The role of future scenarios to understand deep uncertainty for air quality management

Julia Gamas, Rebecca Dodder, Dan Loughlin, Cynthia Gage

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Outline

I. Scenario Planning Process
  - What is it and why is it relevant to air quality management?
  - Four scenarios for air quality

II. Modeling Future Scenarios in MARKAL
  - Incorporation of the scenarios into MARKAL
  - Illustrative Results

III. Next Steps

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Part I. Scenario Planning Process for Air Quality Management

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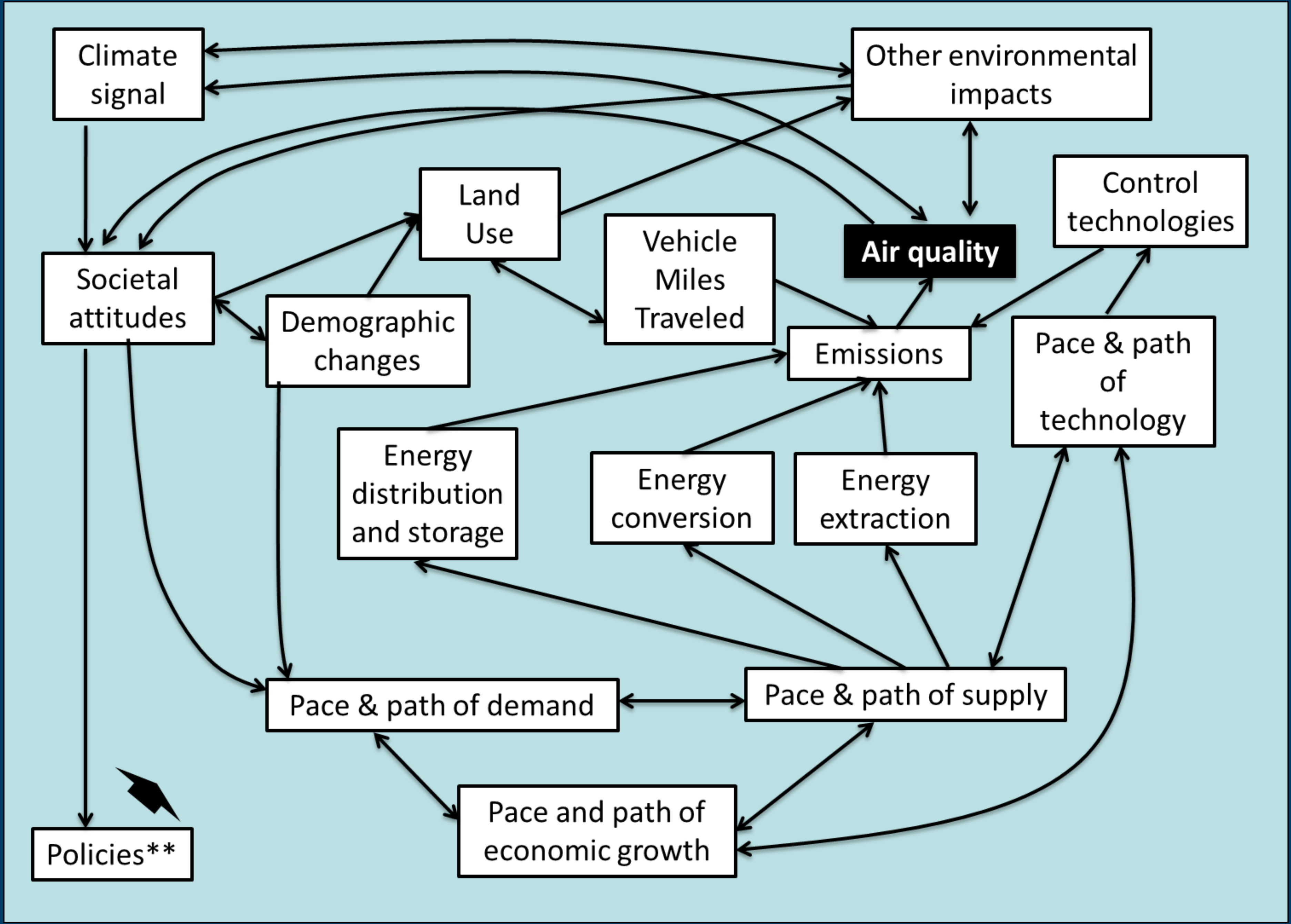
Scenario Planning for Air Quality Management

- There is complexity in the way the environment interacts with human systems (economic, social and political).
- Key drivers may disrupt system dynamics in unforeseen ways, making it difficult to predict future conditions precisely.
- This kind of deep uncertainty presents a challenge to organizations faced with making decisions about the future, including those involved in air quality management.
    - Which driving forces do we consider?
    - How will they behave?
    - How will they interact with other driving forces?
    - What will the end result be for air quality?



Climate signal
Other environmental impacts
Land Use
Vehicle Miles Traveled
Air quality
Control technologies
Societal attitudes
Demographic changes
Emissions
Pace & path of technology
Energy distribution and storage
Energy conversion
Energy extraction
Pace & path of demand
Pace & path of supply
Pace and path of economic growth
Policies**

Scenario Planning (Schwartz 1997; Schoemaker 1991) allows us to:

- Identify relevant driving forces.
- Rank them by how uncertain and critical they are to our problem
- Identify critical futures of interest from those driving forces
- Understand and be prepared for critical futures (rehearse the future)

Scenario Planning has been previously applied in both the private and public sectors, including environmental applications, but has not been previously applied to air quality (Ghanadan and Koomey 2005; NPS 2013; GBN 2007).

For example, the national parks service used scenarios to understand potential impacts of climate change on the parks and future management needs under each scenario.

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Overview of our process

Step	Step 1	Step 2	Step 3	Step 4	Step 5
	Focal question	**Brainstorm on drivers**	**Lay out scenario framework**	**Create narratives**	**Rehearse the future**
Process	• Include multiple perspectives and needs • Not too general • Specific to organizational needs	• Evaluate and rank drivers by how critical and uncertain they are.	• Discuss what form might the most critical and uncertain drivers take, of significance to the focal question.	• From the framework create internally consistent, plausible stories of how we get from the present to that future	• Determine what the organization would face under each scenario and establish policies in preparation • Test policies for robustness
Benefits	• Clarity: what is the fundamental problem we are trying to resolve.	• Understand which drivers are relevant and prioritize • Challenge mental models • Include changes in politics and public opinion	•Capture the most critical and uncertain futures for organization •Discrete manageable number of scenarios	•Beyond BAU • Uncover trends	• Anticipate surprises and opportunities • Flexibility in strategy • Rehearse discontinuities
Sample Questions/Examples	What is the future of air quality in the United States?	• Consumer preferences • Pace of technology • Climate impacts • Economic and population growth	• Most important drivers: Lifestyles and energy mix, and economic growth.	In order for X to happen, Y would have to happen.	• What is the best strategy under each scenario? Is there a robust strategy?

Four Scenarios for Air Quality

EPA held two workshops that included EPA and external experts (Gamas 2012).

Step 1. Specify a focal question

What is the future of air quality in the United States?

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Step 2. Identify key driving forces

Key Driving Forces:

- Energy (extraction, conversion, distribution and storage, efficiency, international energy trends)
- Land Use and transportation patterns (type of human settlements, vehicle-miles travelled)
- Economy (rate and direction of growth)
- Policies (other than EPA policies: e.g. energy efficiency, energy security, direction of research and development)
- Climate change signal (strength, temperature and precipitation, damages from storms and flooding)
- Environmental indicators other than climate change (ecosystem health, persistence of pollutants, water resource quantity and quality)

From the key drivers, identify those most critical and uncertain:

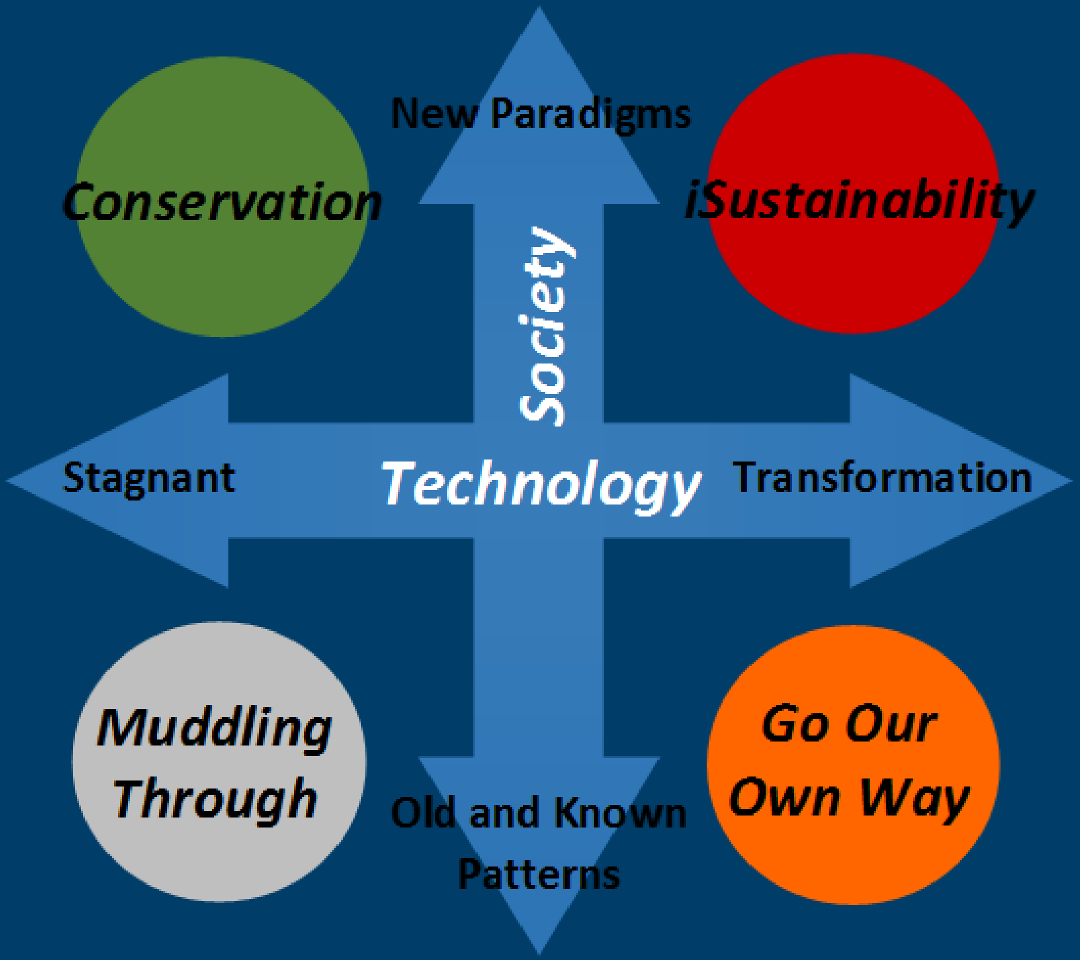
- Technology (emissions reductions technologies, other technological developments)
- Societal attitudes (consumption choices based on support for environmental protection)

These became the backbone of our scenarios framework.

Step 3. Construct the scenario framework

What values of interest to our focal question could these two drivers take?

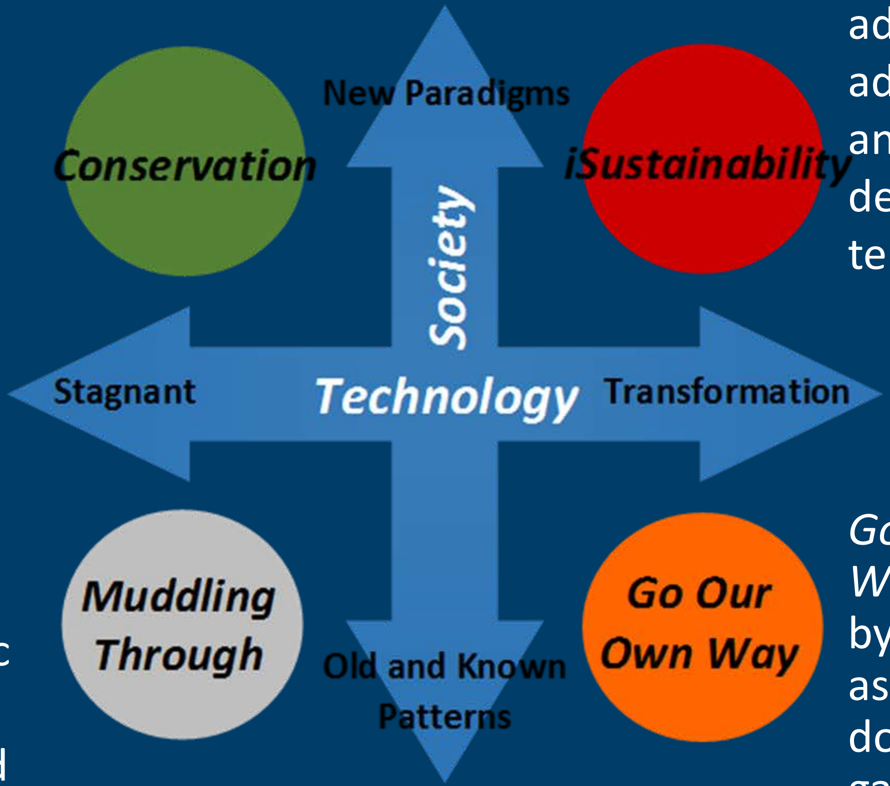
- Technology (high tech vs. low tech)
- Societal attitudes (support for environmental protection vs. indifference).



Step 4. Develop narratives

Conservation is motivated by environmental considerations. Assumptions include decreased travel, greater utilization of existing renewable energy resources, energy efficiency and conservation measures adopted in buildings, and reduced home size for new construction.

iSustainability is powered by technology advancements, and assumes aggressive adoption of solar power, battery storage, and electric vehicles, accompanied by decreased travel as a result of greater telework opportunities.



Muddling Through has limited technological advancements and stagnant behaviors, meaning electric vehicle use would be highly limited and trends such as urban sprawl and increasing per-capita home and vehicle size would continue.

Go Our Own Way includes assumptions motivated by energy security concerns. These assumptions include increased use of domestic fuels, particularly coal and gas for electricity production and biofuels, coal-to-liquids, and compressed natural gas in vehicles.

Step 5. Rehearsing the future

In *Conservation* current technologies as well as conservation measures are moving society towards lower emissions. Emissions in general could decrease substantially. Air quality management would likely focus less on end-of-pipe type controls and more on supporting the development of renewable energy sources, energy efficiency, fuel switching and clean fossil fuels.

In *Muddling Through* emissions would increase. Air quality management would likely focus more on end-of-pipe controls.

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- In *iSustainability* many advanced technologies are available. The need for end-of-pipe controls would be lower, and air quality managers could focus on making sure society reaps the benefits of new technologies coming online (e.g. smart grid).
- In *Go Our Own Way* society, and therefore government, are concerned with energy security. All fuels are being developed. Air quality managers could take advantage of this trend by promoting energy efficiency that would maximize the use of domestic energy sources and decrease emissions in the process.

II. Modeling Future Scenarios In MARKAL

Incorporation of Scenarios into MARKAL

- Illustrate the scenarios quantitatively
- Run sensitivities on the scenarios and gain insights about the roles of different drivers:
  - How different do fossil fuel prices have to be from renewable fuel prices to see a significant shift in their use?
  - What might unintended consequences of shifts in the use of one technology be on the use of another?
- In scenarios it isn’t just values of variables that might change, but also parameters:
  - Elasticities of supply and substitution amongst inputs represent technological change
  - Elasticities of demand represent consumer preferences
- Exploring the efficacy of candidate management strategies over very different realizations of the future
- Use the scenarios to develop management strategies that are inherently robust (are effective under any scenario)

MARKAL is uniquely suited to the task because of its:

- Detailed representation of the full energy system (from extraction of fuels to their use in meeting end-use energy demands)
- Relatively fast runtime and ease with which alternative assumptions and sensitivities can be examined
- Ability to uncover internal inconsistencies in the storylines (for example, in *Conservation*, increased nuclear power was needed to replace baseload electricity production formerly provided by coal plants).

We translated of big picture concepts in the narratives to fairly detailed numbers and parameters into the model:

Example levers included:

- Bounding out advanced technologies in *Conservation* and *Muddling Through*
- Decreasing advanced technology costs in *iSustainability* and *Go Our Own Way*
- Adjusting market share constraints in *Conservation*, resulting in a decrease in vehicles size
- In *iSustainability*, relecting more telework by reducing travel demand and new commercial space, while increasing new home size for home offices

We present results for system-wide NO_x and SO_2 emissions to illustrate relative changes in emissions for the four scenarios, to highlight the relevance to air quality management.

We then show results for three major aspects of the energy system:

- Changes in primary energy consumption
- Changes in electricity generation mix
- Changes in light duty vehicle mix

These examples are key sectors that drive emissions changes for air quality, but also could provide information for decision-makers for other pollutants and environmental impacts of interest.

Illustrative Results

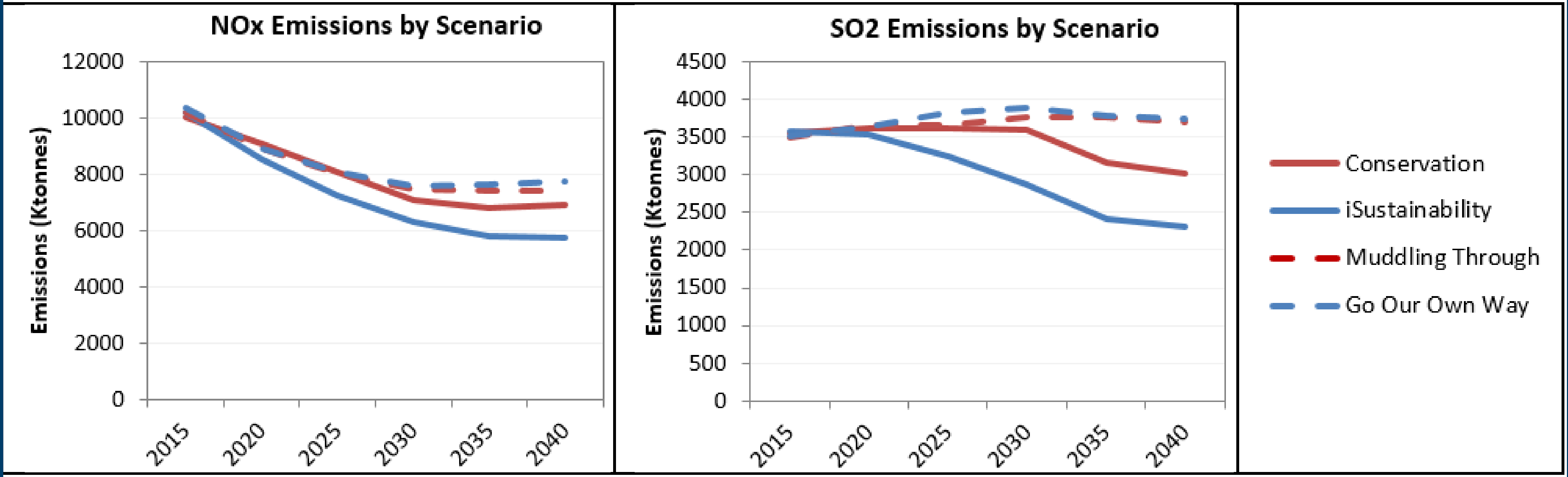
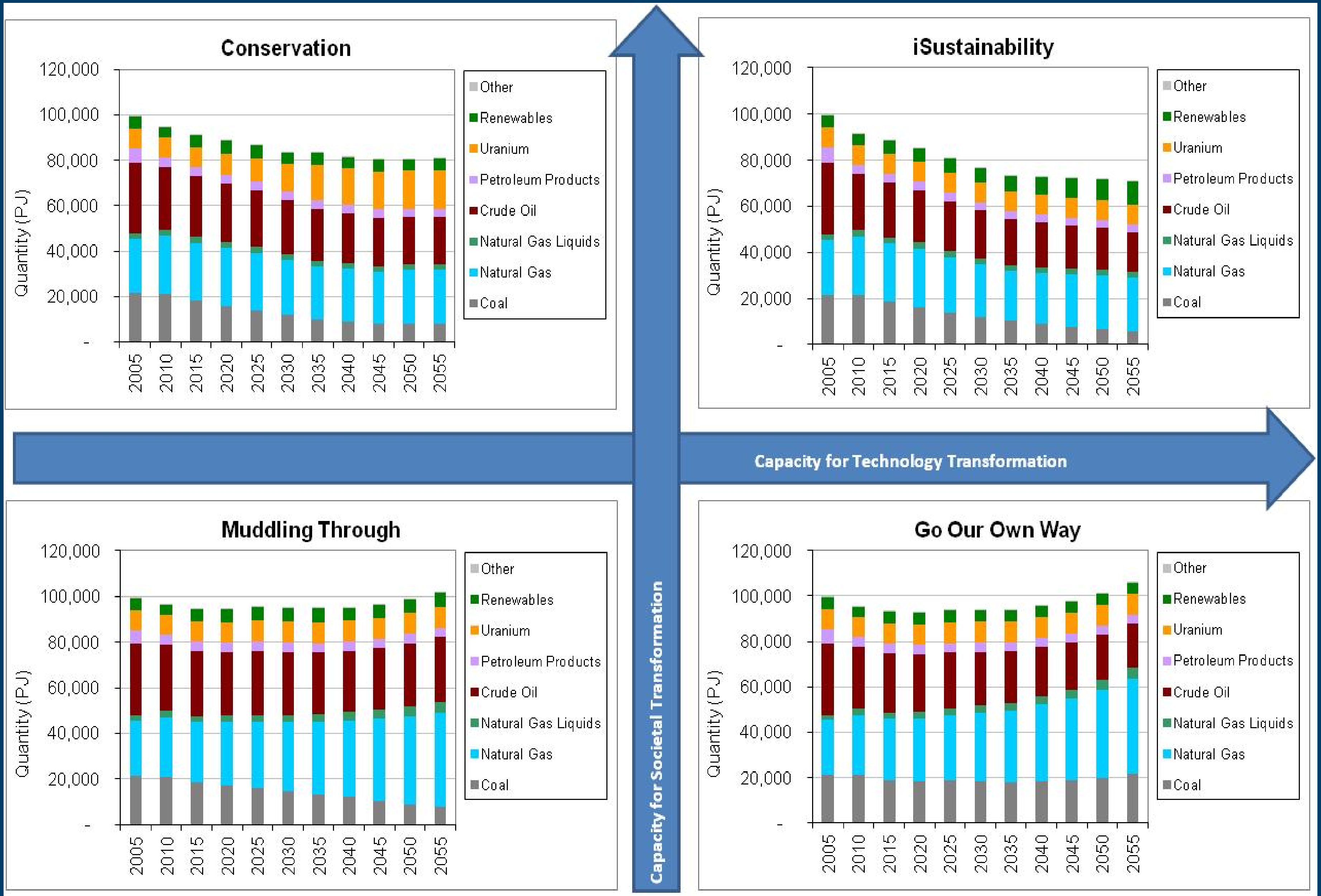
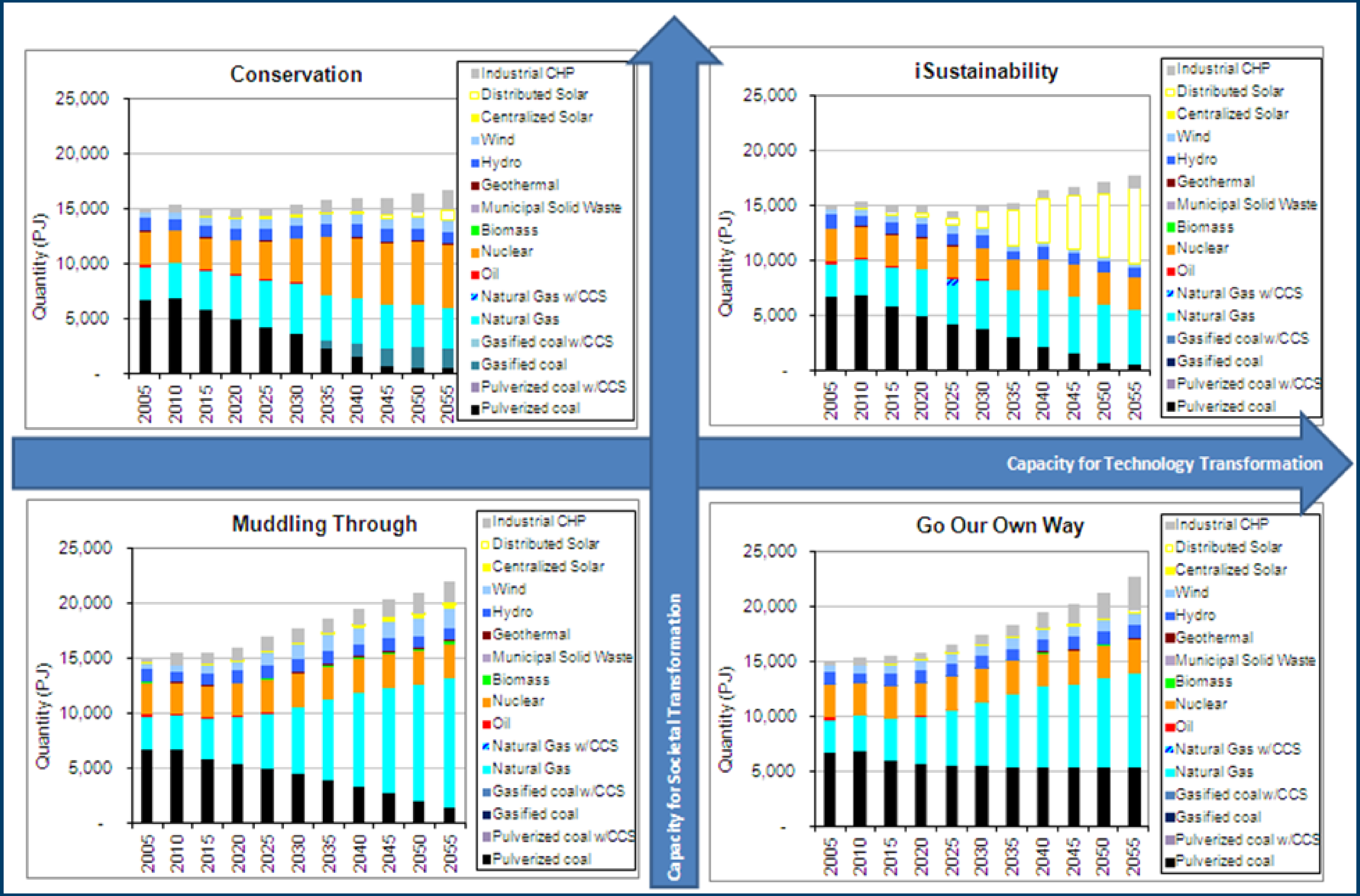


Figure 2. Illustrative result showing the NOx and SO_2 emissions trajectories for preliminary implementations of each scenario in MARKAL.

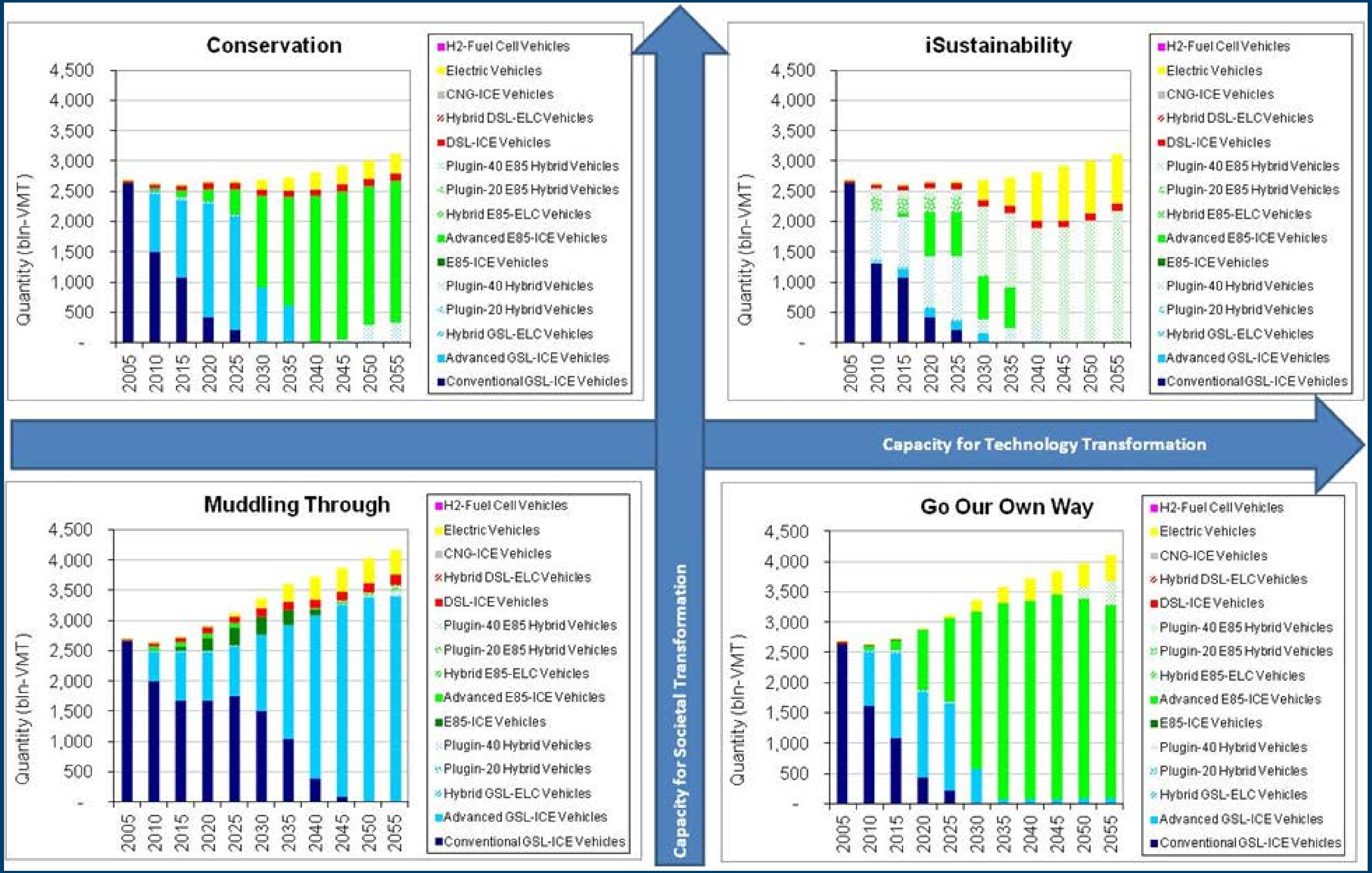
Primary Energy Consumption



Electricity Generation



Light Duty Vehicles



Observations

- On process:
  - Implementing detailed scenario assumptions into MARKAL in some instances proved challenging or tedious. For example, assuming new buildings are net-zero required considerable research into the turnover of the building stock. Forcing in other assumptions limited the flexibility of the model in responding to additional stimuli. Scenario assumptions had to be re-implemented when the underlying MARKAL model changed.
- Results
  - Despite the wide-ranging differences in assumptions regarding technology development and behavior, all four scenarios indicate that the trend of decreasing NOx and SO2 emissions will continue, largely driven by air quality regulations.
  - By 2040, NOx emissions across the scenarios are approximately 20% to 40% lower than in 2015. There is considerably more uncertainty related to future SO_2 emissions. Emissions in 2040 range from approximately 6% greater to 35% less than in 2015.

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Next Steps

- MARKAL 2014 released in September, 2014, we are incorporating the scenarios to the new database.
- Based upon our preliminary results, we are exploring how the scenarios can be refined to yield broader coverage of air quality outcomes.
- We can further explore our analysis from Step 5 within the context of MARKAL by testing how specific controls and policy options behave in each scenario.

Next Steps

- We are also exploring alternative ways to implement the scenarios into MARKAL so that updated scenarios can be incorporated faster:
  - Instead of forcing technological and behavioral changes to match the detailed scenario narratives, in the next implementation, we plan to integrate the broader scenario drivers (technological change and changing societal paradigms) in a manner that gives the model more flexibility to respond to changes in model inputs.
- From the application standpoint, we will begin to explore how the scenarios can be used in a long-term planning context, identifying robust, multi-pollutant management strategies.

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Back-up Slides