Insights into future air quality:

Analysis of future emissions scenarios using the MARKAL model

Julia Gamas[1], Dan Loughlin[2], Rebecca Dodder[2] and Bryan Hubbell[1]

[1] U.S. EPA Office of Air Quality Planning and Standards

[2] U.S. EPA Office of Research and Development

14th Annual CMAS Conference, UNC-Chapel Hill, October 5-7, 2015

Foreword

Objective of this presentation

We describe a scenario-based approach for projecting future pollutant emissions. The scenarios are used to characterize regional emission trends through 2050. The scenarios are also demonstrated in the context of evaluating pathways for achieving a multi-pollutant emission reduction target.

Intended audience

The material presented here is intended to be of interest to modelers who develop and evaluate projections of future-year emissions.

Disclaimers

Modeling results are provided for illustrative purposes only.

The scenario implementation is a work-in-progress, and future results may change.

While this presentation has been reviewed and cleared for publication by the U.S. Environmental Protection Agency, the views expressed here are those of the authors and do not necessarily represent the official views or policies of the Agency.

Outline

1. Introduction
2. The Future Scenarios Method
3. Scenario Implementation
4. Illustrative Results
   - How different are the scenario results?
   - What are the long-term emission trends and how do they differ by region?
   - How can we use the scenarios to test a (hypothetical) policy?
5. Conclusions
6. Next steps

I. Introduction

- **Drivers of future pollutant emissions (and thus air quality) are uncertain. Examples include:**
  - Population growth and migration
  - Economic growth and transformation
  - Technology development and adoption
  - Climate change
  - Consumer behavior and preferences, and
  - Policies (energy, environmental, climate, …)
- **Given these uncertain drivers, are there steps that we can take to:**
  - understand a range of future conditions that may occur,
  - anticipate conditions that may limit the efficacy of air quality management strategies, and,
  - develop management strategies that are robust over a wide range of future conditions?

2. Future Scenario Method

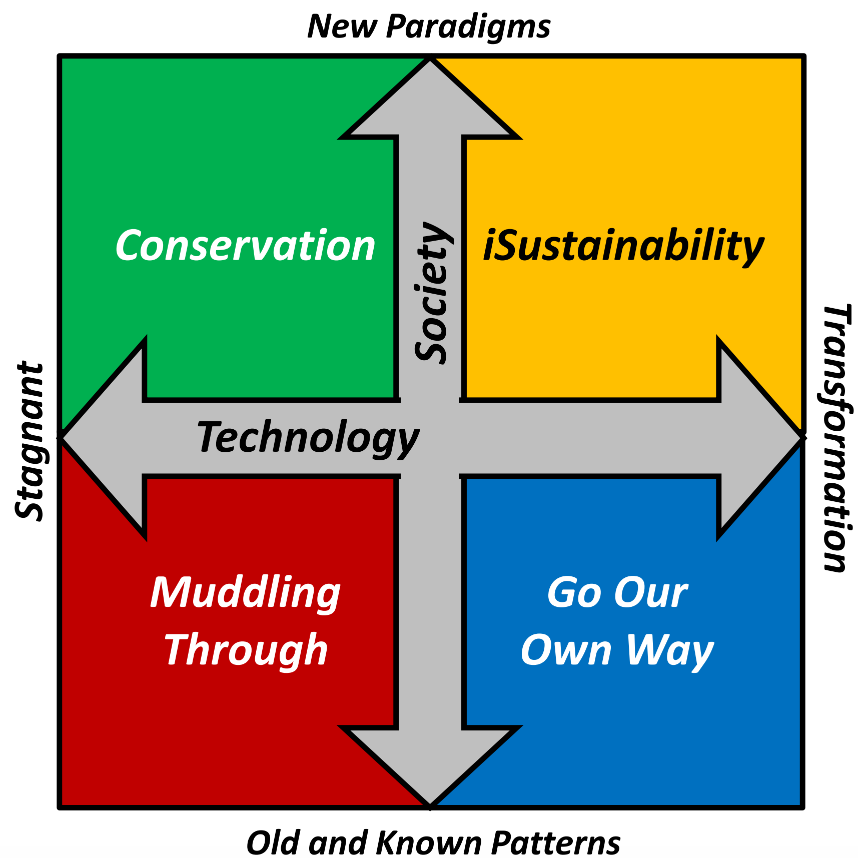
- We applied the Future Scenarios Method to develop scenarios that inform air quality management decisions
- Future Scenarios Method steps:
  - Interview internal and external experts
  - Select the two most important uncertainties and develop a scenario matrix
  - Construct narratives describing the matrix's four scenarios

Note: In this application, we developed a 2x2 scenario matrix. The method is adaptable, however, and could be used to develop more or fewer scenarios.

2. Future Scenario Method, cont'd

This is the resulting Scenario Matrix:

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.

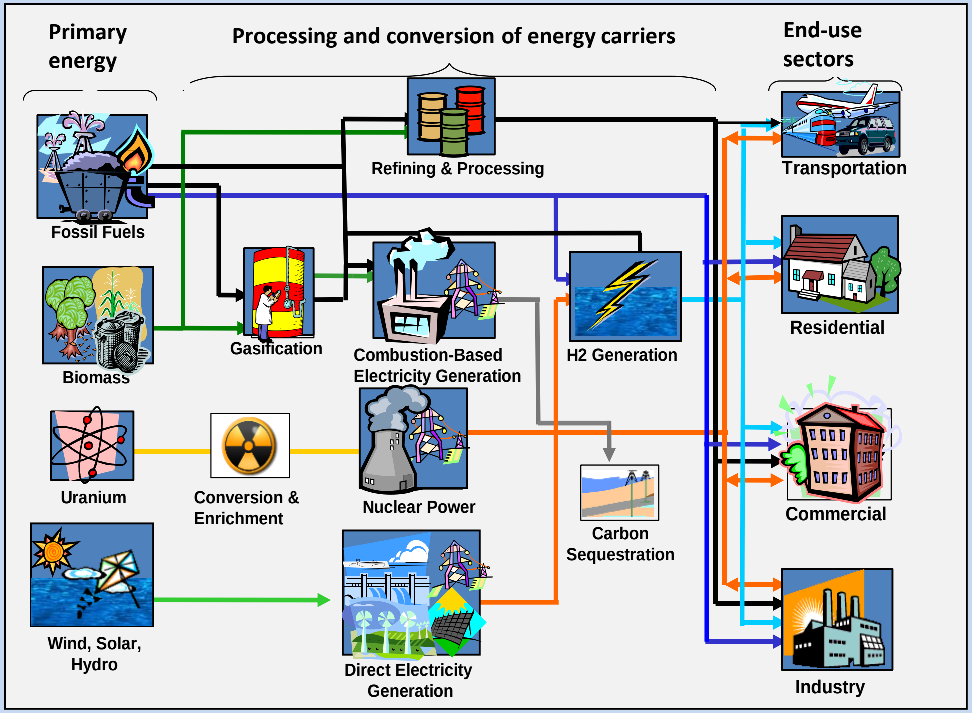
Go Our Own Way includes assumptions motivated by energy security concerns. These assumptions include increased use of domestic fuels, particularly coal and gas for electricity production and biofuels, coal-to-liquids, and compressed natural gas in vehicles.

3. Scenario Implementation

- **The scenarios were implemented in the MARKet ALlocation (MARKAL) energy system model with EPA's US nine-region database**
- **MARKAL details:**

Name: MARKet ALlocation model
Dataset: EPAUS9r_14 database
Resolution: U.S. Census Division
Temporal: 2005-2055, 5-yr steps
Sectoral resolution: electric, residential, commercial, industry transportation, resource extraction
Outputs: energy-related technology penetrations, fuel use, emissions, and water demands
Solution: linear programming with perfect foresight
Runtime: 30 min-1 hour on desktop PC

Energy system components



Note: The Clean Power Plan is not yet represented in EPA MARKAL

3. Scenario Implementation, cont'd

- Implementation of the scenarios continues to be a learning process
- Early approach:
  - Developed highly detailed narratives
  - Constrained MARKAL to follow the detailed narratives
  - Advantage:
    - The scenarios differed considerably with respect to projected technology penetrations and air pollution emissions
  - Disadvantage:
    - The scenario assumptions were hard-coded, leaving the model little freedom to respond to a policy or other "shocks"
    - Scenarios have to be re-implemented in each new MARKAL database version
- Current approach:
  - Step back from the detailed narratives and focus on underlying drivers
  - Let the model drive the narratives
  - Layer the scenarios on top of the current base case

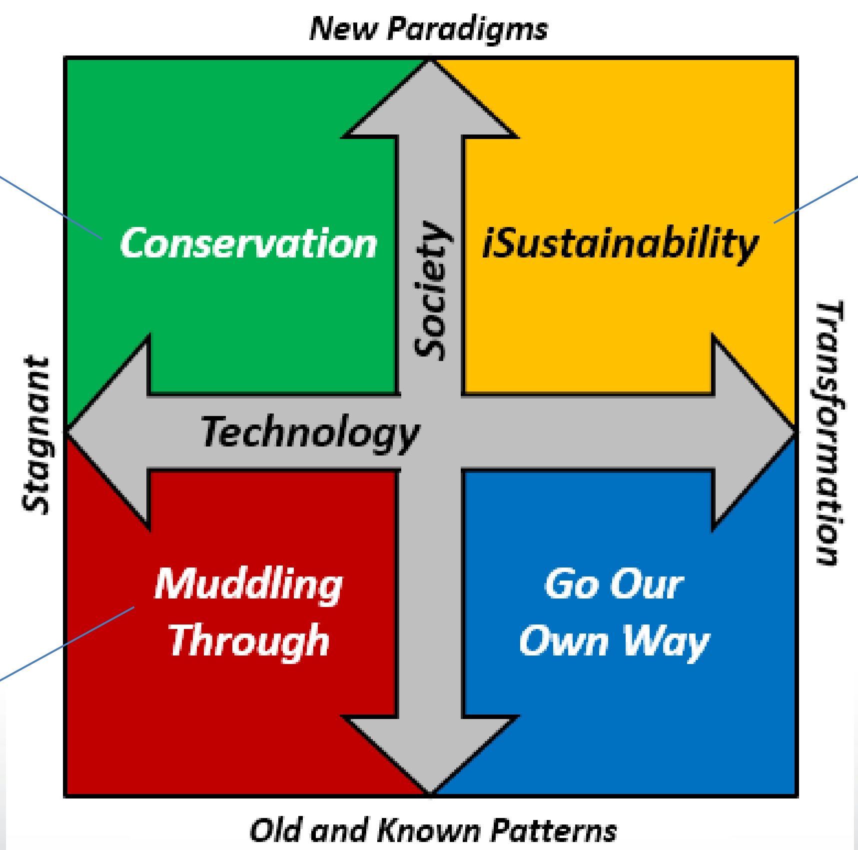
3. Scenario Implementation, cont'd

- **Current approach**
  - **Axis: Technological transformation or stagnation**

Lever: technological availability and cost

No electric vehicles
No IGCC
Conservative wind and solar costs

Only considered technologies that are competitive today without subsidies



Electric vehicles achieve cost parity with conventional
Wind and solar costs follow optimistic cost projections

No electric vehicles
No IGCC
Conservative wind and solar costs

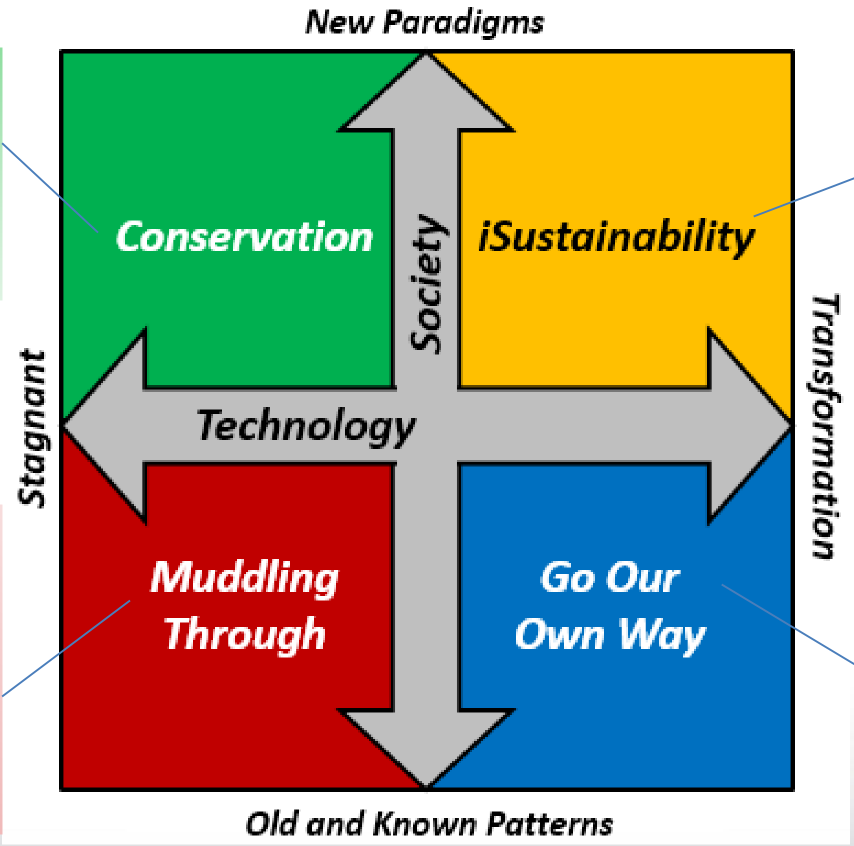
3. Scenario Implementation, cont'd

- **Current approach**
  - **Axis: Social transformation and behavioral change**

Lever: hurdle rates to reflect scenario-specific preferences

Prefer:
- Renewable
- Environmental- and climate-friendly
- Local
- Energy efficient

Prefer:
- Renewable
- Environmental- and climate-friendly
- Energy efficient
- Advanced technologies



Prefer:
- Conventional technologies

Avoid:
- Advanced technologies
- Infrastructure changes req'd
- Environmental- and climate-friendly
- High capital cost

Prefer:
- Advanced technologies
- Energy efficient

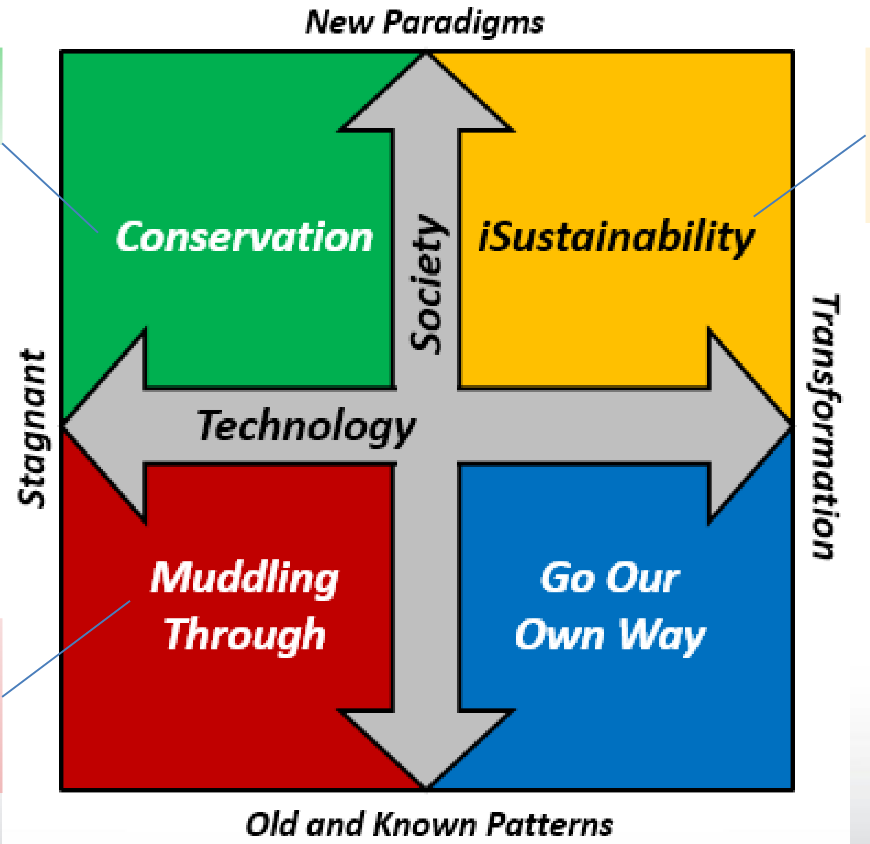
Avoid:
- Infrastructure changes req'd
- High capital cost

3. Scenario Implementation, cont'd

- **Current approach**
  - **Axis: Social transformation and behavioral change**

Lever: end-use energy demands

Passenger vehicle demands reduced to reflect telework



Passenger vehicle demands reduced to reflect telework
New homes larger to accommodate home offices

Historic trends of increasing travel per person and increasing house sizes continue

4. Illustrative Results

How different are the scenario results?

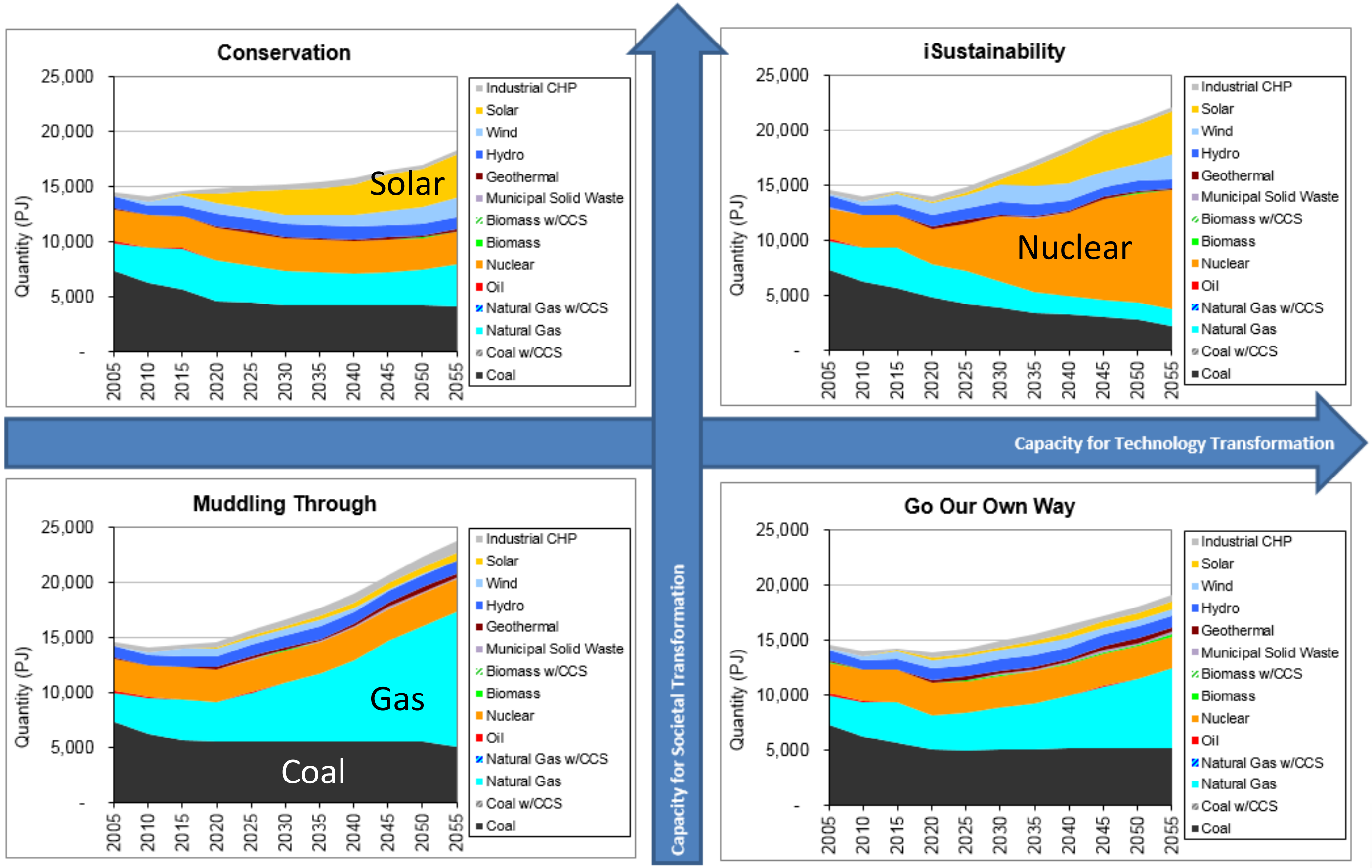
What are the long-term emission trends and how do they differ by region?

How can we use the scenarios to test a (hypothetical) policy?

4. Illustrative Results, cont'd

How different are the scenario results?

Electricity production by aggregated technologies



EPA

4. Illustrative Results, cont'd
How different are the scenario results?

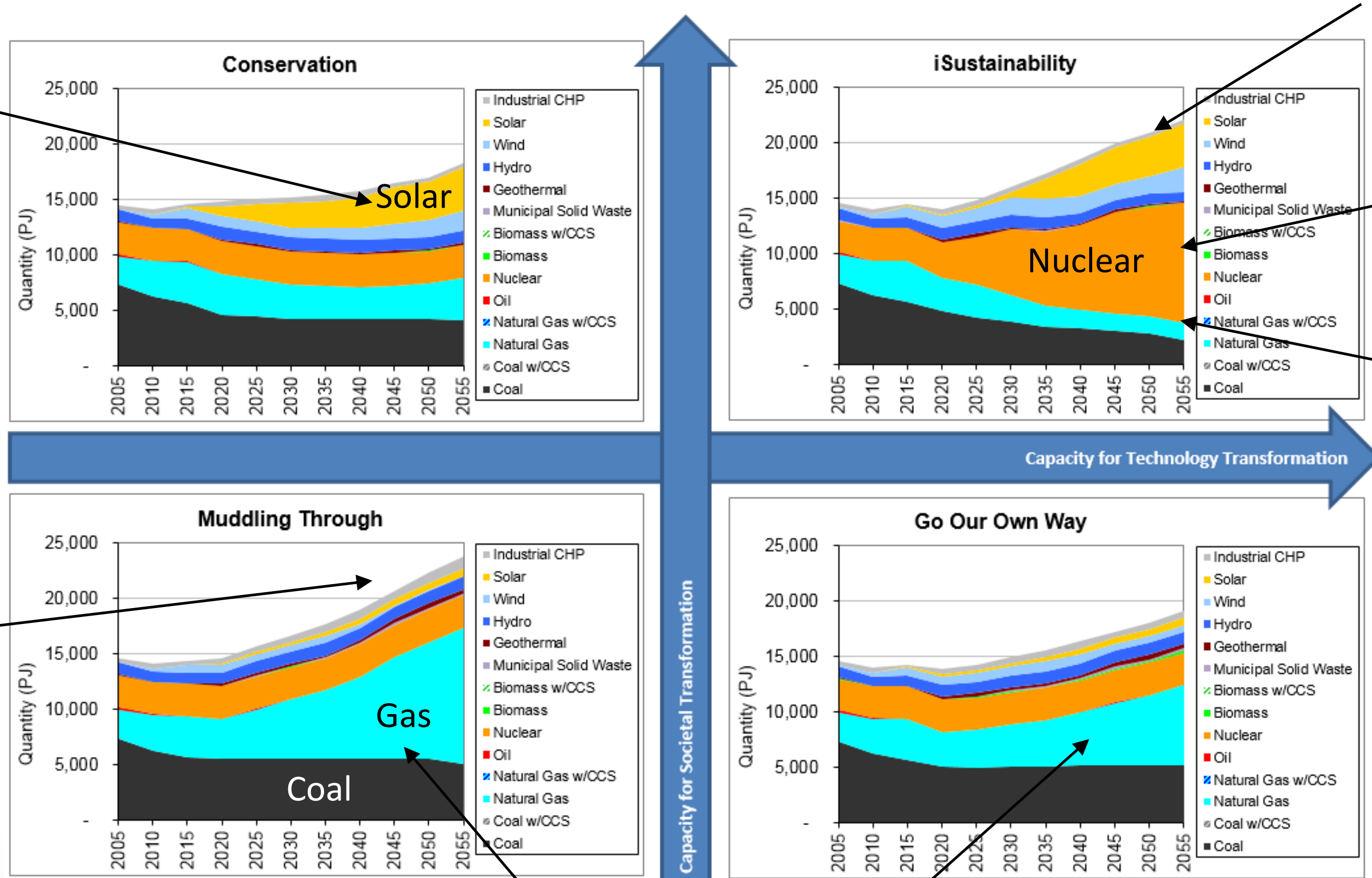
Electricity production by aggregated technologies

Growth in renewables

Relatively high electricity demands

Major increase in nuclear

Limited natural gas



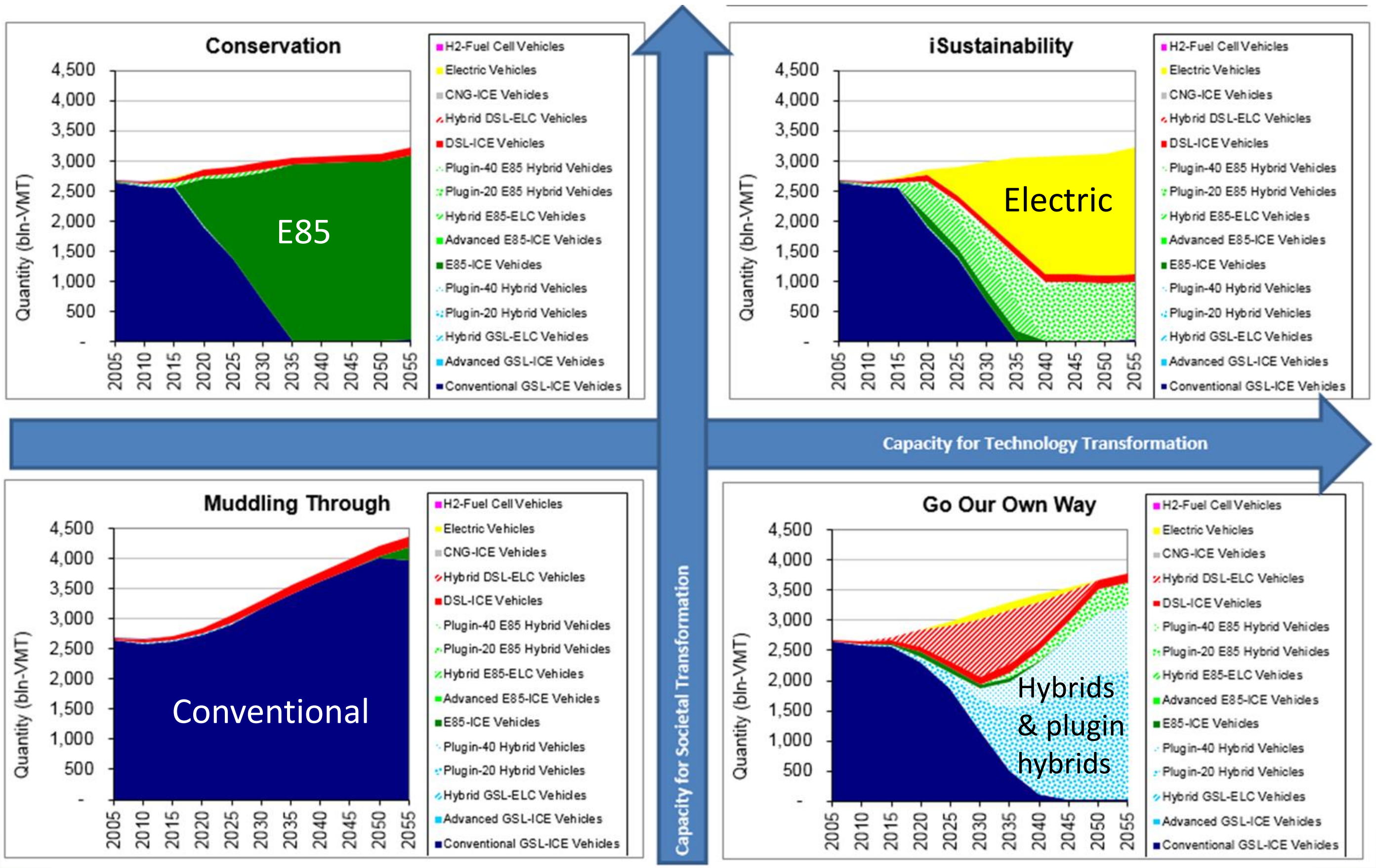
Relatively high electricity demands

Most demand growth met with natural gas

Coal remains in all scenarios. The cost of lifetime extensions is low, and the fuel is inexpensive.

4. Illustrative Results, cont'd
How different are the scenario results?

Light duty vehicle technologies

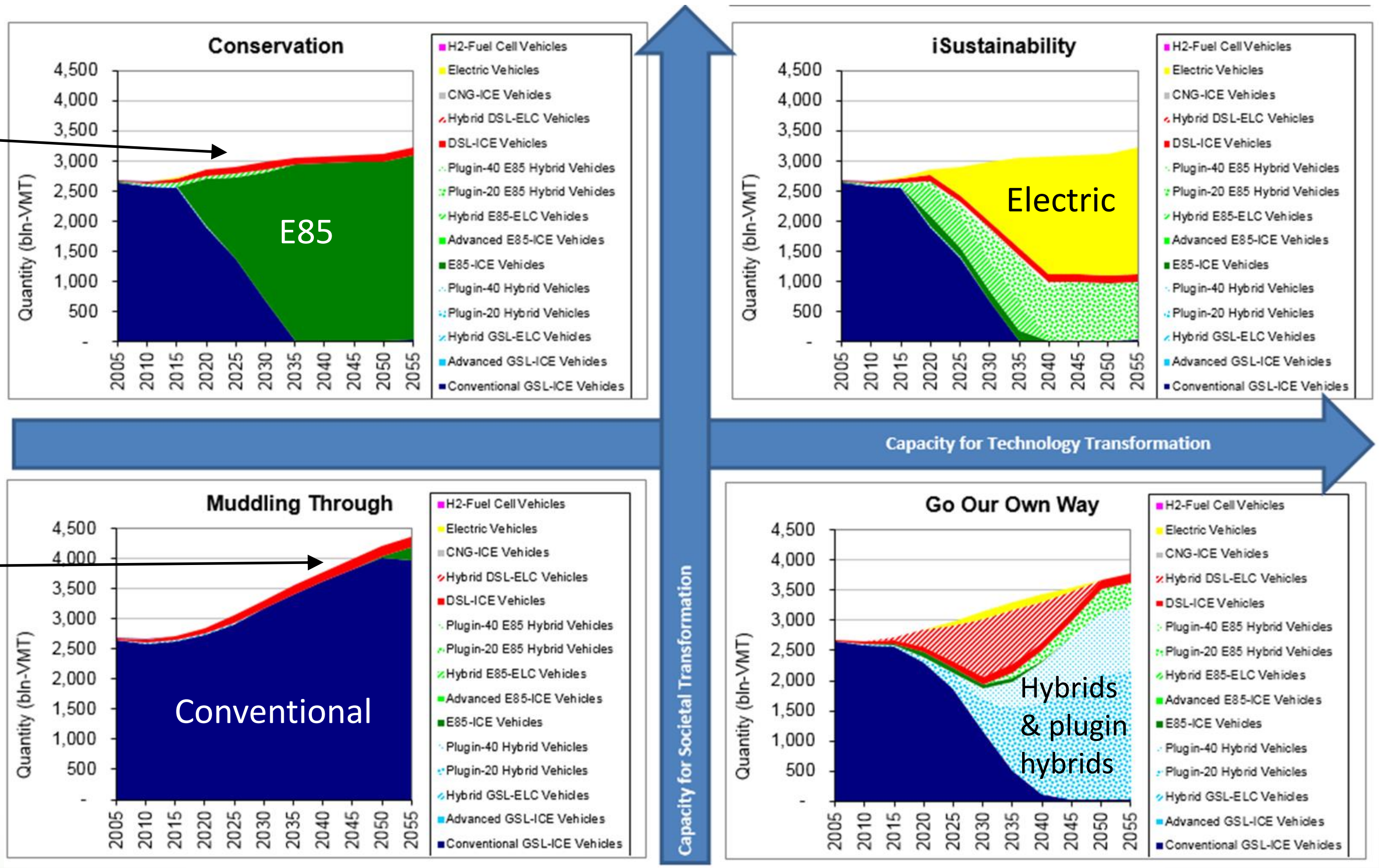


4. Illustrative Results, cont'd
How different are the scenario results?

Light duty vehicle technologies

Demand levels off

Increased demand



From 2020 all vehicles are electrified

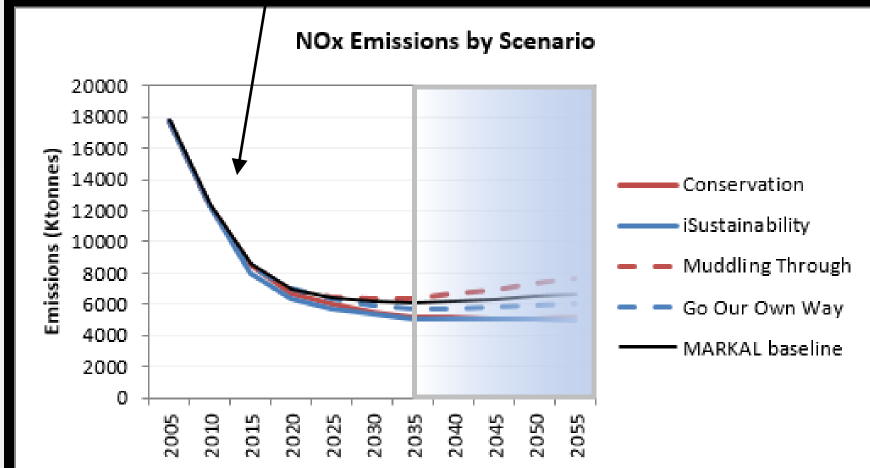
Uses domestic fuels but makes them stretch further

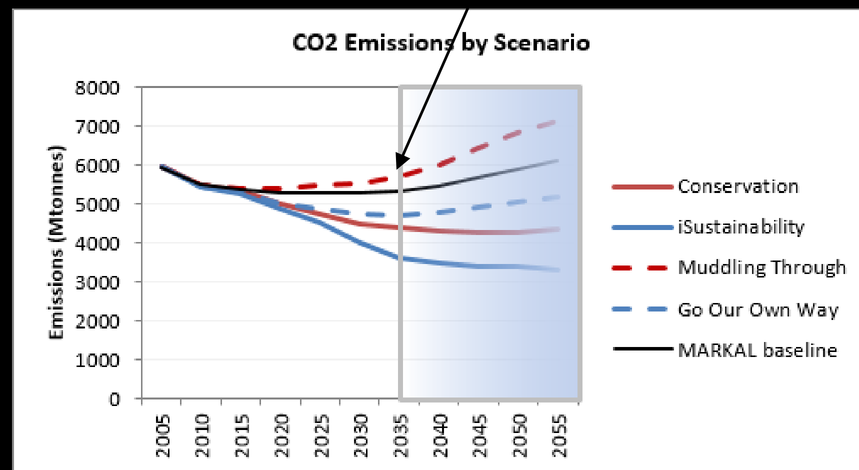
4. Illustrative Results, cont'd
What are the long-term emission trends?

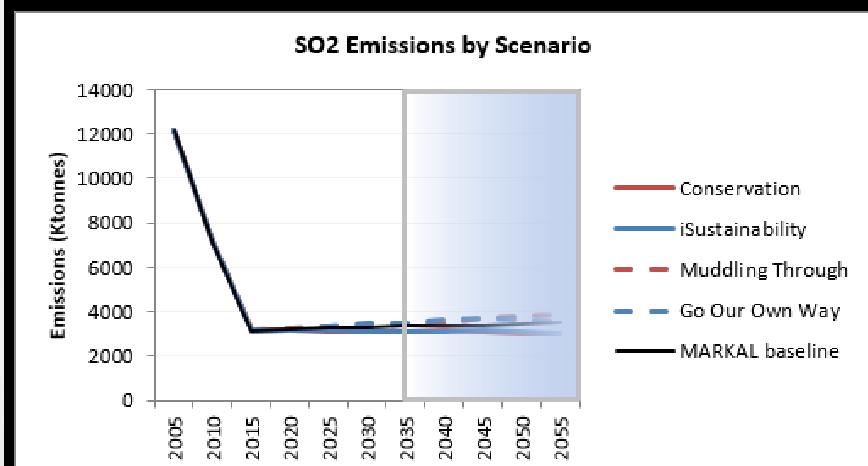
CAIR and Tier-3 drive NOx trend

Emissions

Greatest variability in CO_2







Historic SO_2 reductions are "locked in" but there is a small amount of variability.

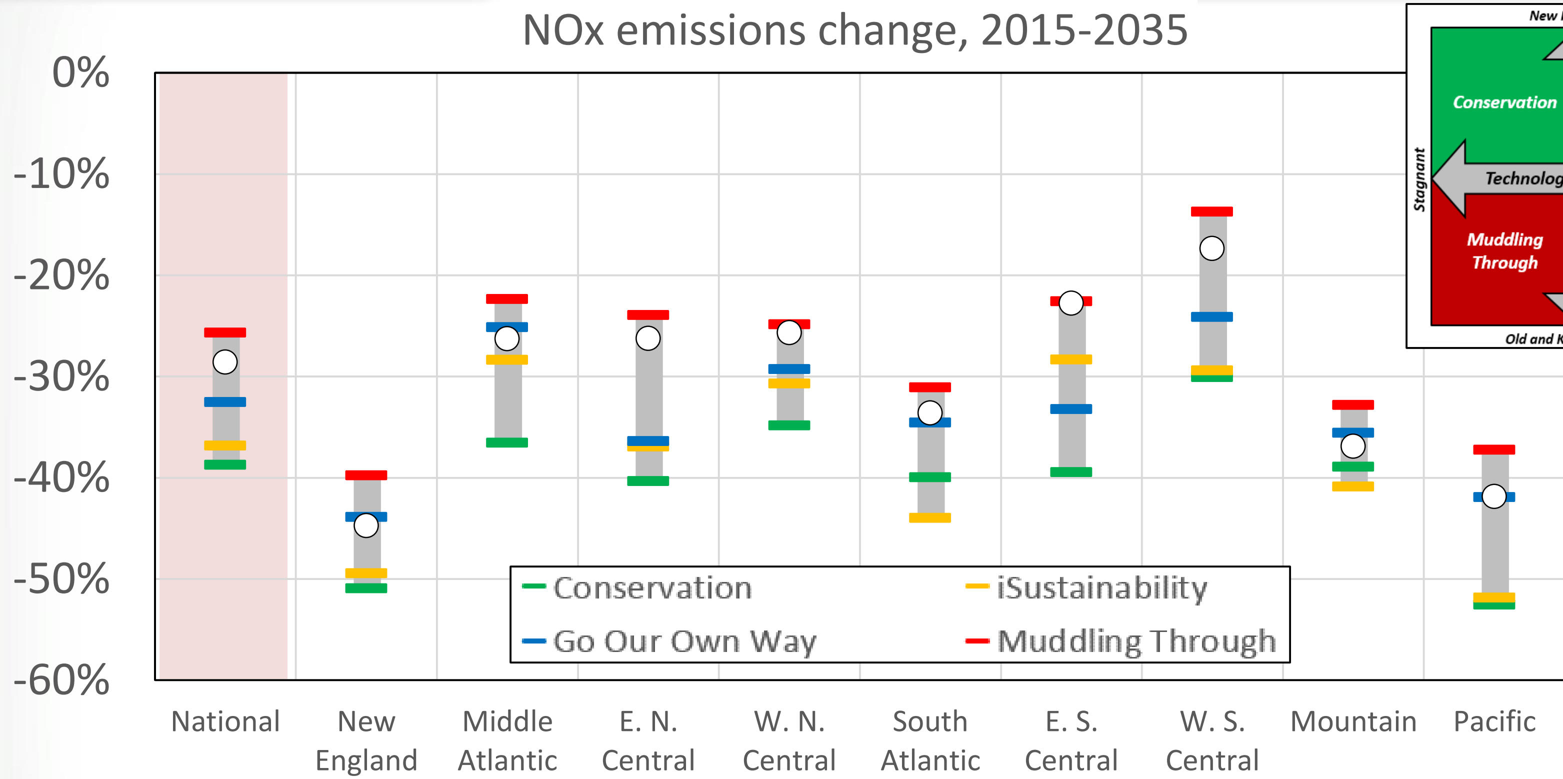
Existing regulations are relatively robust in locking in downward trends for criteria pollutants.

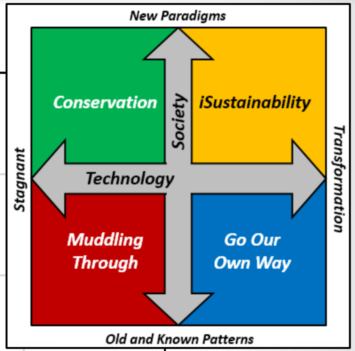
The range of CO_2 emissions across the scenarios is considerably greater than that of the other pollutants.

Note: The Clean Power Plan is not represented in these results

4. Illustrative Results, cont'd

What are the long-term emission trends?





Circles represent MARKAL baseline values. The boxes represent the range of values over the four scenarios.

Regional trends are similar to national trends, although baseline reductions and range can differ substantially from one region to another.

Contributing factors include existing technology stock, access to renewables, energy trade with neighboring regions and fuel-switching within and across sectors.

4. Illustrative Results, cont'd

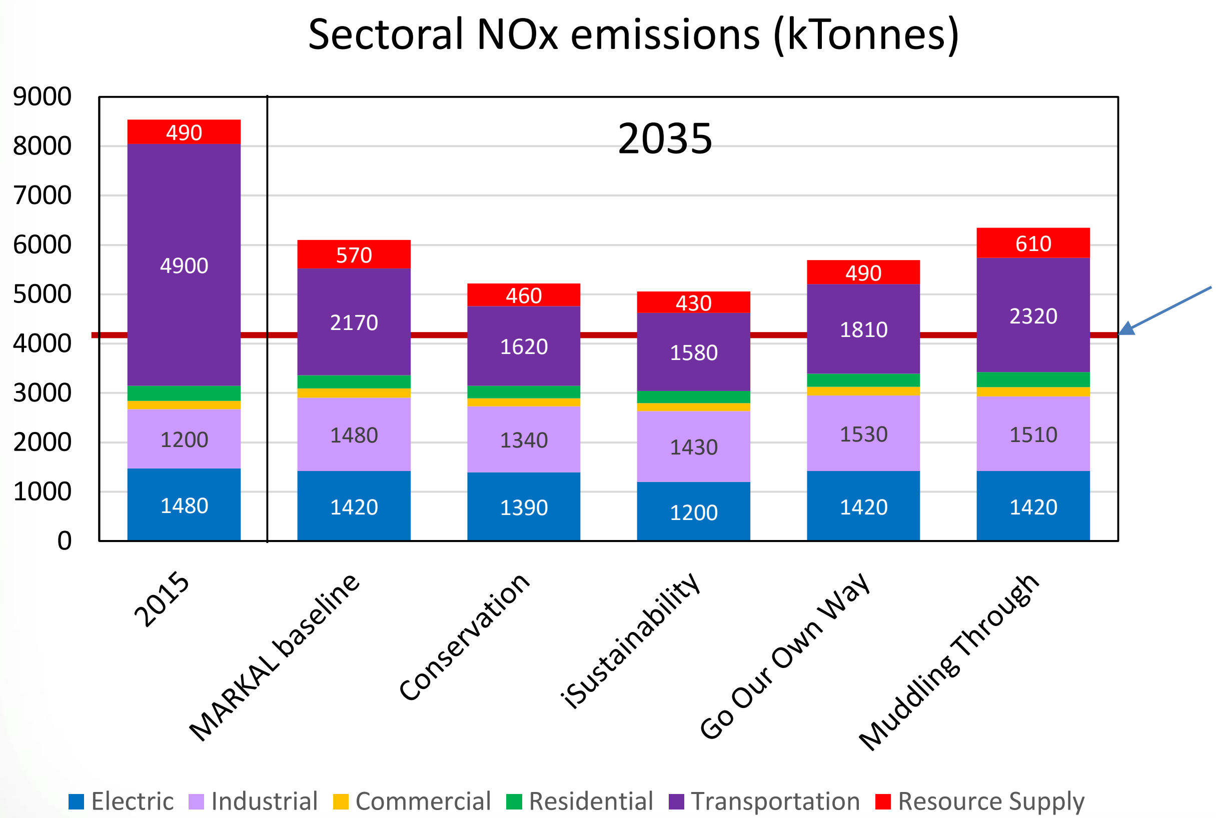
What can we learn testing a policy with the scenarios?

- **Hypothetical policy goal:**
  - Using each of the scenarios as an alternative baseline…
  - Introduce target to reduce national energy system NOx, SO_2 and PM emissions by 50% from 2015 levels by 2035
- **Questions:**
  - Is this target feasible for all of the baselines?
  - From which sectors would the reductions come for each baseline?
  - Are there common technological strategies across scenarios?

4. Illustrative Results, cont'd

What can we learn testing a policy with the scenarios?

Examining NOx



Hypothetical emission target

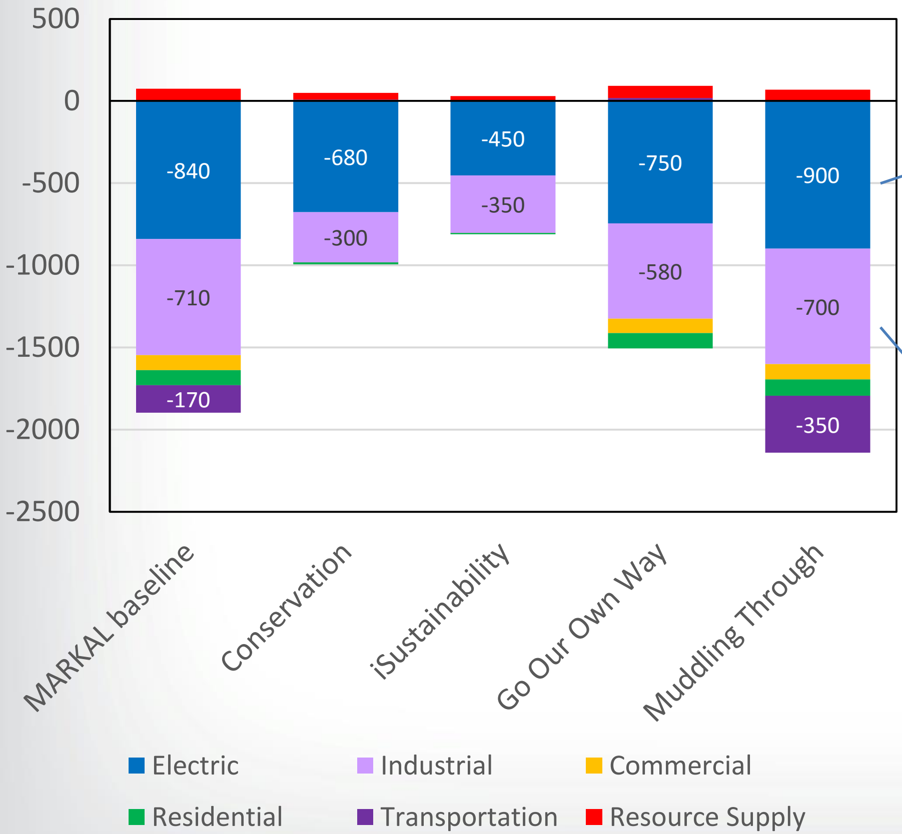
The quantity of reductions needed differs considerably from one scenario to another

4. Illustrative Results, cont'd

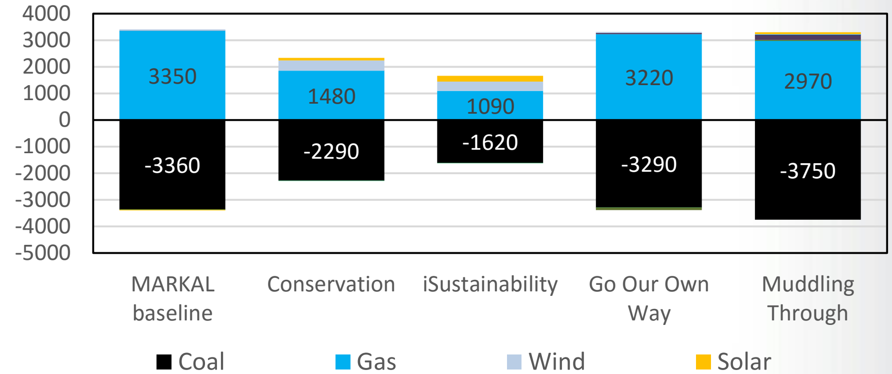
What can we learn testing a policy with the scenarios?

Scenario-specific pathways for reducing NOx, SO_2 and PM

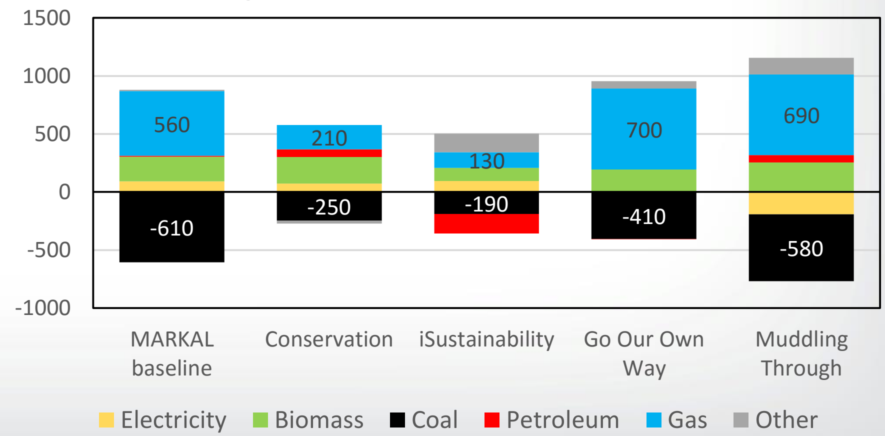
Change in sectoral NOx emissions (kTonnes) in 2035



Change in electricity production by fuel (PJ) 2035



Change in industrial fuel use (PJ), 2035

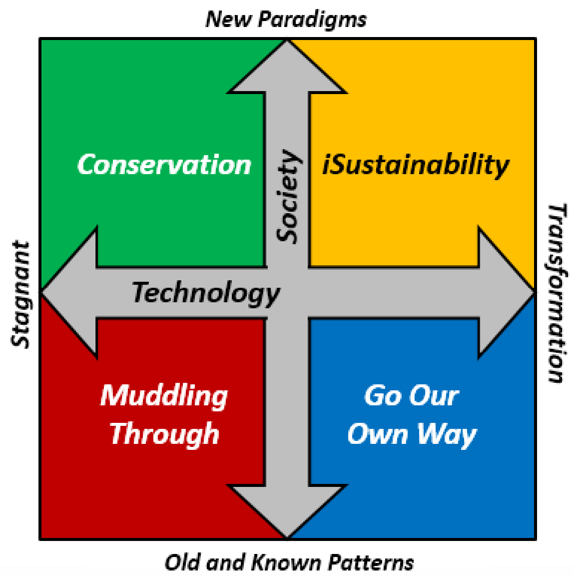


5. Conclusions

- Diverse scenarios have been successfully defined, implemented, and applied as alternative baselines in a hypothetical case study
- The revised implementation (which focuses on drivers and not detailed narratives)
  - Yields very different results from one scenario to another
  - Allows the scenarios to respond to stimuli in unique ways
- Observations include
  - Existing pollutant regulations perform relatively robustly for reducing NOx and SO_2 across the scenarios
  - There is more variability in CO_2 across the scenarios (without considering the Clean Power Plan)
  - For the hypothetical policy case
    - the quantity of reductions needed differed considerably from one scenario to another
    - fuel switching to natural gas in electricity production and industry played a central role for all of the scenarios, although complementary measures differed

6. Next steps

- Integrate land use and economic components into the scenarios
- Continue to explore potential applications
- Examine classes of policy options to explore robustness across the scenarios
- Iteratively refine the scenario representations



Questions?

Contact information:

Julia Gamas, U.S. EPA, OAQPS - gamas.julia@epa.gov

Dan Loughlin, U.S. EPA, ORD – loughlin.dan@epa.gov

For more information on the scenarios:

Gamas, J., Dodder, R., Loughlin, D.H. and C. Gage (2015). Role of future scenarios in understanding deep uncertainty in long-term air quality management. *Journal of the Air & Waste Management Association*. doi: 10.1080/10962247.2015.1084783 (pre-Version of Record)