

Energy Scenario Exploration with Modeling to Generate Alternatives (MGA)

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Talk Outline

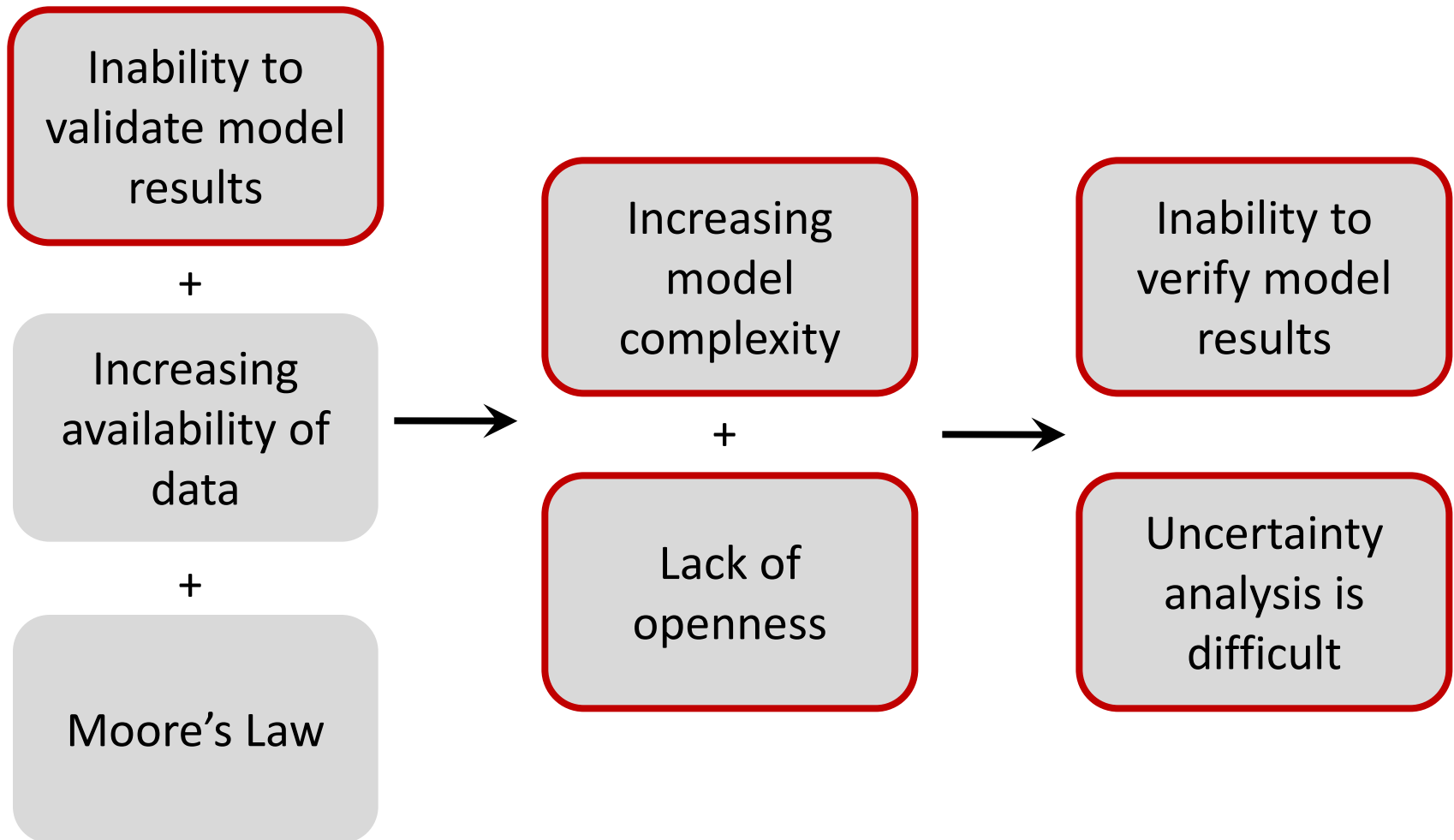
Brief motivation and introduction to the modeling framework (Temoa)

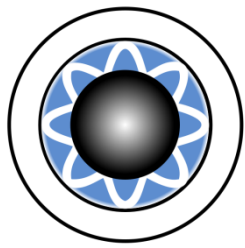
Description of Modeling to Generate Alternatives (MGA)

Application of MGA to a Temoa case study involving the U.S. electric and light duty transport system

Motivation and Introduction

Problems with the status quo





Tools for Energy Model Optimization and Analysis (Temoa)

Temoa is a **bottom up, technology explicit model with perfect foresight**, similar to the TIMES model generator.

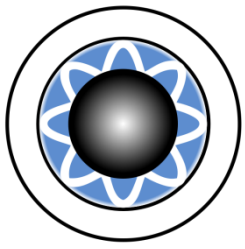
Goals

1. Repeatable analysis

- Data and code stored in a public web repository (github)
- Open source software stack

2. Rigorous treatment of uncertainty

- Designed to utilize high performance computing resources
- Stochastic optimization; modeling-to-generate alternatives



Temoa Capability

Current

- Visualization of energy system map
- Input/output data stored in a relational database
- Optional Excel output produced from database
- Configuration file used to specify model options

Project website: <http://www.temoaproject.org>

Source code: <https://github.com/TemoaProject/temoa>

Uncertainty Analysis with MGA

Types of Uncertainty

There are many ways to categorize uncertainty.

A key distinction:

- **Parametric**: uncertainty regarding the assumed value of model inputs.
- **Structural**: imperfect and incomplete nature of the equations describing the system

Modeling to Generate Alternatives (MGA)

MGA changes the structure of the model to find alternative solutions

MGA explores an optimization model's near optimal, feasible region [†]

MGA generates alternative solutions that are **maximally different in decision space** but perform well with respect to modeled objectives

The resultant MGA solutions provide modelers and decision-makers with a set of alternatives for further evaluation

[†]Brill (1979), Brill et al. (1982), Brill et al. (1990)

Hop-Skip-Jump (HSJ) MGA

Brill et al. (1982)

Steps:

1. Obtain an initial optimal solution by any method
2. **Add a user-specified amount of slack to the optimal objective function value**
3. Encode the adjusted objection function value as an additional upper bound constraint
4. **Formulate a new objective function that minimizes the decision variables that appeared in the previous solutions**
5. Iterate the re-formulated optimization
6. Terminate the MGA procedure when no significant changes to decision variables are observed in the solutions

Case Study

Motivation

U.S. electric and light duty transportation systems account for approximately 60% of national CO₂ emissions

Following the OPEC oil embargo, the electric and transportation sectors have evolved independently: petroleum is 0.7% of U.S. electricity fuel supply and 91% of light duty transportation

Plug-in vehicles rapidly deployed over the last 5 years and may lead to a significant future coupling of the electric and transport sectors

Goal: Examine alternative technology pathways for achieving low carbon emissions

Study Design

Run three scenarios to benchmark MGA:

- Base case
- 40% cut in 2015 CO₂ emissions by 2050
- 80% cut in 2015 CO₂ emissions by 2050

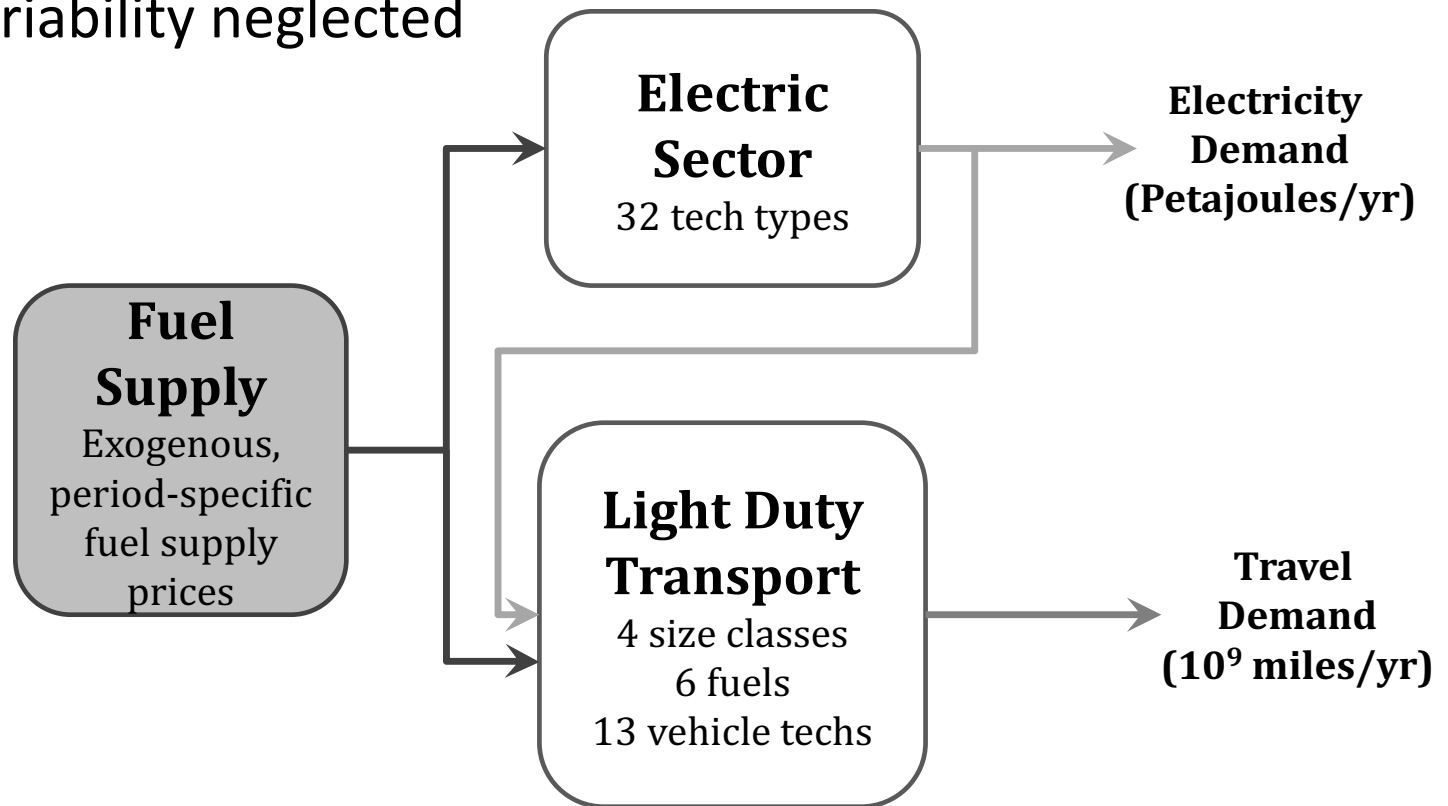
Test two different MGA weighting algorithms

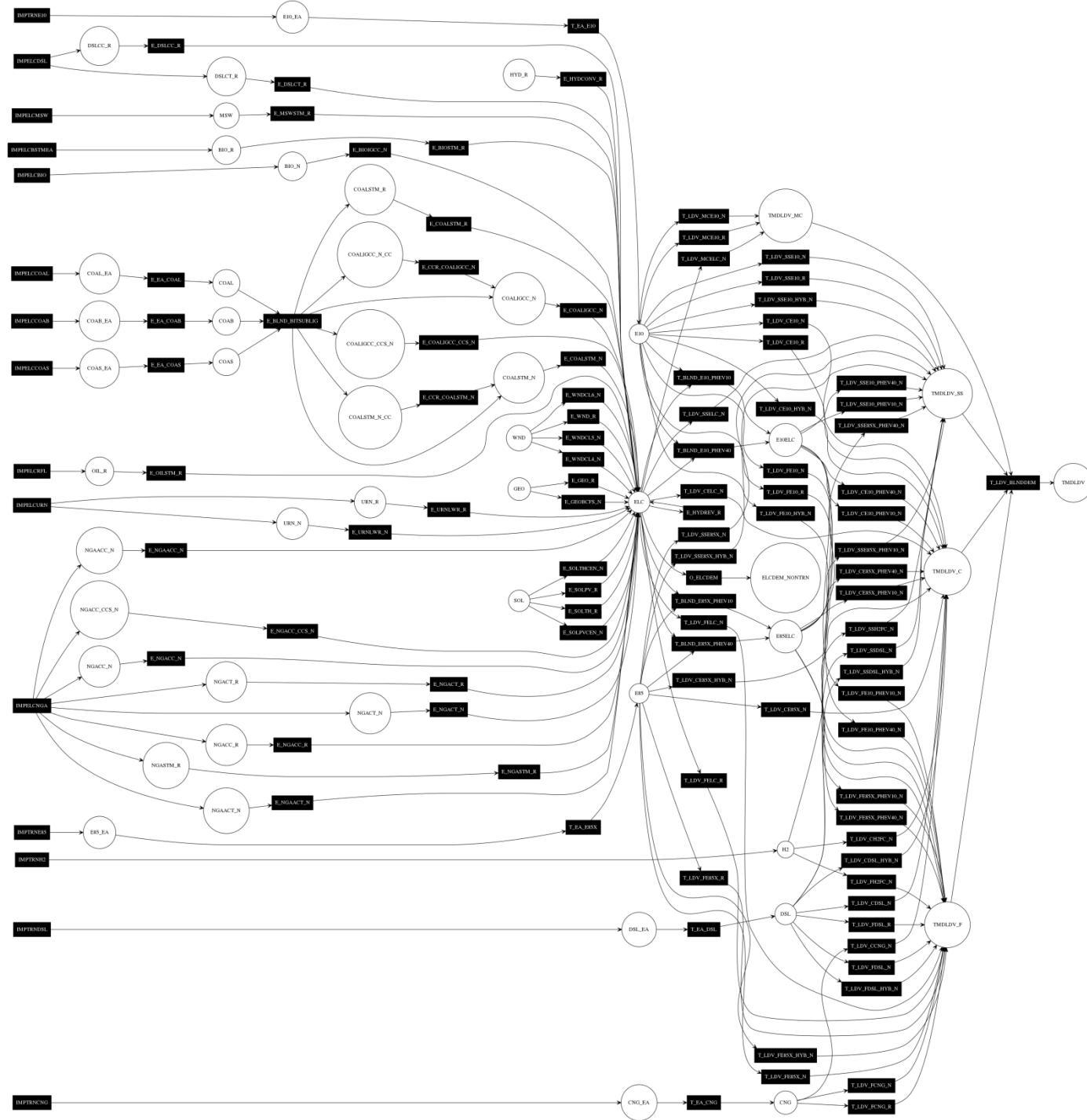
Run MGA at different slack values

Examine outputs and look for insights

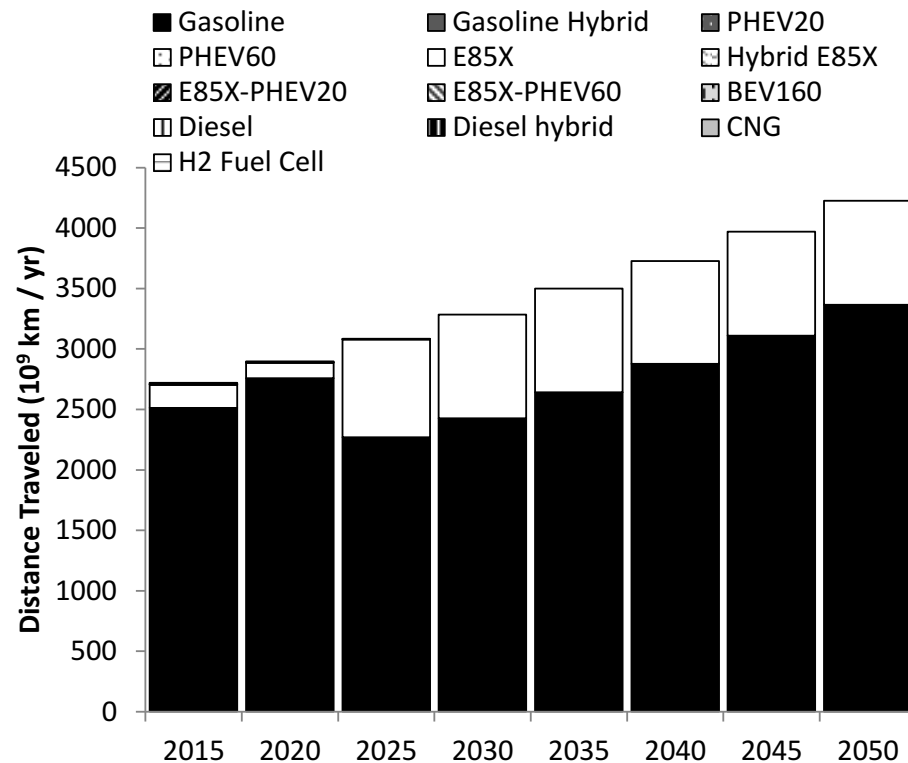
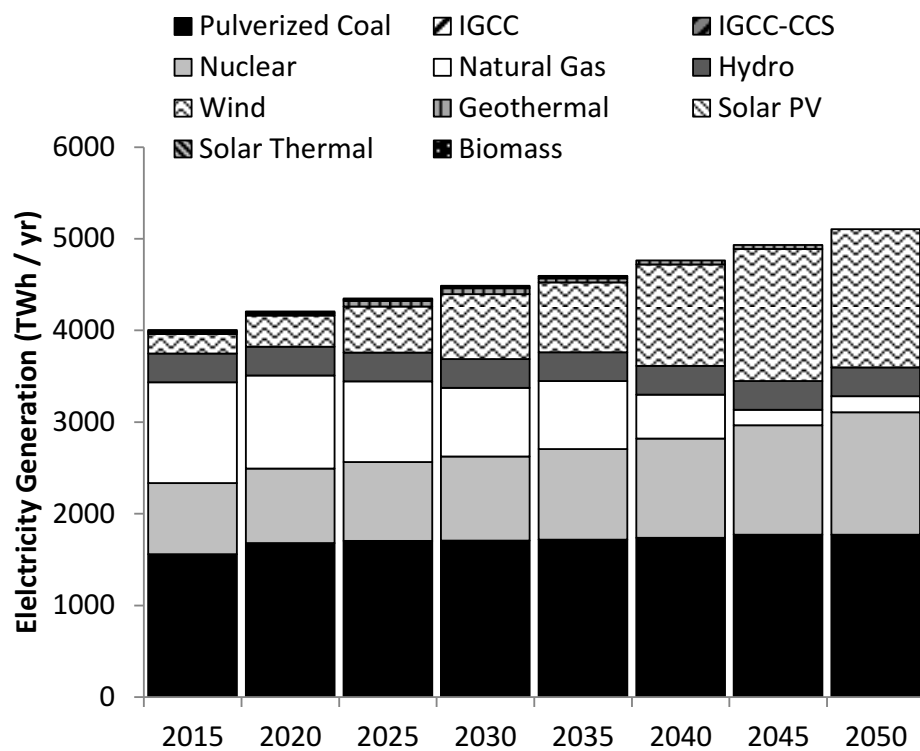
Input Dataset

- Approximately 110 processes spanning electric and transport sectors
- Model time horizon is 2015 to 2050; 5-year time periods
- Four diurnal time segments (i.e., morning, mid-day, evening, night)
- Seasonal variability neglected

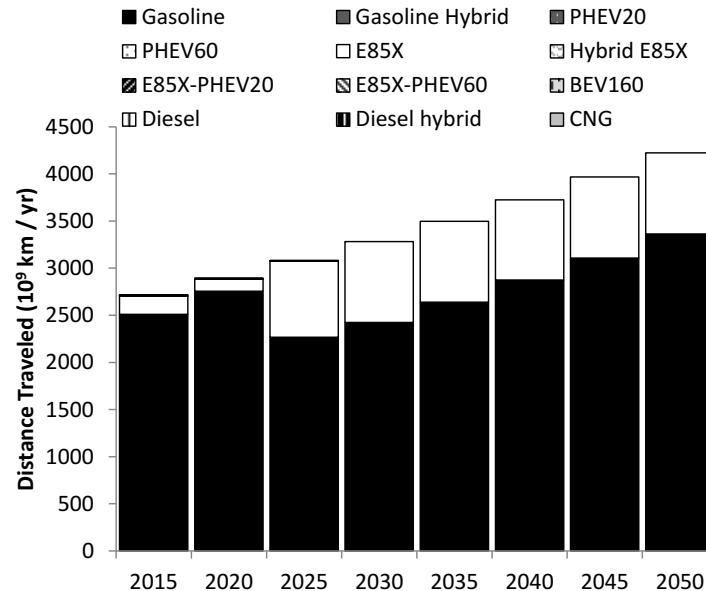
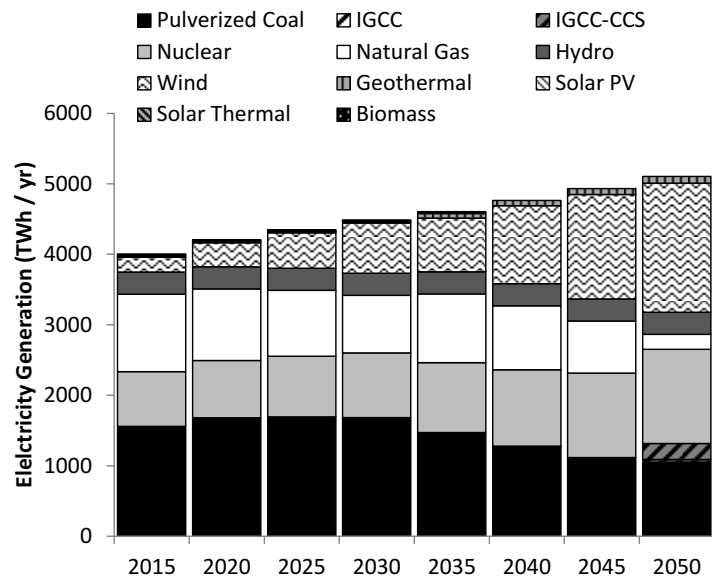




Base Case Results

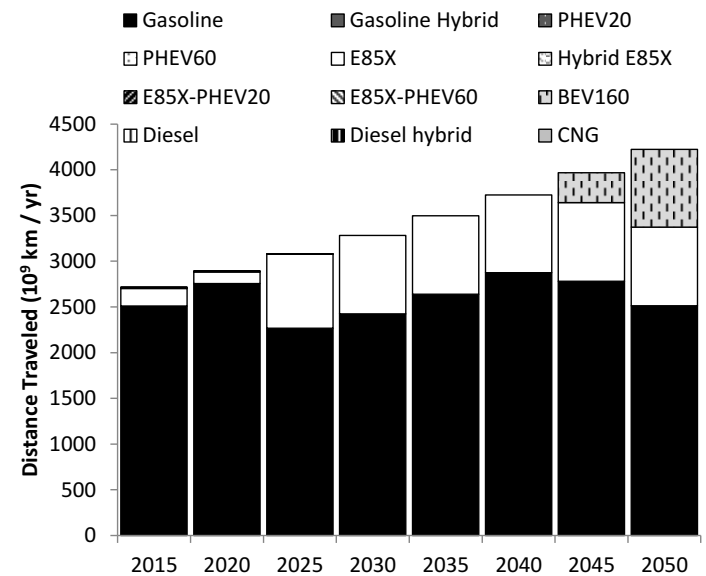
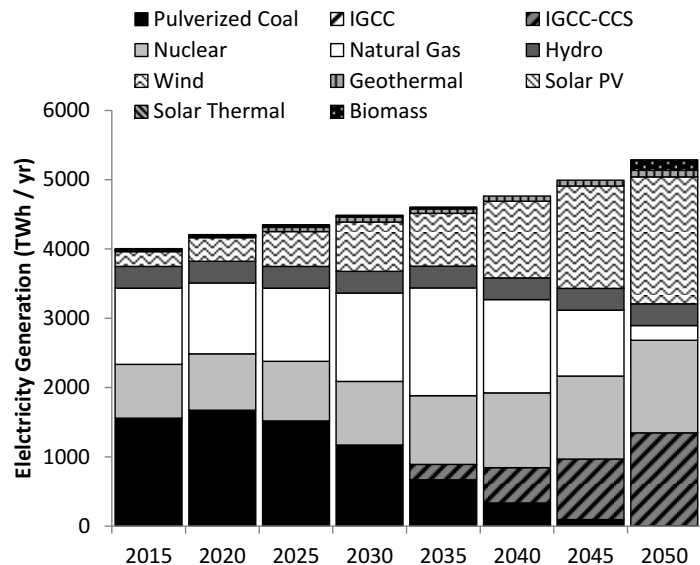


40% CO₂ Reduction Scenario



Increased cost
over base:
0.5%

80% CO₂ Reduction Scenario



Increased cost
over base:
2%

Tuning the MGA Algorithm

MGA should be tested and customized to better suit the specific modeling context.

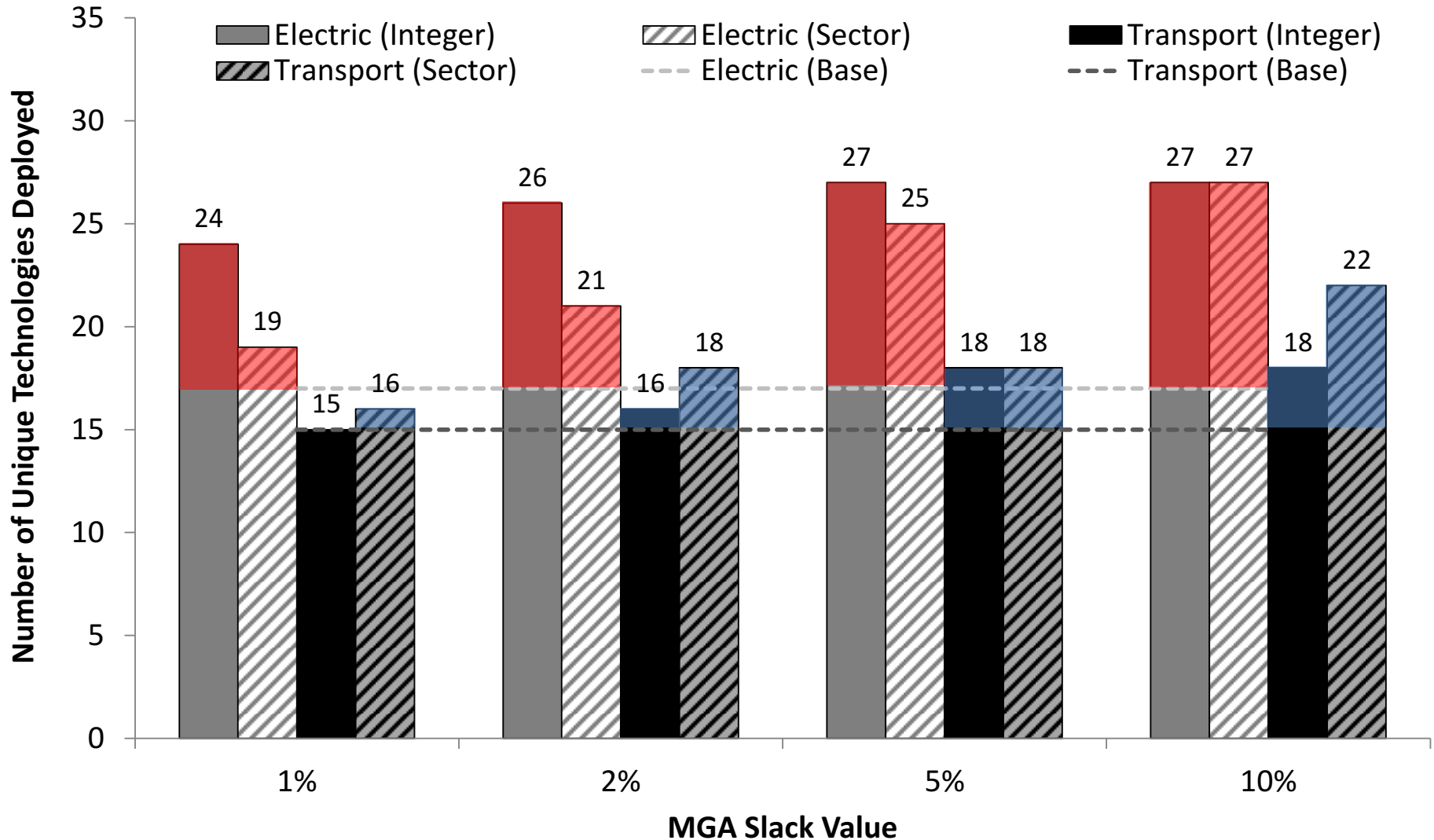
Target decision variable: total technology activity over the model time horizon

Tested two ways to assign objective function weights:

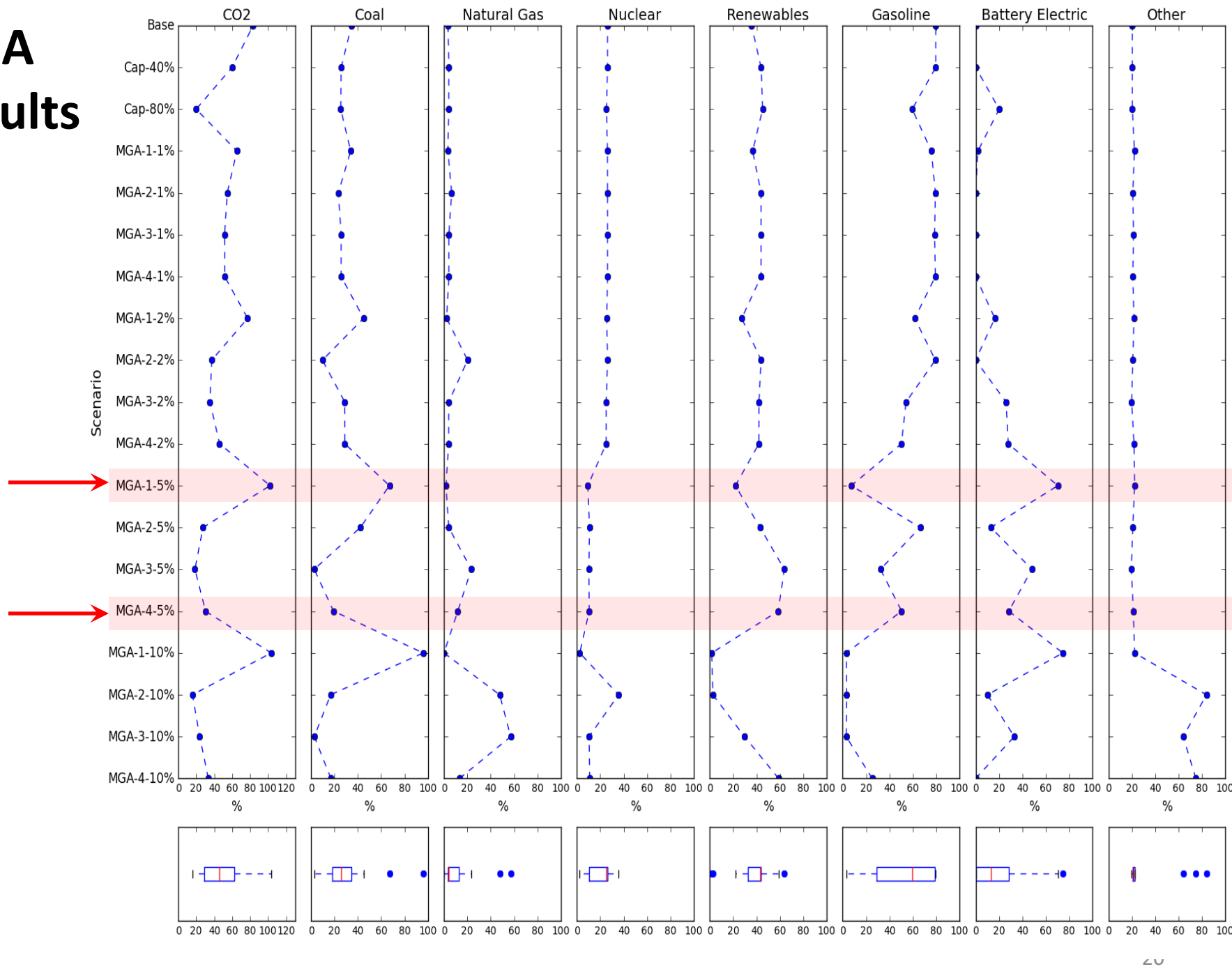
- **Integer Weighting:** Increment technology-specific MGA objective function weight by +1 after each model iteration with positive activity
- **Normalized Sector Weighting:** Increment technology-specific MGA objective function weight by normalized technology activity by sector

Goal: Deploy the maximum number of technologies to characterize flexibility in system design

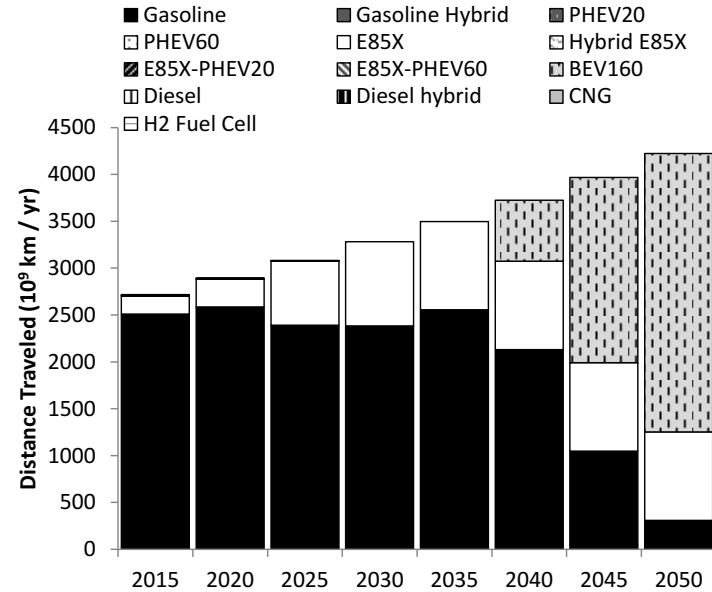
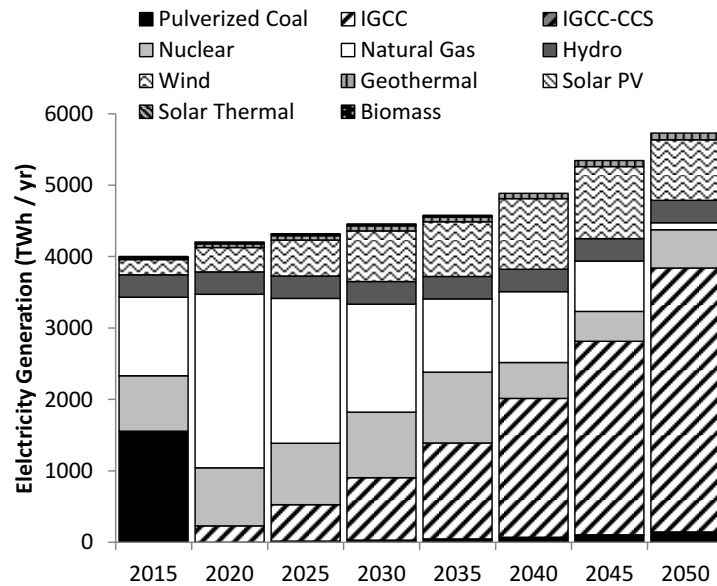
Total Technology Deployment by MGA Method



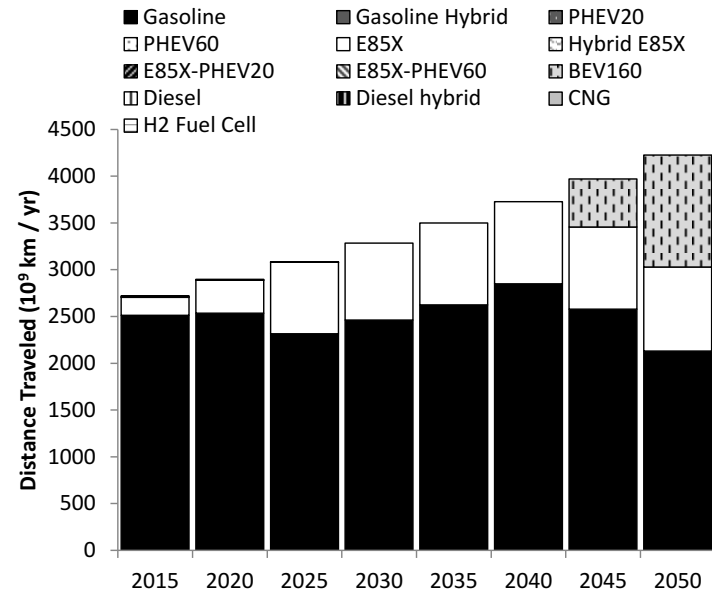
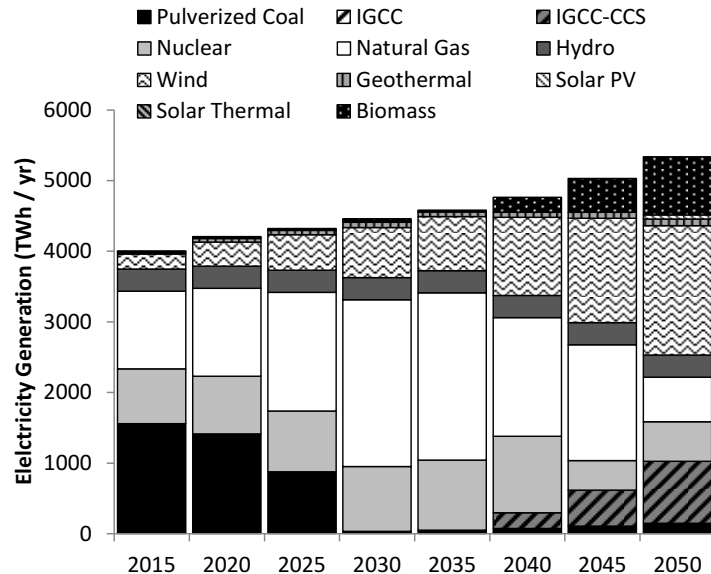
MGA Results



MGA Iteration 1 with 5% Slack (MGA-1-5%)



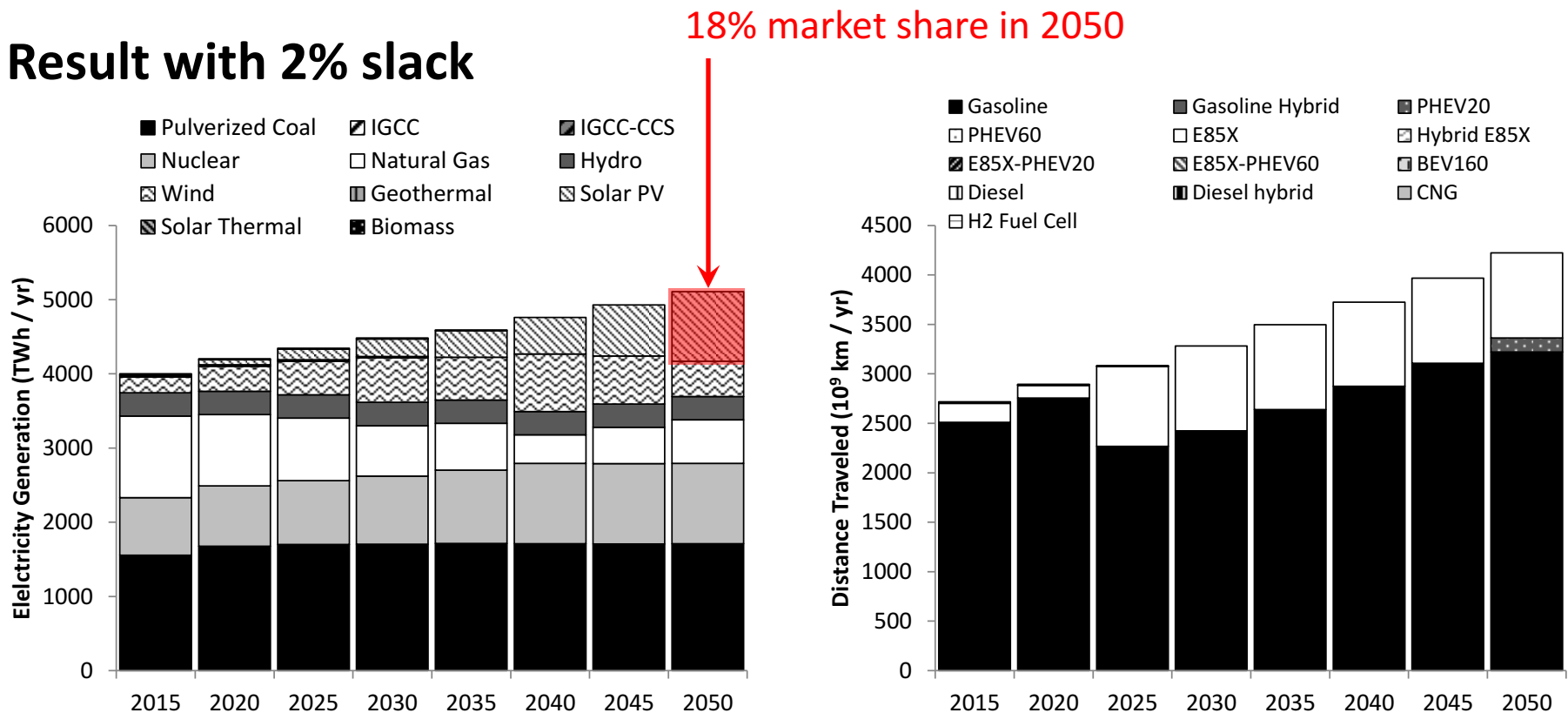
MGA Iteration 4 with 5% Slack (MGA-4-5%)



Focus on Solar PV

- Solar PV only appears at 10% slack
- Modify MGA integer method to minimize all previously deployed technologies **except** solar PV

Result with 2% slack



Insights

Many technologies deployed in MGA runs are not present in base and CO₂ cap scenarios:

- IGCC, biomass, and solar PV in the electric sector
- PHEV20, diesel, and diesel hybrids in the transport sector

Cheap coal-fired electricity often coupled with high electric vehicle deployment in order to meet cost target

Wide variation in coal, natural gas, wind, and gasoline vehicle utilization

Variation in technology deployment increases with MGA slack value

Conclusions

MGA represents a simple method for systematically exploring the decision space of an energy system model

Results highlight the false precision underlying the often limited results produced with conventional scenario analysis

Energy system models should be used to interactively probe the decision space in a way that challenges our mental models and leads to new insight

Perhaps the most useful deliverable is not a set of projections, but a tool of exploration that allows users to interrogate the model.

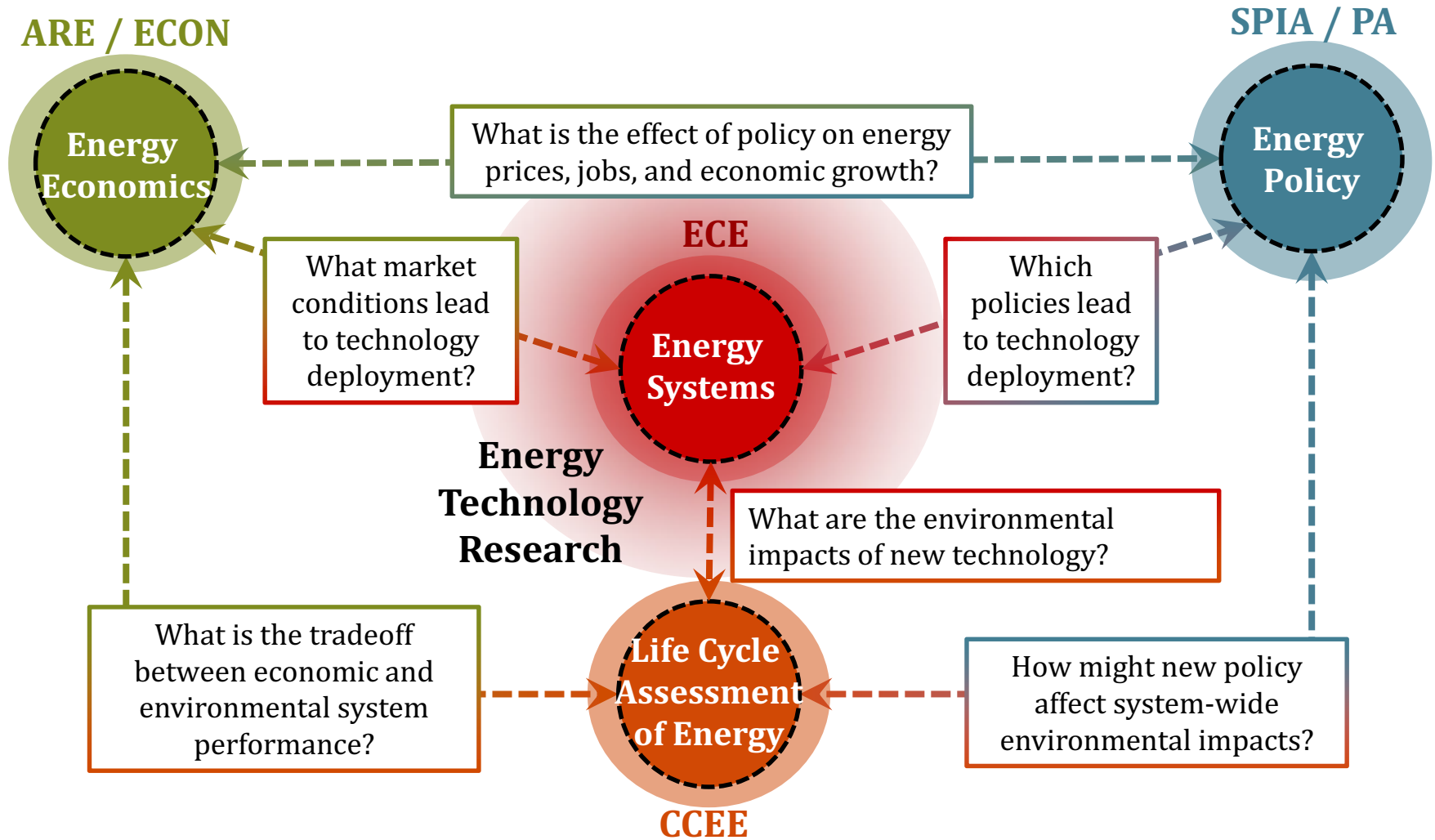
Acknowledgments

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National Science Foundation
WHERE DISCOVERIES BEGIN

New Energy Cluster at NC State



Ads for all four positions will be announced this fall.

