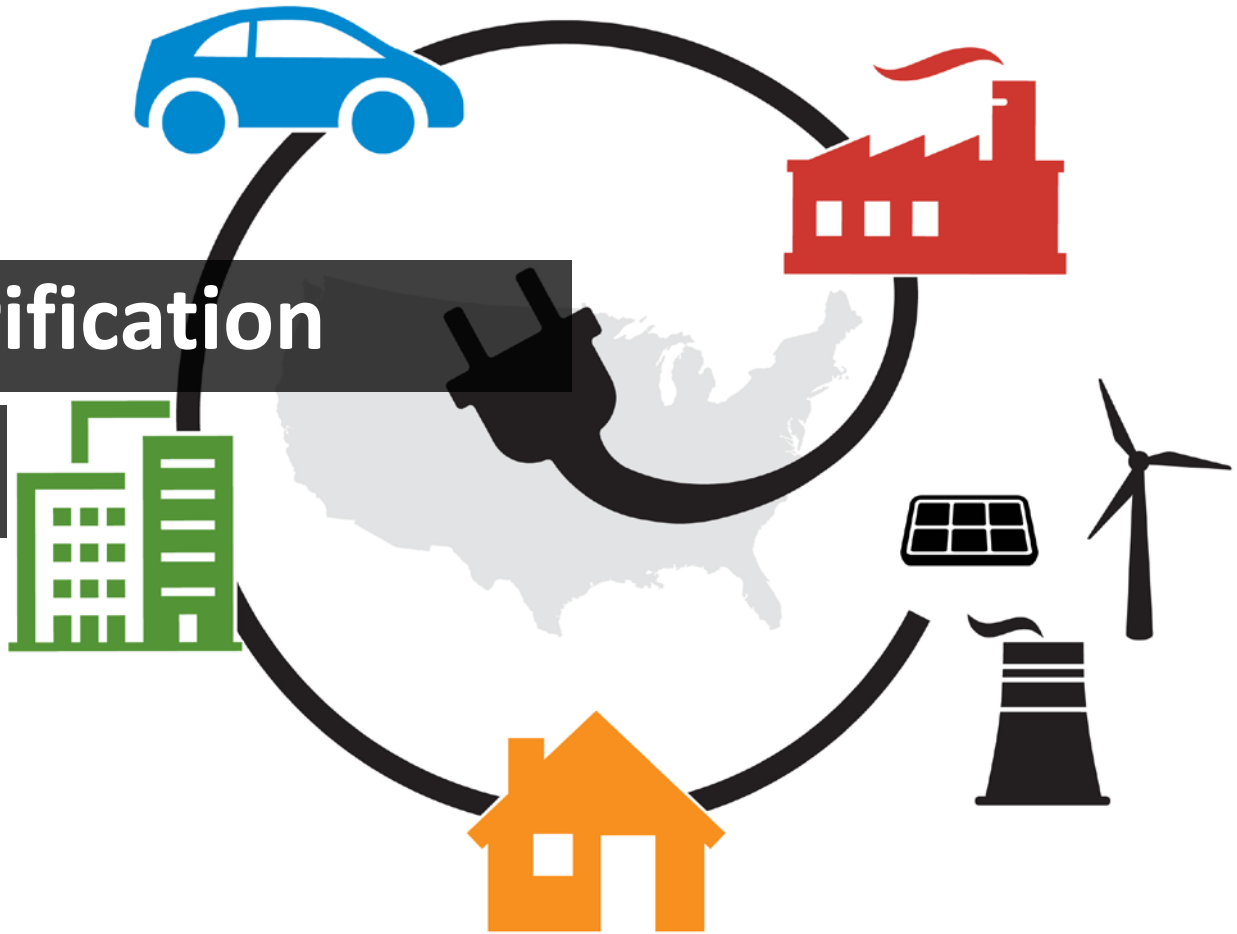
figure 7. Projected energy system and electricity system emissions.

Source: Mai et al. (2018).

Future research

- **End-use technology adoption**
- **Electricity technology roadmaps**
- Data on current energy use
- **Cost and value of grid flexibility**
- **Macro-economic modeling and analysis**
- Policy design and analysis
- Nonelectric options

EFS: The Electrification Futures Study



nrel.gov/EFS

Answering **crucial questions** about:

Source: Mai (2018).

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

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

EPRI

EVOLVED ENERGY RESEARCH

NORTHERN ARIZONA UNIVERSITY

OAK RIDGE National Laboratory

BERKELEY LAB
Lawrence Berkeley National Laboratory

U.S. DEPARTMENT OF ENERGY

Published

- Technology cost and performance (December 2017)
- Demand-side adoption scenarios (June 2018)
- dsgrid model documentation (August 2018)

Ongoing and Planned

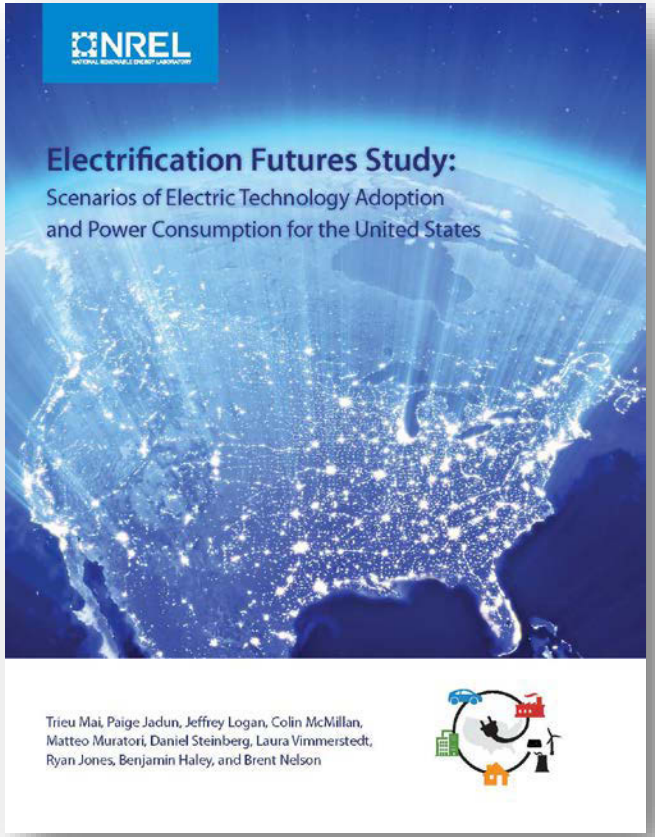
- Supply-side evolution scenarios (2019)
- Impacts of electrification (2019)
- Electricity system operations (~2020)
- Distribution System Impacts (~2020)

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

Demand-Side Scenarios Report

(June 2018)

https://www.nrel.gov/docs/fy18osti/71500.pdf



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

Kelly.Eurek@nrel.gov

www.nrel.gov

NREL/PR-6A20-73759

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Appendix

What is technical potential?

Our Analysis

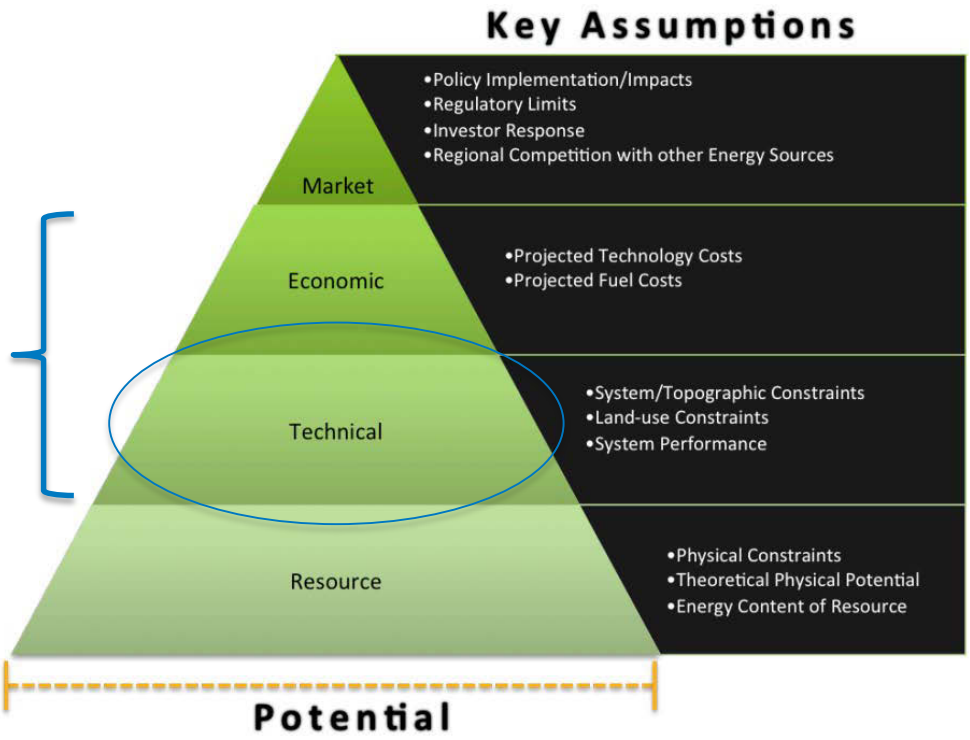


Figure 1. Levels of potential

Source: Lopez et al (2012).

CO2 emissions by sector and source

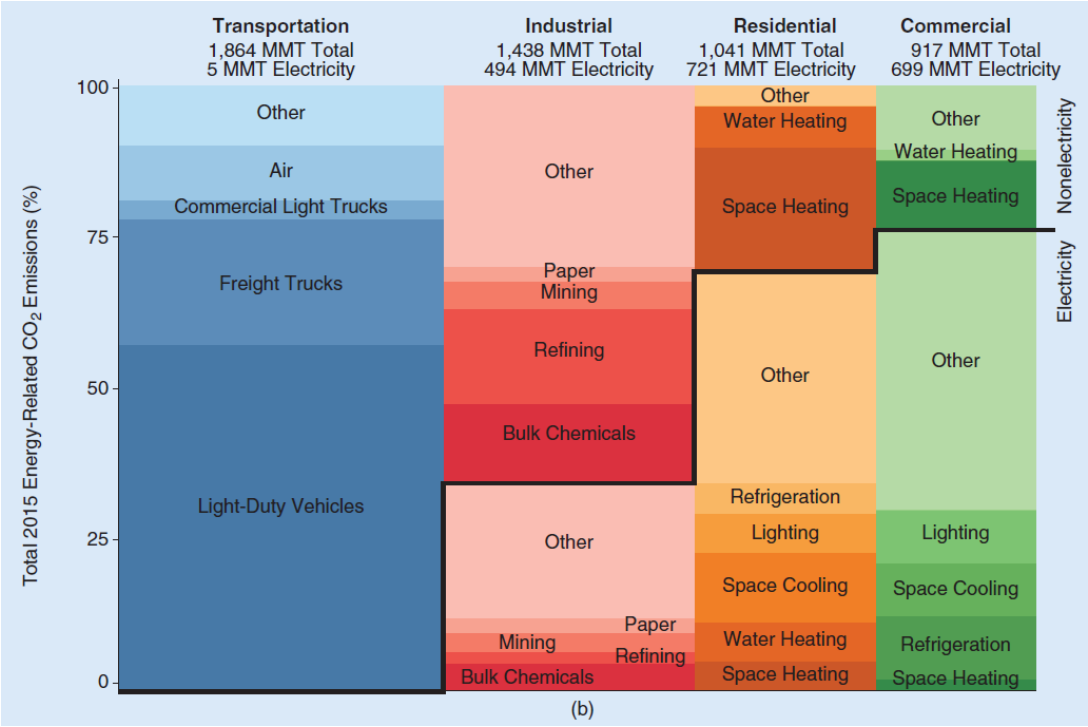
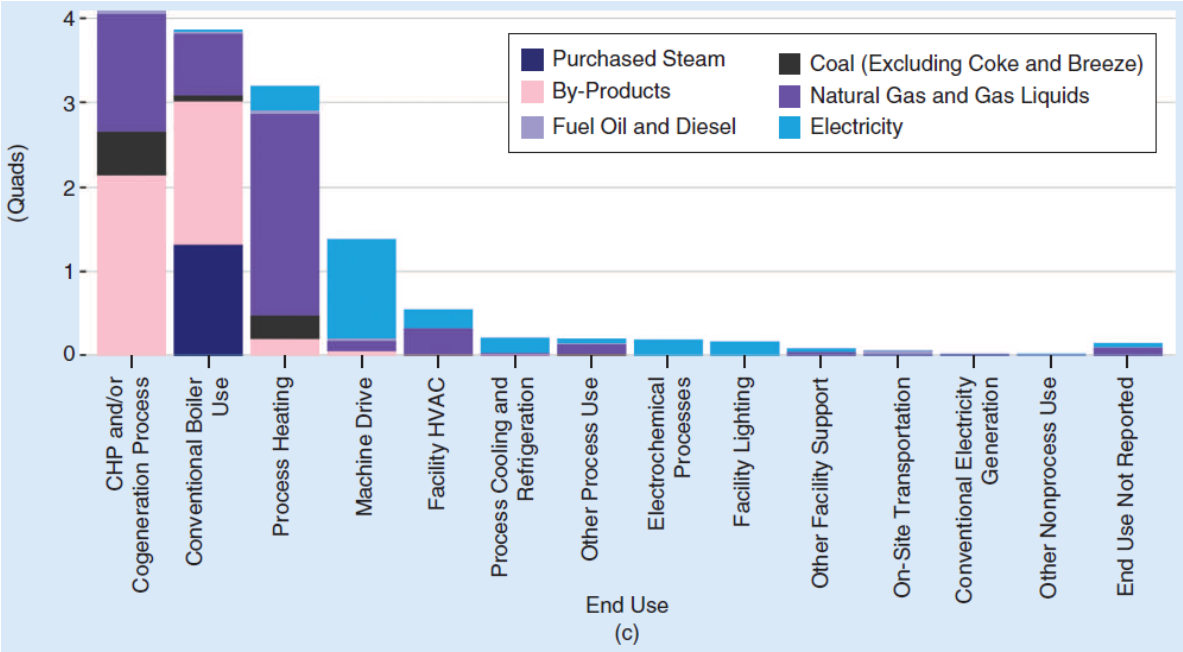


figure 1. The 2015 U.S. (a) primary energy consumption and (b) 2015 CO_2 emissions by sector and end use. [Data from "Annual Energy Outlook 2017," U.S. Energy Information Administration, and figure design courtesy of Jadun et al. (2017).]

Source: Mai et al. (2018).

Industrial



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Source: Mai et al. (2018).

Building electrification

Table A-1. Residential and Commercial End-Use Services Represented in the NEMS Model[a]

Residential	Commercial
Space Heating	***Space Heating***
Space Cooling	Space Cooling
Water Heating	***Water Heating***
Refrigeration	Ventilation
Cooking	***Cooking***
Clothes Dryers	Lighting
Freezers	Refrigeration
Lighting	Office Equipment (PC)
Clothes Washers	Office Equipment (non-PC)
Dishwashers	***Other Uses***
Televisions and Related Equipment	
Computers and Related Equipment	
Furnace Fans and Boiler Circulation Pumps	
Other Uses	

[a] End uses with significant potential for electrification are shown in bold italics.

Source: Steinberg et al. (2017).

Building efficiency improvements

Table 2. Annual Average Incremental Efficiency Improvement in Electric End-Use Devices from 2017–2050 Assumed in the High-Efficiency Case

End Use	Residential	Commercial
Space Heating	1.08%	1.18%
Space Cooling	1.08%	1.38%
Water Heating	0.73%	0.57%
Refrigeration	0.73%	0.79%
Cooking	0.52%	0.56%
Clothes Dryers	0.52%	
Freezers	0.54%	
Lighting	1.95%	1.86%
ClothesWashers	0.88%	
Dishwashers	0.78%	
Televisions & Related Equipment	0.78%	
Computers & Related Equipment	0.78%	
Furnace Fans & Boiler Circulation Pumps	0.88%	
Other Residential Uses	0.79%	
Ventilation		1.38%
Office Equipment (PC)		0.55%
Office Equipment (non-PC)		0.55%
Other Commercial Uses		0.88%

Source: Steinberg et al. (2017).

Transportation electrification

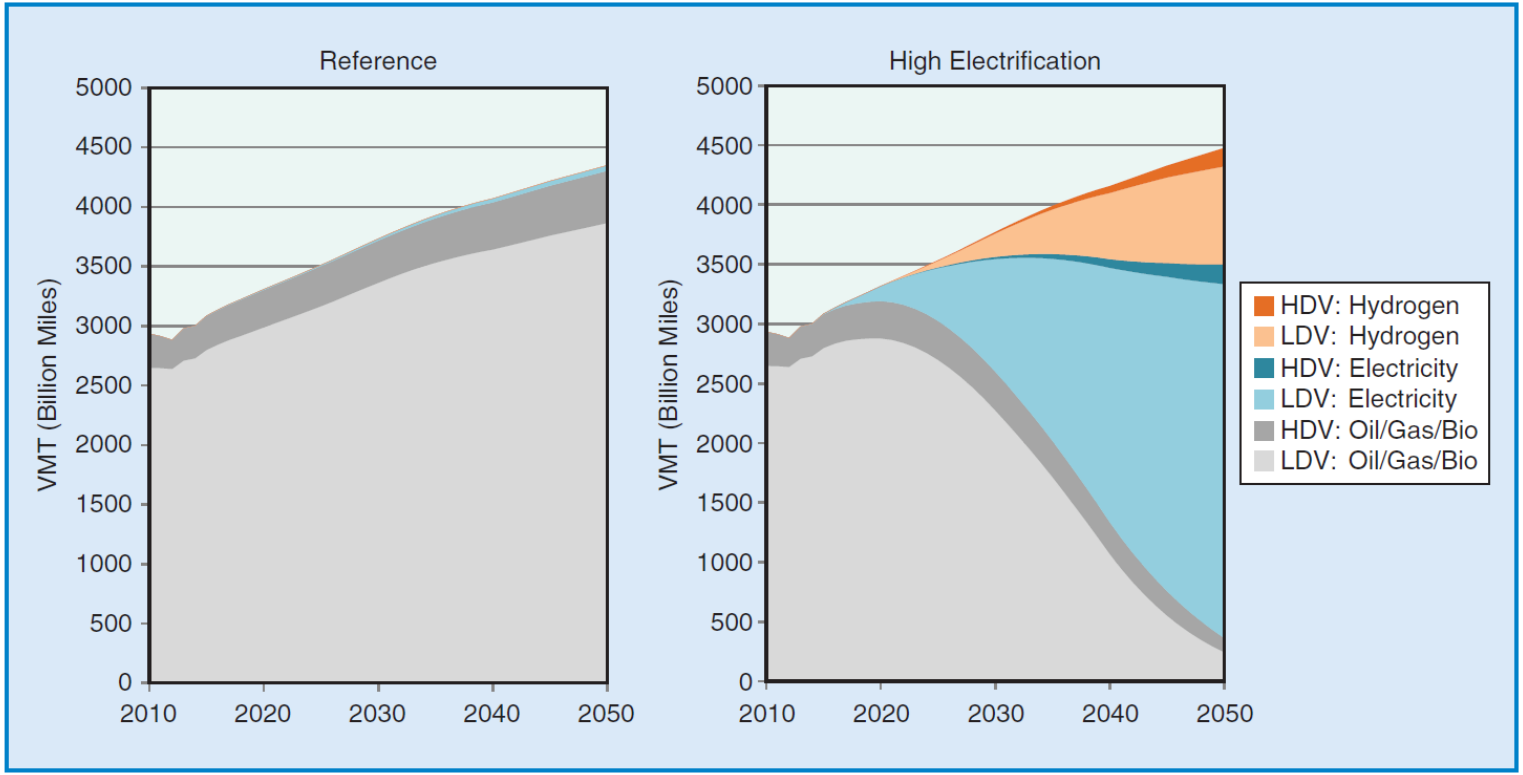


figure 3. Vehicle miles traveled from 2010 to 2050 under the reference and high-electrification scenarios. LDV: light-duty vehicles; HDV: heavy-duty vehicles.

Source: Mai et al. (2018).

Industrial electrification

table 1. The industrial end uses and electric technologies selected for analysis.

Electrotechnology	Industry	End-Use Service	Percent Electrified by 2050
Electrolytic reduction	Nonferrous metals, excluding aluminum	Process heating	100
Induction heating	Metal fabrication	Process heating	100
Electric boilers	All manufacturing industries	Conventional boiler use	100
Resistance heating and melting	Glass	Process heating	100
Direct arc melting	Iron and steel	Process heating	21
Industrial process heat pump	Food, pulp and paper, and chemicals	Process heating	100

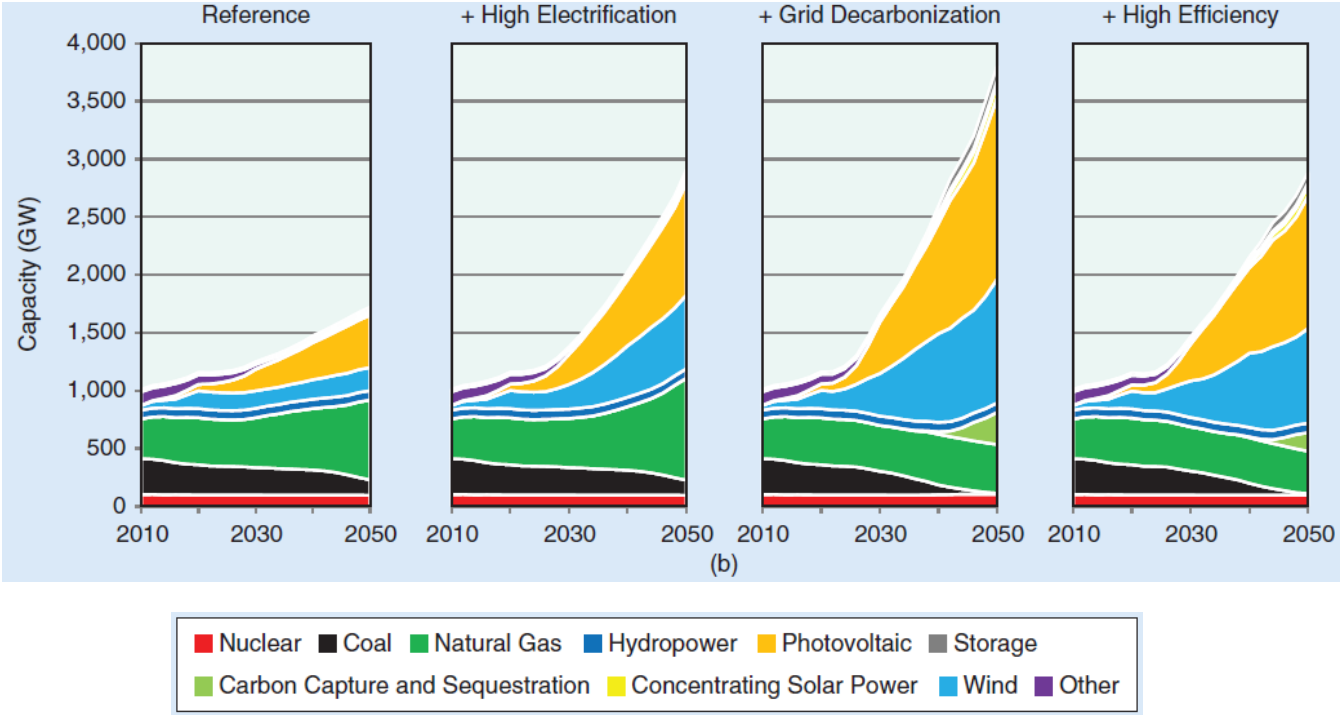
Source: Mai et al. (2018)

Table A-2. Assumed Growth Rates of Electrotechnologies in Their Applicable Industries and by End Use

Electrotechnology	Industry	End Use	Annual Growth Rate (2017–2020)	Annual Growth Rate (2021–2050)
Electrolytic reduction	Nonferrous metals, excluding aluminum	Process heating	7.0%	3.4%
Induction heating	Metal fabrication	Process heating	2.4%	5.5%
Electric boilers	All manufacturing industries	Conventional boiler use	8.6%	16.9%
Resistance heating and melting	Glass	Process heating	3.6%	6.8%
Direct arc melting	Iron and steel	Process heating	4.8%	0.0%
Industrial process heat pump	Food, pulp and paper, chemicals	Process heating	1.3%	10.0%

Source: Steinberg et al. (2017).

Capacity Mix



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Source: Mai et al. (2018).

Citations

- National Renewable Energy Lab (NREL) (2012). Renewable Electricity Futures Study. https://www.nrel.gov/analysis/re-futures.html
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- Mai, Trieu T. *The Electrification Futures Study: Demand-Side Scenarios*. No. NREL/PR-6A20-72096. National Renewable Energy Lab.(NREL), Golden, CO (United States), 2018.
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- Lopez, Anthony, Billy Roberts, Donna Heimiller, Nate Blair, and Gian Porro. *US renewable energy technical potentials: a GIS-based analysis*. NREL, 2012.
- Steinberg, Daniel, Dave Bielen, Josh Eichman, Kelly Eurek, Jeff Logan, Trieu Mai, Colin McMillan, Andrew Parker, Laura Vimmerstedt, and Eric Wilson. *Electrification and Decarbonization: Exploring US Energy Use and Greenhouse Gas Emissions in Scenarios with Widespread Electrification and Power Sector Decarbonization*. No. NREL/TP-6A20-68214. National Renewable Energy Lab.(NREL), Golden, CO (United States), 2017.