NREL
Transforming ENERGY

A Co-Simulation Framework to Study Future Energy-Economy Interactions

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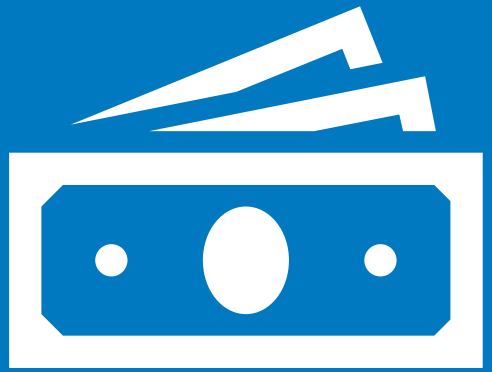
This version has been modified slightly compared to the conference presentation to reflect peer review, and notes have been edited for clarity.

Project Objective and Overview

- To illustrate methodologies that could quantify the effects of renewable energy and energy efficiency technology innovation on **consumer energy affordability in energy programmatic benefits analysis**
- Quantitative results are for illustration only, with the key project purpose being the creation of new analysis methods and capabilities.
    - Illustrative results show the types of metrics that can be calculated.
    - Technology innovation assumptions show the types of inputs that can readily be modified in these methodologies
    - **Numerical values for assumptions were selected in 2019, and do not reflect current expectations or objectives.**

What Does it Cost?



NREL is Well-known for Detailed Energy Models

ReEDS

Electric sector capacity expansion

Scout

Building energy demand projection

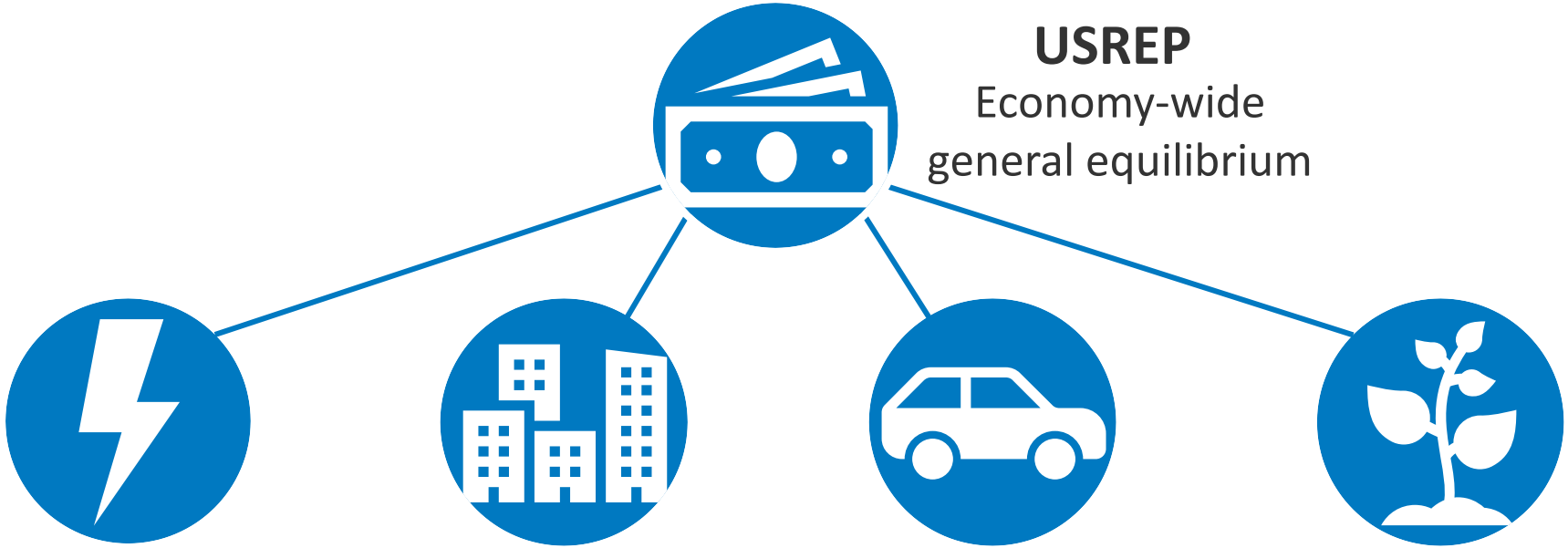
ADOPT

Vehicle consumer choice

BSM

Biofuel supply chain

Recent Work Envisions an Energy-Economy Modeling Ecosystem



USREP
Economy-wide general equilibrium

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Electric sector capacity expansion

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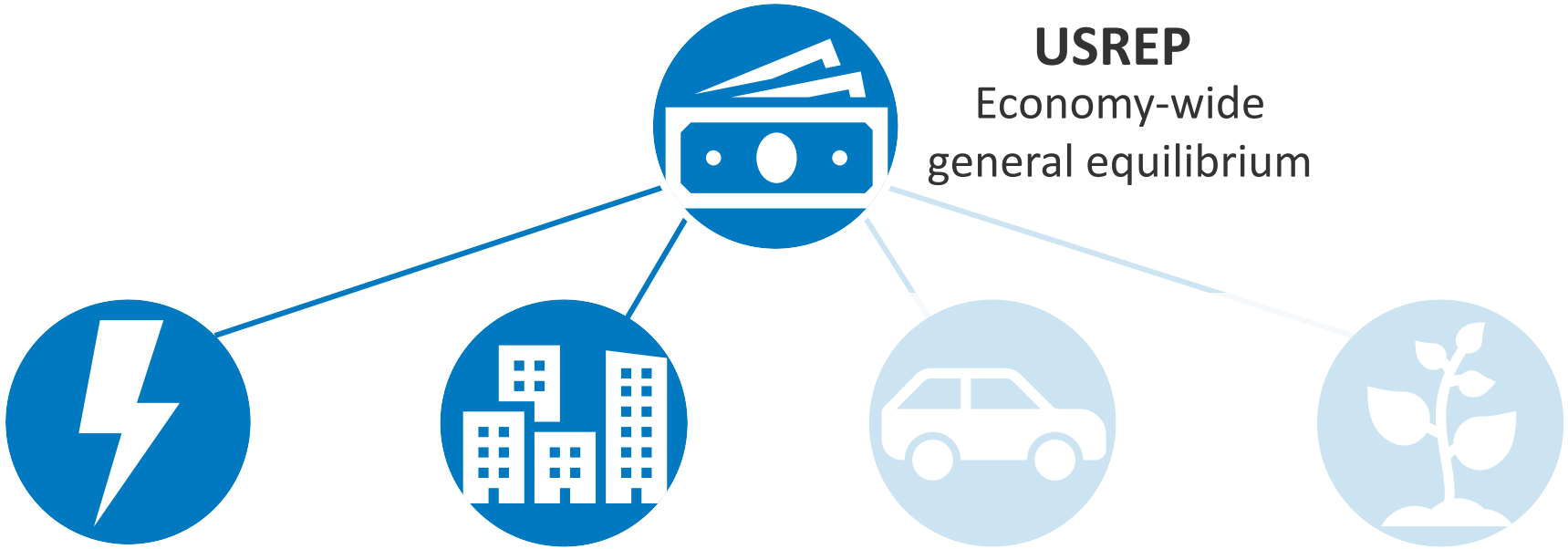
Initial Work Links Economy, Electricity, and Buildings Models



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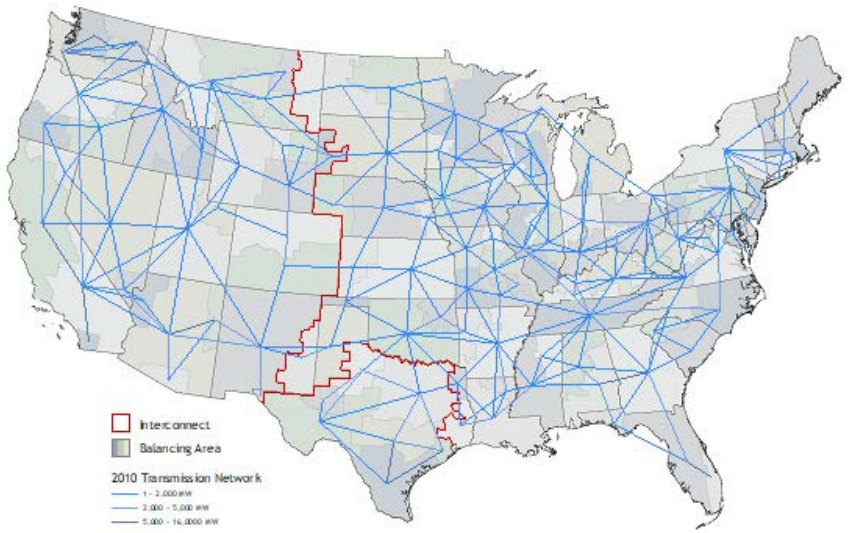
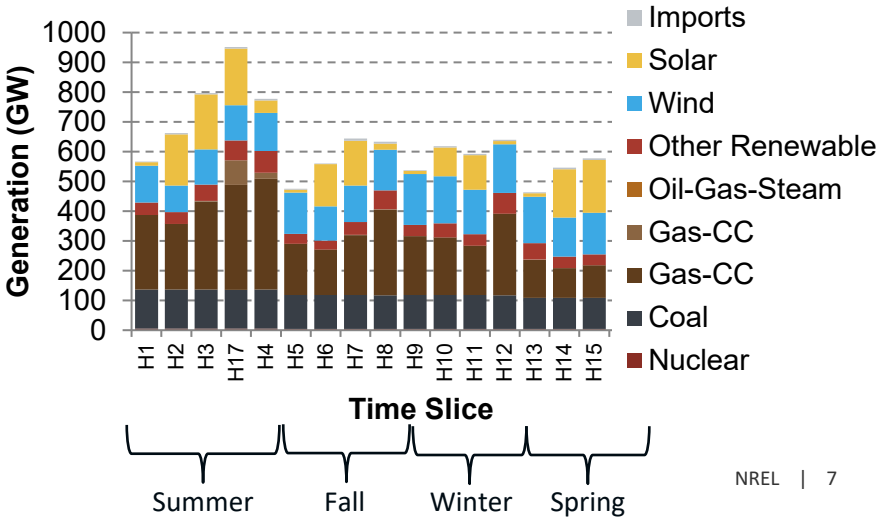
ReEDS Provides a High-Resolution Picture of U.S. Electric Sector Evolution

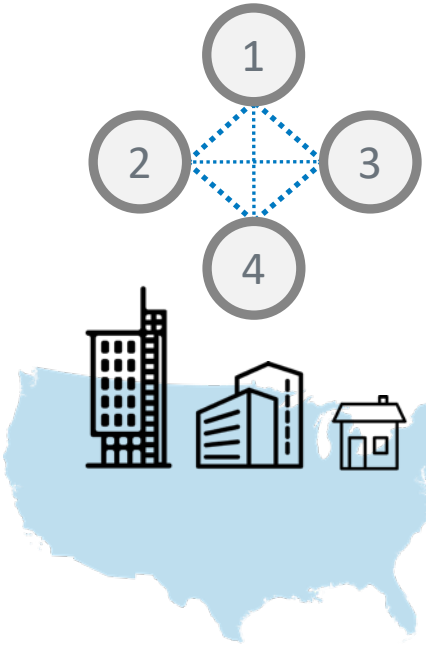
- ReEDS: Regional Energy Deployment System
- Linear program minimizes cost of generation, transmission, and storage investment and operation
- Satisfies energy and capacity requirements under resource, transmission, policy, and power system constraints
- Solves annually with 17 intra-annual time slices
- 134 balancing areas represent transmission and resource heterogeneity
- Includes comprehensive technology options and characterization of renewable resource availability and variability





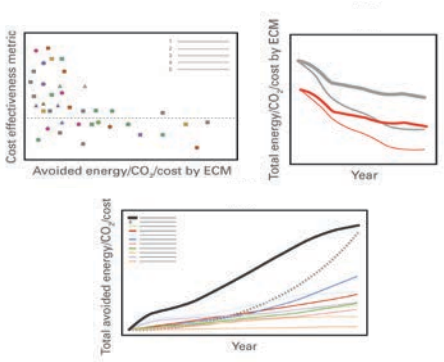
Scout Projects Building Component Technology Adoption and Use

- Scout: portfolio analysis tool for building energy efficiency technologies
- Implements component-specific energy conservation measures (ECMs)
- Simulates building stocks and flows and competition between ECMs
- Resolves residential and commercial building energy use into 5 climate zones
- Projects building natural gas and electricity use, CO_2, and cost



Competing ECMs

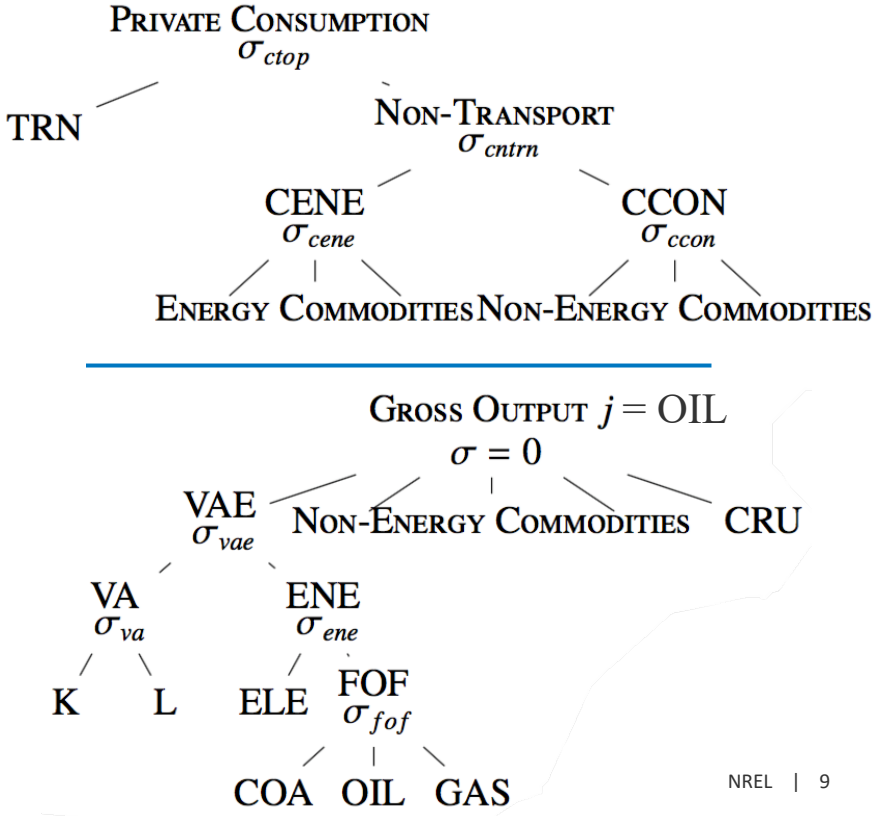
National building stock and market diffusion model



Energy, CO_2, cost outcomes from adoption scenarios

USREP Can Assess Net Economy-wide Impacts of Energy System Changes

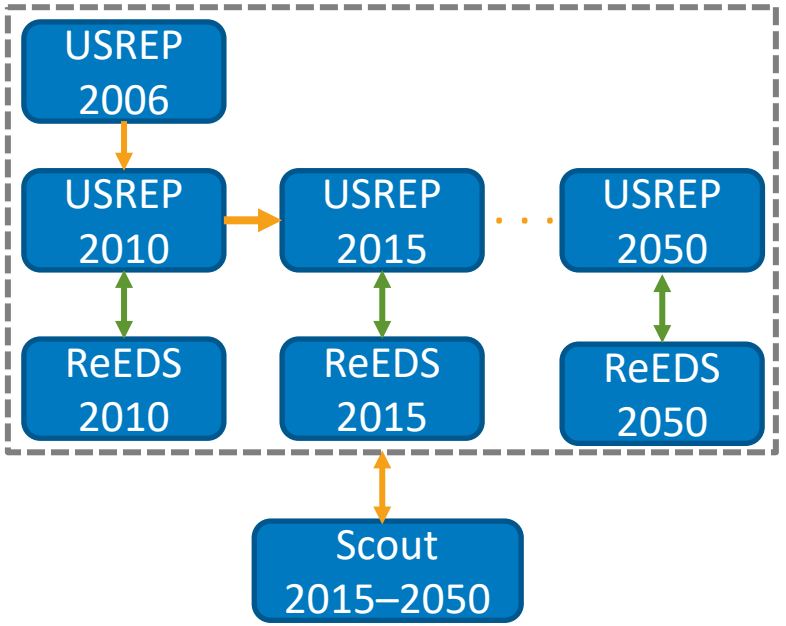
- USREP: U.S. Regional Energy Model built by Massachusetts Institute of Technology
- Computable general equilibrium model of the U.S. economy
- 10 sectors differentiate energy, transportation, agriculture, and other markets
- 30 US sub-regions for regionally differentiated markets
- 9 income classes describe distributional effects
- Reports net impact on welfare, gross domestic product (GDP), and other economy-wide metrics



Linking the Models Can Assess Energy-Economy Feedbacks

- Data transfer
  - USREP fuel prices → ReEDS & Scout
  - ReEDS & Scout fuel/electricity demand → USREP
- Solution Procedure
  1. ReEDS-USREP benchmarking. Assumed consistent with standalone Scout reference
  2. ReEDS-USREP iterates in 5-year intervals from 2010 to 2050 for a counterfactual case
  3. Changes to Scout demand in the counterfactual adjusts USREP and ReEDS demand
  4. Return to step 2 and iterate
- Linkages described in this presentation
  - ReEDS-USREP
  - ReEDS-USREP with single Scout iteration

Linked Model Solution Flow

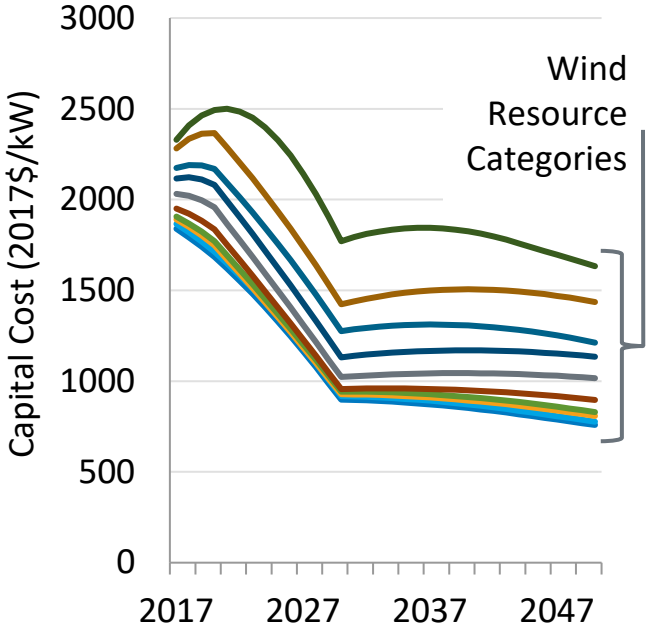


Exploring the Value of Linking and the Economic Impacts of Technological Innovation

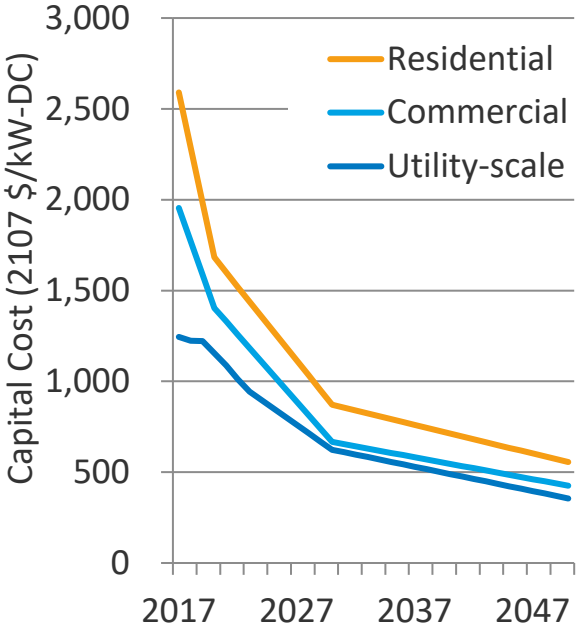
- Value of linking
  - Standalone ReEDS (*E*), Standalone Scout (*S*)
  - ReEDS-USREP (*EE*)
  - ReEDS-USREP-Scout (*EEB*)
- Economy-wide impacts of technological innovation
  - Reference (*Ref*): input data is based on U.S. EIA 2019 Annual Energy Outlook (AEO) reference case.
  - Innovation (*Innov*): technology advances improve cost and performance for wind, solar, geothermal, hydropower, (NREL ATB 2019 low cost case) and building efficiency technologies (U.S. DOE Buildings Multi-Year Program Plan).

The *Innov* Scenario Assumes Renewable and Efficiency Technology Cost Reductions

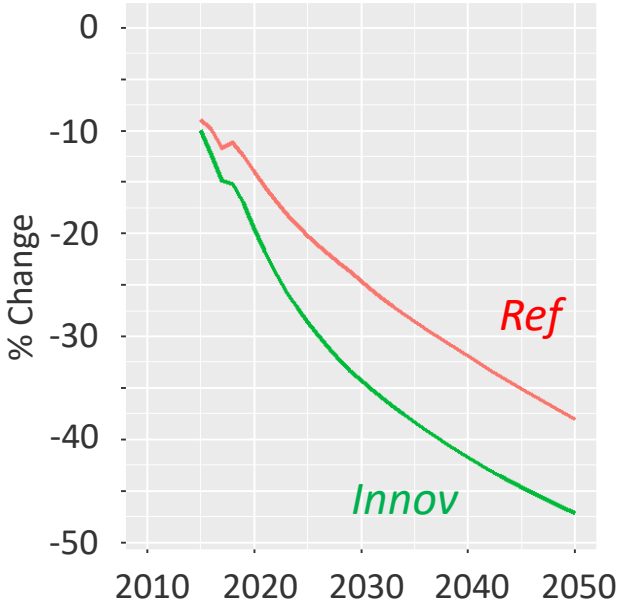
Land-Based Wind in *Innov*



PV in *Innov*



Building Efficiency Change

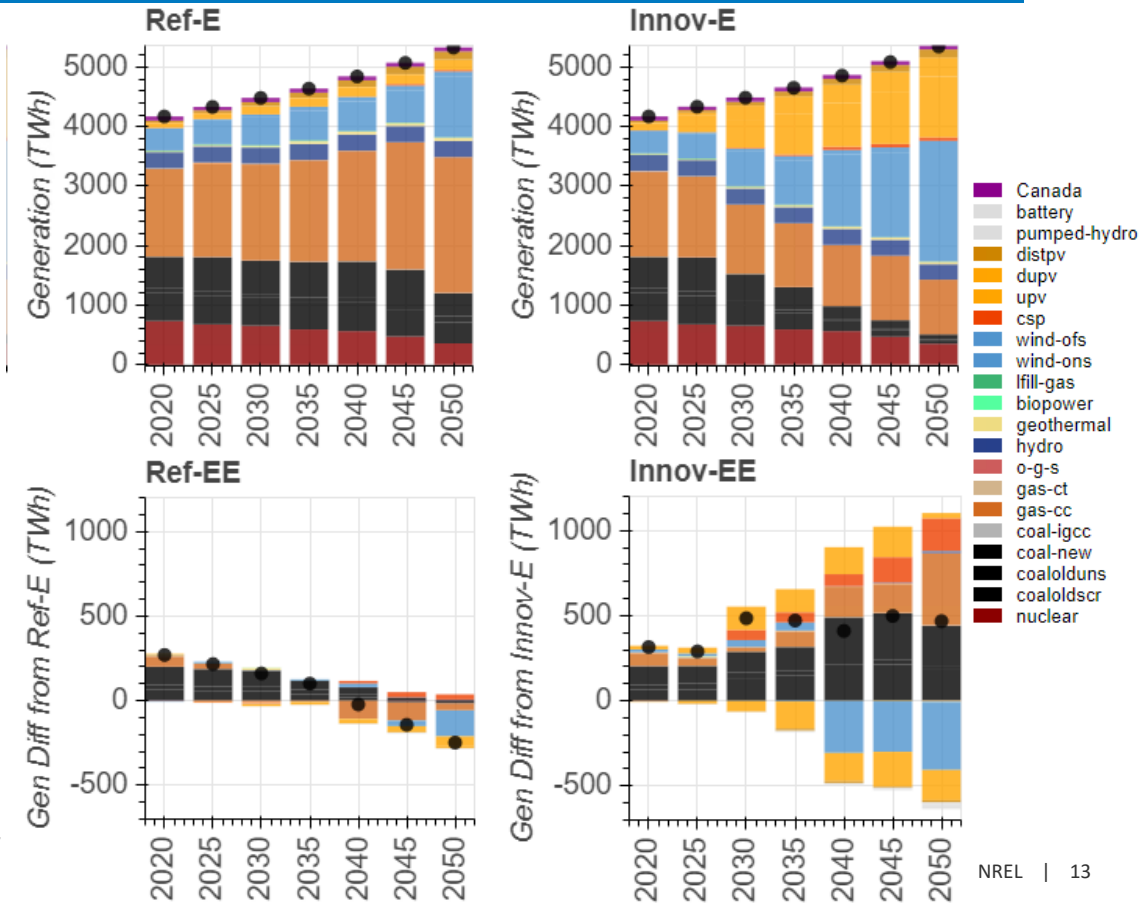


- Input assumptions are based on data current as of 2019
- Cost reductions in *Innov* represent aspirations for future technology innovation.
- Models do not currently incorporate any R&D investment (government or otherwise) to foster innovation.

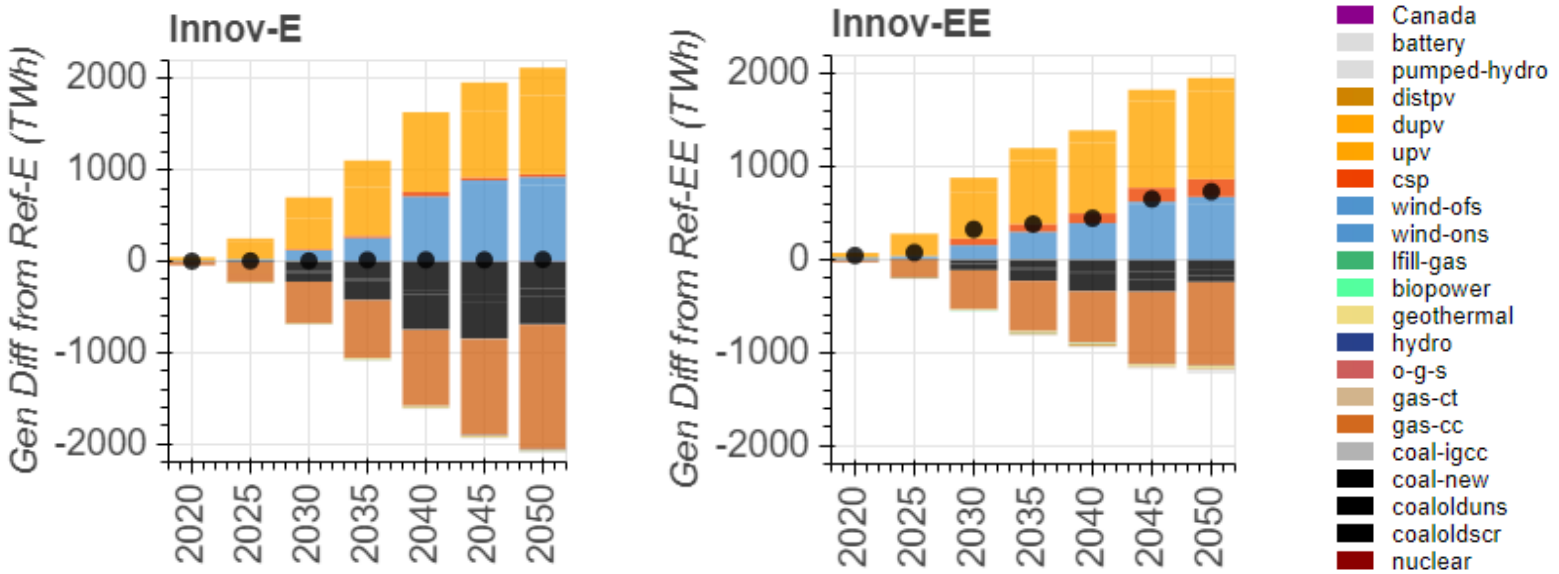
Linking ReEDS and USREP Incorporates Fuel and Electricity Price Feedbacks

- Standalone ReEDS (*E*) shows impact of innovation on electricity mix.
  - Gas dominates in *Ref.*
  - Wind/PV grows in *Innov.*
- Comparing linked (*EE*) to standalone (*E*) results shows the importance of price response and multisectoral interactions.
  - *Ref* demand is similar, with more near-term coal and less gas/wind beyond 2040.
  - *Innov* has higher demand, greater fossil use, more CSP built, and less wind.

Results were calculated in 2019 and are for illustration only.



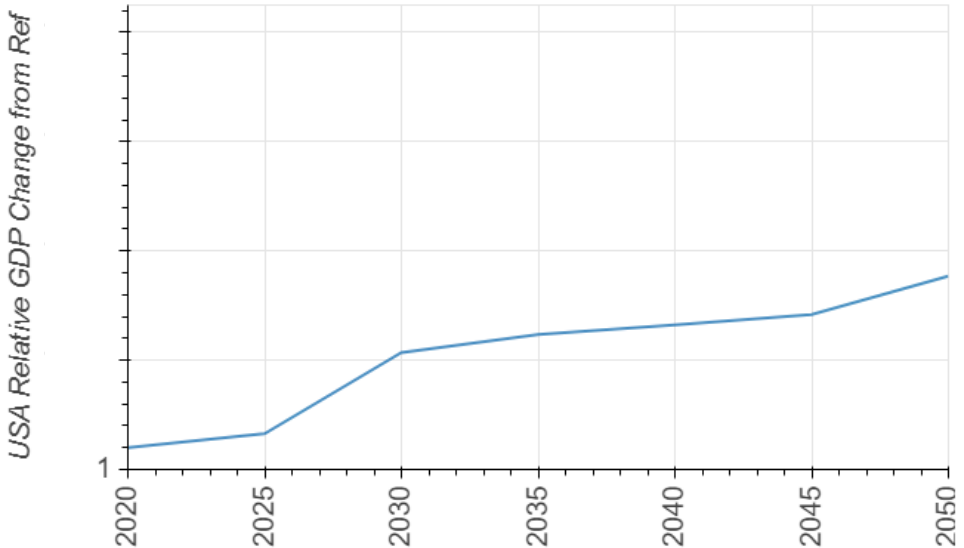
Price Response Is Important to Understand the Electric Sector Impacts of Innovation

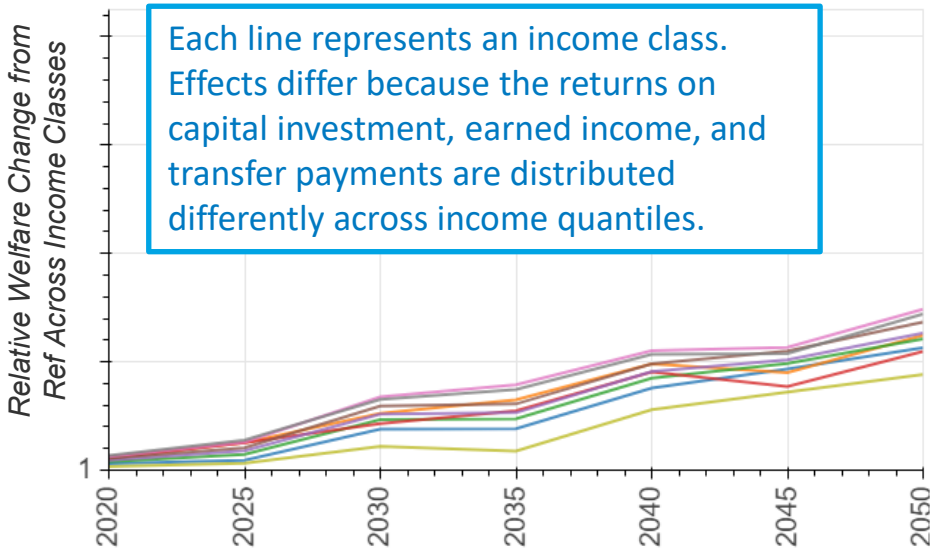


- When comparing *Innov* to *Ref* for standalone ReEDS (*E*) and ReEDS-USREP (*EE*):
  - Standalone ReEDS (*E*) requires 1:1 displacement of generation, so increased wind and PV directly offsets gas and coal.
  - Increased demand from price response (*EE*) reduces fossil displacement and shows greater innovation impact on CSP.

Results were calculated in 2019 and are for illustration only.

ReEDS-USREP GDP and Welfare Impacts of Generation Technology Innovation by Income





Each line represents an income class. Effects differ because the returns on capital investment, earned income, and transfer payments are distributed differently across income quantiles.

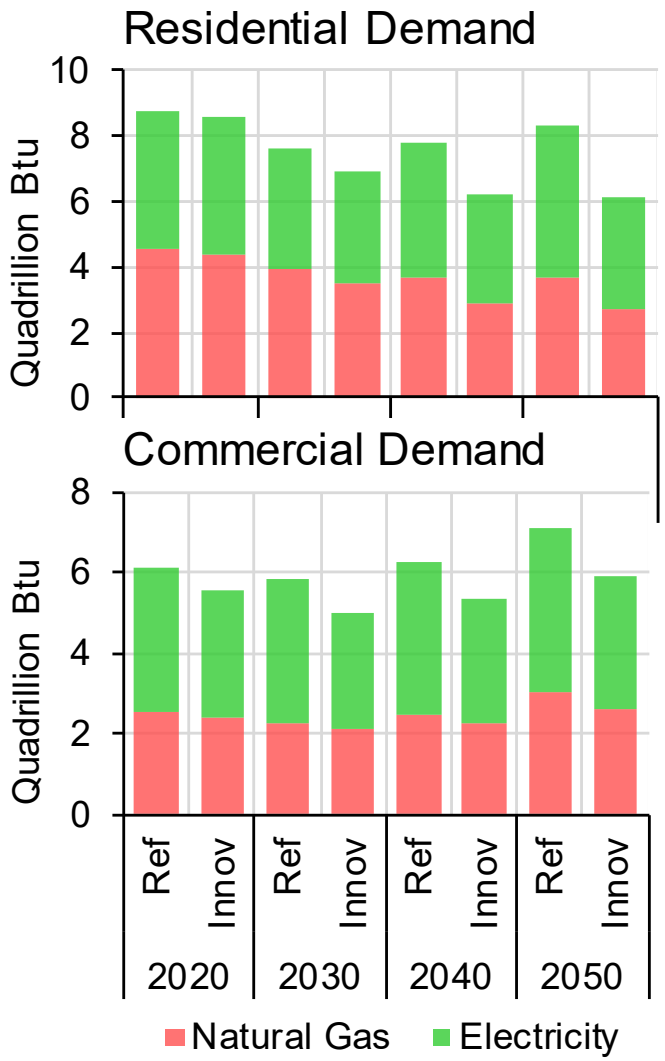
- Preliminary ReEDS-USREP results show economic benefit of innovation, but further review is required.
- *Innov* scenario has higher GDP and welfare for all income classes in these scenarios.
- There are distributional differences reflecting complex economic interactions.
  - Higher income classes benefit from capital returns on renewable investment.
  - Lower income classes benefit from lower electricity prices.

Results were calculated in 2019 and are for illustration only.

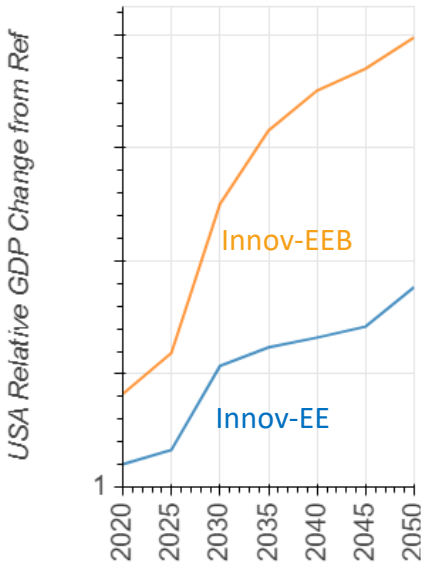
Scout Projections of Building Energy Use Can Then Be Applied

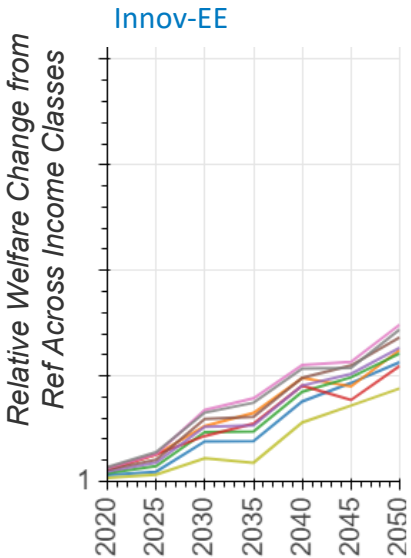
- Ref has decreasing then increasing residential demand but increasing commercial demand
- *Innov* achieves residential demand reduction while commercial demand is similar in 2050 as 2020
- Trends are similar for both natural gas and electricity
- Initial 1-way Procedure
  - USREP adjusts energy demand in households and service sector
  - ReEDS does not yet adjust electricity demand for building efficiency improvements

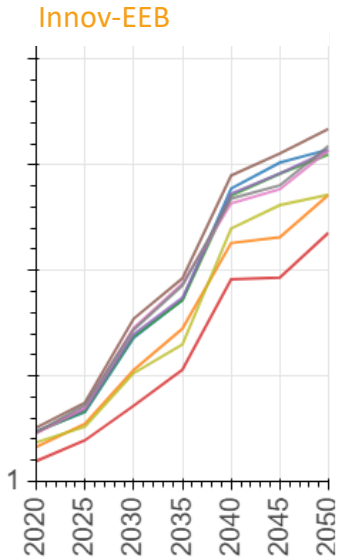
Results were calculated in 2019 and are for illustration only.



Scout + ReEDS-USREP GDP and Welfare Impacts of Buildings Efficiency + Generation Technology Innovation by Income







Each line represents an income class. Effects differ because the returns on capital investment, earned income, and transfer payments are distributed differently across income quantiles.

- Initial results show amplified economy-wide impacts with building efficiency improvements, but efficiency-driven reduction in electricity demand is not implemented in ReEDS.
- Distributional trends are similar for both linkage configurations.

Results were calculated in 2019 and are for illustration only.

Key Points

1. Multisectoral feedbacks and market equilibrium responses are important for understanding electricity-economy interactions.

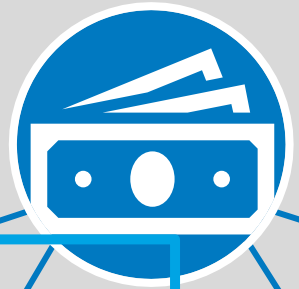
2. Linking detailed energy models with economy-wide models allows a more robust assessment of net energy-economy impacts; for example, the economy-wide impacts of energy sector innovation.

3. Initial results suggest innovation in the buildings and electric sectors provide broad economic benefits that can be disaggregated by income class.

4. Not all feedbacks are considered.

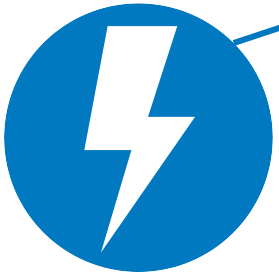
Results were calculated in 2019 and are for illustration only.

Future Work Could Extend this Method to Other Sectors



USREP
Economy-wide general equilibrium

This presentation



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Key References

- USEIA 2019 Annual Energy Outlook: https://www.eia.gov/outlooks/archive/aeo19/
- NREL 2019 Annual Technology Baseline: https://atb-archive.nrel.gov/electricity/2019/data.html
- 2016 BTO Multi-Year Program Plan (MYPP): https://www.energy.gov/sites/prod/files/2016/02/f29/BTO_MYPP_2016.pdf, https://www.cell.com/joule/pdfExtended/S2542-4351(19)30357-5
- 2019 ReEDS documentation: https://www.nrel.gov/docs/fy20osti/74111.pdf
- USREP model description: https://globalchange.mit.edu/research/research-projects/us-regional-energy-model
- Scout model description: https://www.energy.gov/eere/buildings/scout

Thank you

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