Scenarios for the Future of Air Quality: Planning and Analysis in an Uncertain World

June, 2012

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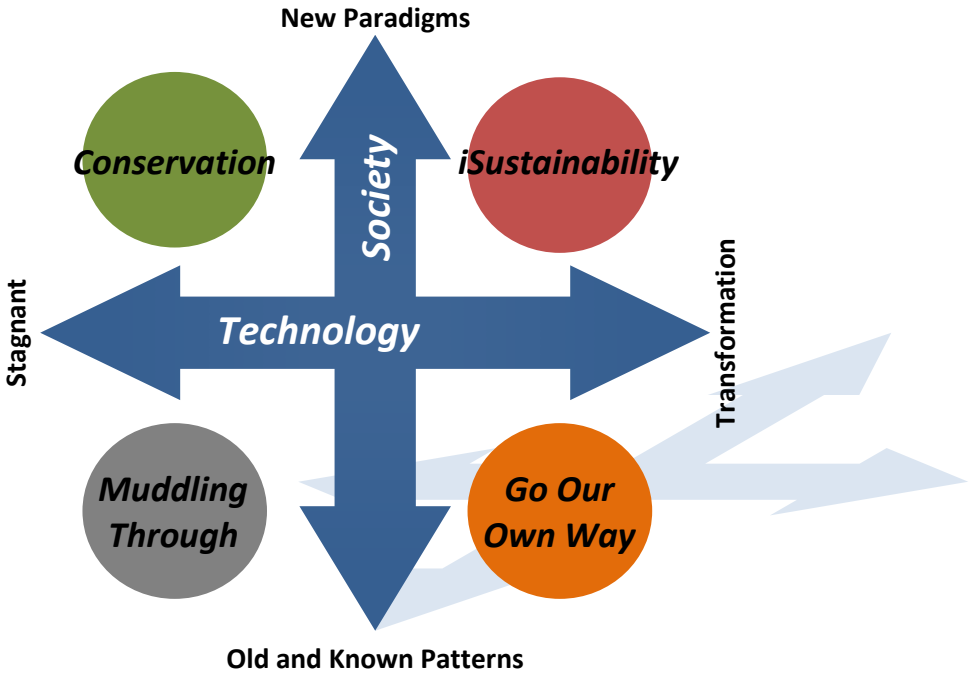
Background

On November 2010 OAR and ORD held the workshop: "The Future of Air Quality: Planning and Analysis in an Uncertain World." There were two main objectives of the workshop. A short-term objective was to develop a small but diverse set of ***critical*** alternative future scenarios which could be used for Regulatory Impact Analyses (RIAs) of air quality rules. The rules would be evaluated under these scenarios to consider the uncertainty of our results, within the context of a complex economic and environmental system.

A longer-term objective was to improve the Agency's ability to consider alternative future air quality concerns and develop cost-effective and robust policy responses.



The result of that workshop was a set of four scenario sketches. The sketches were further developed and feedback was received from the workshop participants. This feedback was used to then develop four narratives presented here.

The scenario exercise conducted during the workshop and further developed here is different from a sensitivity analysis where a few variables are projected to behave differently in the future. It is also different from establishing one "Business as Usual" (BAU) scenario with variations around that one baseline. The exercise is also not the construction of scenarios we think most likely to happen because the intent of this exercise is to explore the future around the most critical and uncertain variables to the future of air quality, given the complexity of the system under consideration. They are most critical because of their potential impact on other drivers and, thus, ultimately on future air quality, and this impact, depending on the scenario, could lead to large unexpected and unforeseen costs of air quality management. This allows us to ask the question "what if" and think outside the box in terms of the answers. Focusing on a single BAU and variations or focusing on the scenario we think most likely to

occur negates the value of the scenario exercise because it sets aside the discovery of potential ugly surprises, as well as potential opportunities.

Out of the myriad of possible futures, these narratives describe four distinct futures that cover the range of values that the most critical (important and uncertain) drivers could take. In this sense the scenarios can serve as a bound to our analyses and can further be used to test policies for their robustness. The actual future will likely hold a combination of elements of each of these scenarios. It is precisely because we do not know what combination will ultimately manifest that we are best served considering the bounding cases.

Summary of the Scenarios

Development of the Four Scenarios

The development of the four scenarios started from the focal question: What is the future of air quality? The most critical and uncertain drivers were found to be: ***societal attitudes*** with respect to factors such as the environment, consumption, mobility, and conservation and the direction and pace of the evolution of ***technological change***. Additional important drivers covered in the workshop and the resulting narratives were: energy (extraction, conversion, distribution and storage, efficiency, international energy trends); development patterns (type of human settlements, vehicle-miles travelled); the path and direction of the economy; policies (energy efficiency, energy security, direction of research and development); the strength of the climate change signal (temperature and precipitation, damages from storms and flooding); emissions reductions technologies; other technological developments; and finally, environmental indicators other than climate change (ecosystem health, persistence of pollutants, water resource quantity and quality).

During the workshop, a structured and well established method was followed in order to elicit those variables or drivers believed to be the most critical and uncertain with respect to air quality. The process was meant to capture the range of different viewpoints and perspectives from the different offices, centers and laboratories within the U.S. EPA as they relate to future air quality management. Once the list of key drivers was developed, a number of combinations of those variables/drivers were tested with the group, using the matrix format illustrated in the figure above. These variables were laid out on scenario axes leading to a matrix of scenarios. Different combinations of axes were developed and tested by the workshop participants, who evaluated the results matrices according to whether they generated four divergent, challenging, and plausible (not probable) futures. The scenarios presented here represent the result of the structured and iterative dialogue followed during the workshop, as well as the follow-up refinement of the scenarios and periodic discussions with the full set of workshop participants. Each quadrant in the figure above corresponds to one scenario representing where the scenarios fall with respect to the direction of technological innovation and societal change. The narratives that follow from this combination of critical drivers are described below.

Snapshot and Comparison of the Four Scenarios

The following table and radar charts show a snapshot of the four scenarios. The table below presents a summary of each scenario conveying its general storyline; how we get from the present moment to the conditions laid out by each of the four quadrants on our scenario axes. It also illustrates how the combination of societal attitudes and technological evolution leads to four distinct outcomes. For

example, Conservation and Muddling Through both have stagnant technological change. Yet, the movement toward new societal paradigms in Conservation results in a scenario that is substantially different from Muddling Through, where old and known societal patterns continue to hold. Along similar lines, iSustainability and Go Our Own Way both reflect a future of transformative technological change. However, the direction of technological development and the application of emerging technologies are also highly influenced by the different societal drivers in each of the two scenarios (see table).

Conservation (New paradigms, stagnant technology) *Society finds low-cost conservation alternatives to progress with what we have at hand already.* Strong climate signals early on together with shifts in relative energy prices compel society to re-evaluate its position on environmental protection. The economy recovers slowly, uncertainty about oil supplies from the Middle East translates into high oil prices and the climate changes bring damage to ecosystems and human infrastructure. Limited federal funds exist to make significant investments in research and development (R&D) of new energy and mitigation technologies. Using existing low-technology measures and imported technologies developed abroad society transforms markets over the course of two decades towards goods with a low impact life-cycle, with the consequent shift in energy sources from fossil fuels to renewable energy. Consumption patterns tend towards conservation, energy efficiency and sustainable production practices. By the end of the scenario timeline society has moved towards a new paradigm where coupling economic development goes hand in hand with environmental sustainability.	**iSustainability (New paradigms, transformative technology)** *Movement towards a new societal paradigm occurs from the bottom-up, armed with cutting-edge technologies.* Initially, new technology developments allow U.S. patterns of consumption and energy production and use to continue. However, strong climate signals combined with large-scale failures in the existing energy system move the public to reassess this pathway. Cheaper renewable energy and new energy efficiency technologies help power economic growth. Movement toward a new societal paradigm occurs from the bottom-up, mobilized by highly networked individuals, initiatives and technological innovation that drive society towards local and distributed solutions to our needs for food, housing, and transportation. Support for science and technology are strong. However, there is also an emerging consensus that technological change needs to be coupled with societal change and transformation to begin to mitigate climate change, develop sustainable adaptation approaches, and provide a higher quality of life while minimizing environmental impacts.
Muddling Through (Old paradigms, stagnant technology) *Society is divided about priorities; technological development mirrors societal gridlock* Confusing climate signals, oil price fluctuations and a sluggish economic recovery leave most of the population unimpressed with a plea from the scientific community to put resolving climate change ahead of all other priorities. Society is divided regarding the prioritization of environmental problems above other competing concerns. By the end of 2028 the use of natural gas has increased its share in the primary fuel mix substantially, while coal remains important. As domestic oil reserves dwindle imports have increased substantially to keep up with demand. Some biofuels come online without making a significant contribution. Renewables are a minor proportion of the fuel mix, concentrated in specific areas of the country. Electricity has prevailed in residential, commercial and industrial uses as well as in transportation, with a mostly centralized grid. Climate signals become stronger over time revealing system vulnerabilities.	**Go Our Own Way (Old paradigms, transformative technology)** *Concerns over energy security override all other priorities, giving the environment a back seat.* Instability and uncertainty continue to prevail in global oil markets and energy security via more domestic self-reliance and imports from Canada, Mexico, and other "friendly" Western hemisphere countries becomes priority. At the same time, the climate signal is so weak, that addressing climate change is not considered a priority. Yet, technological advances in biotechnology, materials, manufacturing, and information and communications technologies, are taking off, and leading to new investments in R&D and snowballing into new innovations. Many of the emerging technological developments are geared towards maximizing the domestic resource supply, increasing domestic employment, growing the economy and achieving energy security. While environmental considerations take a back seat, appreciable energy efficiency is achieved.

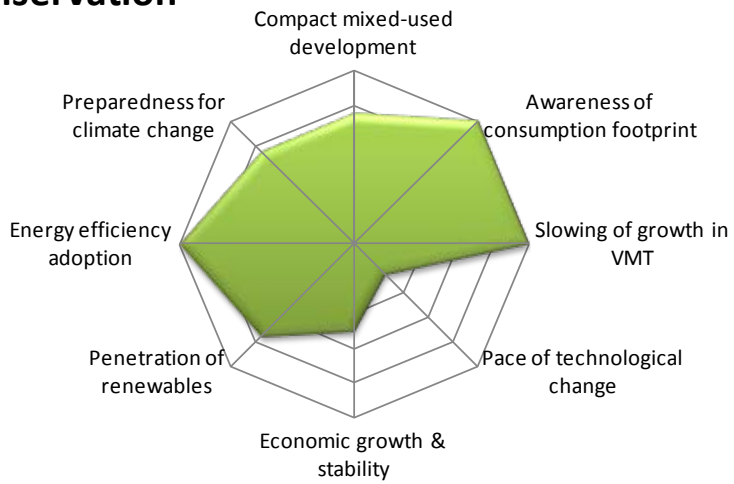
The radar plots below highlight some major similarities and differences among the scenarios. They are a visual aid to help summarize, illustrate and communicate the scenarios. They portray eight factors, each representing a subset of drivers. Additionally, help show if and how the scenarios are distinct enough from each other to provide meaningful and useful information. As is clear from the radar plots, the scenarios vary substantially for a number of trends that directly or indirectly affect the future of air quality. The scenarios have not been modeled quantitatively yet so that the factor represented in each spoke runs a qualitative spectrum (from high to low). A shorter spoke (closer to the center of the plot) means that the factor it represents in that scenario manifests to a lower degree; for example, Muddling Through has lower energy efficiency adoption as compared to the other three scenarios. Conversely, a longer spoke (closer to the edge of the plot) means that factor manifests to a higher degree; for example, the pace of technological change is higher in iSustainability and in Go Our Own Way than it is in Conservation and Muddling Through.

Both Conservation and iSustainability are scenarios where society's thinking has shifted and is highly sensitive to environmental concerns. Thus, in both scenarios it is aware of its consumption footprint and is moving towards adopting compact and mixed land use and reducing VMT growth. In Muddling through and Go Our Own Way, the opposite is the case. In all scenarios except Muddling Through energy efficiency is also a strong driver; in Conservation and iSustainability it is because society is highly sensitized to environmental concerns, but in Go Our Own Way it is because society is looking towards energy independence. Thus, penetration of renewable technologies is stronger in these three scenarios than in Muddling Through, where the public's environmental awareness is focused on a more traditional paradigm of growth. Because societies in Conservation and iSustainability have faced strong climate signals already and are more aware of their environmental impact, their awareness and level of preparedness for climate change is higher than in Muddling Through and Go Our Own Way. This does not mean that these societies are not incurring significant costs to deal with climate change, but rather, that they are more prepared to deal with the problem than in the other two scenarios. Both in Conservation and Muddling Through the pace of technological change is low given low economic growth and in Muddling Through this is also due to a lack of clear direction in which the economy should invest.

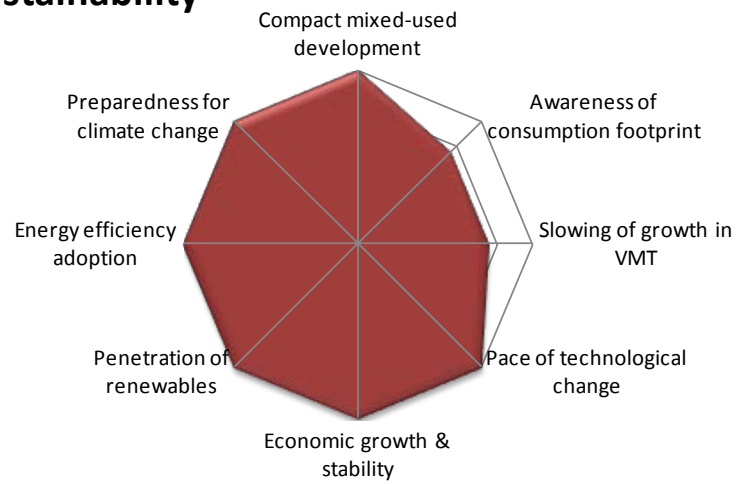
The magnitude of the lines and the overall area are intended to illustrate the potential improvement in air quality over the long-term. For example, energy efficiency, penetration of renewables, and compact urban development would all be anticipated to be positive from the perspective of reducing air emissions, although there could clearly be exceptions. However, these are small subset of the variables that were considered in the development of the full scenarios narratives, and the potential air quality impacts will only be determined after quantitative analysis – described below in our next steps.

Comparison of selected trends across the four scenarios

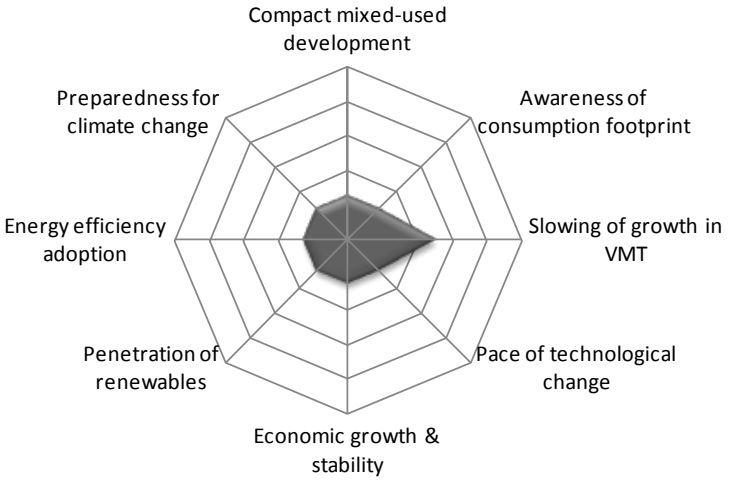
Conservation



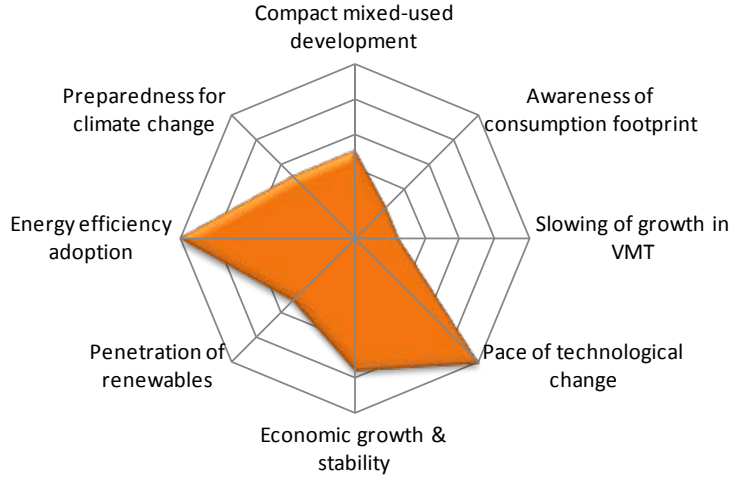
iSustainability



Muddling Through



Go Our Own Way



Conservation Scenario Summary

Early Years: 2013-2018

A paradigm shift is underway after strong climate signals shock people into awareness of the impact of their consumption on the environment and consequent action to reduce that impact significantly. Economic recovery is slow so investment in new technology is limited. However, the population begins to adopt current technologies to reduce energy use and emissions via energy conservation and energy efficiency. Movements by consumers to seek out U.S.-made products and local products (e.g., "locavore" trends for food) gain popularity. Revival of urban neighborhoods and an awareness of the impact of private transportation use lead to a reduction of vehicle miles traveled (VMT) and urban sprawl. Policies happen mostly at the state and local level with support from the Federal government when possible, as Federal resources begin to get tied up in repairs and reconstruction from damage due to strong climate signals. Communities begin to pool resources in order to purchase renewable energy technologies.

Middle Years: 2019-2023

International pressures on oil and gas prices continue to push the U.S. towards increased adoption of renewable energy. The population is deeply concerned about climate change's impacts on the U.S. as they have evidenced strong climate signals that are only getting worse. Problems with natural gas extraction using hydraulic fracturing steer people towards renewable energy. Fuel efficiency in industry, transportation and consumption continues to increase. Learning curves and energy savings begin to kick in. Consumers demand more sophisticated information about the life cycle of the products they purchase. American made becomes synonymous with "cleanly made" with awareness that it also supports domestic employment. The trend toward more dense human settlements continues.

End Years: 2024-2028

Renewables have become prominent in the U.S. fuel mix with fossil fuels occupying a small proportion. The U.S. lags behind the rest of the world in terms of new energy technologies but continues with energy efficiency improvements. Climate signals have forced coastal populations to move inland. Energy savings are beginning to add up allowing the population some additional disposable income.

iSustainability Scenario Summary

Early Years: 2013-2018

With the economy starting to rebound around 2013, consumption levels begin to pick up. Technology breakthroughs in nanomaterials and networking spur job creation, and improve manufacturing processes and products. Support for more stringent environmental protection – whether on climate change, air quality, water quality or conservation – is low. Existing consumption patterns for goods and services are maintained, while technology helps reduce their environmental impact. A rebounding economy and growth in energy consumption mean a push to keep up with demand. In the absence of major public or political concern about environmental impacts and climate change in these early years, there is some push toward unconventional oil and gas. Coal is seen as remaining in the mix as technological breakthroughs make carbon capture and storage (CCS) feasible for retrofits.

Middle Years: 2019-2023

General consumption patterns of energy, goods and services continue, with some efficiency and lifecycle environmental improvements enabled by technological innovations. By 2020, the climate signal is strong, leading to extreme flooding abroad and droughts in the U.S. Earlier advances in carbon capture technologies, and the rush to select and design injection sites, are followed in this period by poor performance of geological CO_2 sequestration. Water shortages lead to a number of power plant shutdowns, extended blackouts and a record number of heat-related deaths and emergency responses to provide "cooling shelters" from the heat in areas affected by the blackouts. The combination of CCS' failure as a viable technological option, public outcry regarding the heat waves and their response, and clear climate-related impacts in the US and abroad leads to a fundamental shift in societal attitudes and priorities.

End Years: 2024-2028

As we move toward 2030, the transformation that began in 2020 continues to play out. Earlier breakthroughs in nanotechnology and IT and investments in RD&D (research, development and deployment) laid the groundwork for a technological transformation that opens up a range of possibilities with respect to energy production and use, manufacturing, mobility and land use. Technological advances are coupled with new societal attitudes and paradigms, which guide the development and use of technology towards more sustainable applications, whether in the home, vehicle, or manufacturing plant.

Muddling Through Scenario Summary

Early Years: 2013-2018

Economic recovery is slow. Climate anomalies seem confusing to the public. Some believe they are climate change related, others think of them as natural random transitory phenomena. Some think climate change is man-made while others believe it is part of nature's design. Expectations for cheap and abundant natural gas begin to drive the primary fuel mix towards natural gas and away from oil and coal. The electric grid model is mostly centralized. Energy efficiency improvements take place slowly, mostly to cater to a segment of the population that demands it.

Middle Years: 2016-2023

The economy begins to recover, resuming its growth. Existing patterns of consumption and consequent emissions continue along the same path as before. The population continues to be divided regarding what energy strategy the U.S. should follow. The grid becomes increasingly vulnerable to extreme weather events. BRIC countries continue to put pressure on world primary energy supply pushing prices up. The U.S. continues to extract domestic natural gas. A lack of investment in biofuels and some other technologies means no significant breakthroughs are made regarding alternatives to fossil fuels.

End Years: 2024-2028

Climate worsens and resources are increasingly deviated from other productive uses towards repairing damages. Vulnerabilities in the supply of energy are revealed during extreme weather events. The U.S. is behind on renewable technologies and smart grid. With no previous investment in alternative technologies the dependence on fossil fuels continues with natural gas playing the largest role in the primary energy supply. Electricity is mostly coming from coal and natural gas with some renewable. The population remains divided on prioritization of environmental problems and on what to do about climate change, if anything. While there are more electric vehicles given the availability of natural gas to generate electricity, advanced internal combustion engine vehicles are still present, although less so than in the initial time period. Hybrids have also taken over a larger share of the market.

Go Our Own Way Scenario Summary

Early Years: 2013-2018

With the overwhelming focus of the political and public debate centering on the need for economic growth and energy security, a renewed focus is given to developing domestic resources and imports from Canada and Mexico. This is driven by instability in the Middle East and the growing global demand for oil. Environmental issues remain a lower priority, and are widely perceived as a barrier to full exploitation of domestic resources. At the same time, there are major technological advances that are bringing down the costs of exploiting unconventional resources, such as oils sands and shale gas, giving a major impetus to these sectors. Societal attitudes and priorities center on economic growth; consumption picks up substantially, and very little changes in what type of goods and services people consume.

Middle Years: 2019-2023

As technological advances continue to play out, economic growth is high and energy production from new sources continues to expand. Consumption levels are high, and manufacturing grows substantially. There is a pervasive sense of technological optimism that continues to convince the public that little change is necessary in broader societal attitudes or personal responsibility for environmental and ecological impacts. As energy security starts to seem like an achievable goal in the not too distant future, much of the public eye turns inward to the priorities and needs of the U.S., and in fact, quality of life is high. Therefore, as climate signals become clearer for the rest of the world, the lack of major impacts in the U.S. foster a sense of indifference, and lack of any real motivation to either reduce GHG emissions, or take steps to adapt or help others adapt.

End Years: 2024-2028

By this end period, the U.S. has achieved what it considers to be energy security, in the form of energy produced predominantly in North America. However, to a large extent, there is a sense that a large share of most productive resources is already undergoing development, with few “low hanging fruit” left. Therefore, there is a greater impetus given to the energy efficiency side. Economic and population growth, as well as a major increase in passenger and heavy duty vehicle miles traveled are beginning to pose major challenges in the form of emissions growth but are also affecting quality of life. Although societal patterns have changed little in terms of how and what people consume, a tipping point is being reached. At the same time, the climate signal is becoming clear, and this begins to redefine the extent to which the U.S. can indeed “go its own way” for the long run.

Discussion

The key drivers, represented by the axis on our scenario graphic – transformative versus stagnant technology change and new paradigms or old and known patterns for society – frame the four scenarios and define their core differences. These emerged as the most critical and uncertain per our group discussion during the workshop. The summaries of the four scenarios presented above provide an overview of the storylines and highlight their differences.

The reader will note that we have left air quality policy out. That is because these scenarios will be the context in which we will assess the effectiveness of policy options to manage air quality, thus testing the robustness of different policies. Each scenario gives us insights into the influence of different technological and societal pathways on air quality. Ultimately, one scenario may lead to lower pollution levels than another. While such a scenario might be more desirable from the standpoint of an air quality manager, this does not make that scenario any more likely to happen as compared to the other scenarios, given the level of complexity and uncertainty in the system. The main advantage of laying out the scenarios is that then air quality managers can understand the influence of their policy choices under different circumstances. This will allow them to consider potentially negative future problems as well as to take advantage of potential future opportunities.

Next Steps

Our goal is to develop a set of critical scenarios that would be plausible, and internally consistent. Addressing the most uncertain and important drivers of the future of air quality can help us bound our analyses and test the robustness of policy options in the short term. The longer-term and more ambitious objective is to advance this framework as a way to improve the Agency's ability to consider alternative future air quality concerns and develop cost-effective and robust policy responses. With the scenario narratives we can begin to take steps towards this goal by conducting a further qualitative and quantitative analysis. The next steps will be to model the scenarios and begin to discuss the qualitative and quantitative implications of the scenarios for future air quality. This is an ongoing learning process and feedback is welcome.

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