Appendix F
2050 Visioning:
Brookhaven National Laboratory Report

As part of its climate action planning, the state of New York is unique in undertaking a visioning process to assist the long-range goal of reducing greenhouse gas emission 80 percent below the levels emitted in 1990 by the year 2050. To develop a plan capable of setting in motion the radical, long-term changes required to achieve the 80 by 50 goal, the Council and its technical work groups and panel — indeed, decision makers at many levels — must be able to imagine the kind of low-carbon clean energy future toward which they are working.

An initial step in that visioning process was a conference held January 5, 2009, Envisioning a Low-Carbon Clean Energy Economy in New York. The conference, organized by the New York Academy of Sciences, Brookhaven National Laboratory, the New York State Energy Research and Development Authority, and the New York State Department of Environmental Conservation, involved members of the Climate Action Council, the Integration Advisory Panel, and the Technical Work Groups.

Led by subject matter experts, the participants in the workshop explored innovative strategies for meeting the State's energy needs, reducing energy demand, managing greenhouse gas (GHG) emissions, driving technological change, and creating economic opportunities for "green-tech" in New York. The workshop considered specific scenarios that outlined possible pathways to reducing GHG emissions. The purpose was not to validate a particular pathway, but rather to explore possibilities and their implications, as well as to identify obstacles to achieving the goal.

The January conference led to the creation of the report, *Envisioning a Low-Carbon Clean Energy Economy in New York,* produced by Brookhaven National Laboratory and appended here in its entirety and keeping its original pagination.

Envisioning a Low-Carbon 2050 for New York State

A white paper submitted to the
New York State Climate Action Council

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Important note to readers:

This is the first complete draft of a paper designed to inform the NYS Climate Action Council's work to develop a State Climate Action Plan.

The Council's mandate is uncommonly broad in scope. It has a planning horizon far longer than what most planners address. It entails large uncertainties. No clear precedent for an enterprise of this scope exists.

Consequently, this draft paper is necessarily provisional. As the planning process proceeds, the paper will be revised, and it will steadily gain in value as fresh insights are acquired and the knowledge base it draws from expands.

One feature of this paper is a description of three scenarios that illustrate different versions of a low-carbon 2050 future for the state. It's important that readers understand that these scenarios are offered for illustrative purposes only. In no sense do they constitute the elements of a plan, and indeed even a casual review of them reveals that there is no way in which they could be fashioned into a plan. Rather, they're intended to facilitate and provoke thinking about the future.

We hope other parties will generate their own 80x50 scenarios and share them. The ability to *imagine* a sustainable future, model it rigorously, and explore it is as vital to achieving that future as the clean-energy technologies, best management practices, and behavioral changes that must be developed, advanced, and adopted.

SUMMARY

The State of New York aims to reduce state greenhouse gas (GHG) emissions to 80% below 1990 levels by 2050. The fact that the state is already more energy efficient than most other states makes this goal particularly ambitious. A State Climate Action Council is charged with developing a draft Climate Action Plan by November, 2010. Toward this end, it has organized technical work groups and an integration advisory panel of stakeholders and experts.

To develop a plan capable of setting in motion the radical, long-term changes required to achieve the 80x50 goal, the Council and its team must be able to imagine the kind of low-carbon future toward which they are working. To facilitate this, the Council also formed a 2050 Visioning Advisory Panel. Comprising experts from many fields, that panel was convened at a workshop held on January 5, 2010.

This draft visioning paper draws from insights and knowledge shared at that workshop, and from other expert sources. It also draws from three GHG mitigation scenarios for 2050 that we developed for the workshop to illuminate how a low-carbon future might be achieved, and what it would mean. Making assumptions about future energy demand, patterns of energy use, the technologies that might be available to supply needed energy with reduced emissions, and what their levels of performance might be, we estimated emissions for each major sector of the state's economy. We found that reaching the 80x50 goal is challenging and that modeling required aggressive assumptions.

Together, the workshop, scenario development, and the crafting of this visioning paper constitute a "visioning process." Its focus has been manifold: an examination of technologies that might prove scalable and those that might be dead ends, of technical issues that require assessment, of policies that favor or constrain GHG reductions, and of management and societal changes needed to reduce emissions.

While the state's energy future cannot be predicted, some points are already clear, among them, these:

- Reducing emissions is imperative because atmospheric levels of GHGs are already perilously high, and emissions are cumulative – and there are real costs associated with inaction.

- The 80x50 goal is ambitious, and achieving it will require investments in new energy systems and infrastructure that have very low or no net carbon emissions. Patterns of energy use will also need to change.

- Energy efficiency is an essential, but not sufficient, strategy that can be aggressively pursued today.

- A broad shift from reliance on burning fossil fuels to electricity generated from low- or no-carbon sources, or widespread use of carbon capture and sequestration, will be needed.

- Transportation and buildings (residential and commercial) will have to move away from reliance on combustion of fossil fuels to alternate sources with significantly lower carbon or no carbon emissions.

- Development and redevelopment based on smart growth principles, as well as the building design practices, building technologies, and construction methods can significantly reduce the energy demand for buildings, as well as transportation.

- Incremental, short-term planning cannot achieve the goal. Near-term decisions – both those taken and not taken – can preclude longer-term options, such as infrastructure projects requiring long lead times. Key climate strategies *must* reflect this inexorable reality.

- The goal must be pursued in part through extensive, long-term partnering among all levels of government and across the region, and between the public and private sectors. It will take sustained effort on the part of all.

THE BROAD CONTEXT FOR THIS PAPER

In the face of climate change, the stakes are so high, the challenge so immense, and the opportunities so richly promising that business as usual and conventional wisdom are themselves risky. Innovation is imperative — not only in technology but in ways of thinking, working, and living.

In fact, what's demanded transcends "innovation": transforming an entire economy from largely carbon-based energy sources to largely carbon-neutral sources in a scant 40 years will be a true revolution, a radical shift that can renew New York's economy, enhance its natural environment, and improve its citizens' quality of life for generations to come.

For this revolution to succeed, institutions must be mobilized, businesses must adapt or fail, and individuals, families, and communities must make better-informed energy choices. And all of this change must be scaled up massively and rapidly.

The 80x50 challenge

Recognizing the benefits of action and the risks of inaction, in August 2009 the Governor signed Executive Order 24, which tasks the State to reduce GHG emissions from all sources within the state to a level 80% below the 1990 level by 2050. It establishes a Climate Action Council that is to develop a Climate Action Plan to achieve that goal, taking into account economic and other considerations. The plan is to be drafted by November, 2010. The Council will hold public comment hearings on the draft and after reviewing comments prepare a final plan.

That plan will be reviewed annually and revised as appropriate. The Executive Order says it "is not intended to be static, but rather a dynamic and continually evolving strategy to assess and achieve the goal of sustained reductions of greenhouse gas emissions."

To advance and inform its work, the Council has convened stakeholders from New York, as well as experts from New York and beyond, and organized them into technical work groups and an integration advisory panel. Working in support of the Council and these groups is the Center for Climate Strategies. The Council's comprehensive web site offers detailed information about its work, and it links to the *New York Greenhouse Gas Emissions Inventory and Forecast*. Readers unfamiliar with the Council are urged to consult the site for essential information that complements this paper.

How visioning contributes to the Council's work

To develop a plan capable of setting in motion the radical, long-term changes required to achieve the 80x50 goal, the Council and its technical work groups and panel must be able to imagine the kind of low-carbon clean energy future toward which they are working. To facilitate this, a 2050 Visioning Advisory Panel comprising experts drawn from many fields was convened at a January 5, 2010, workshop held at the New York Academy of Sciences. At the workshop, the experts made presentations and responded to concerns and questions from the floor. (The link above leads to a link to a webinar of the workshop, the slides speakers showed, and the agenda.)

This draft paper draws from insights and information shared at the January workshop. It also draws from many other expert sources, such as reports from the National Academies of Science. And it draws from three GHG mitigation scenarios for 2050 that we developed for the workshop, described below. Together, the workshop, the development of scenarios, and the crafting of this visioning paper constitute what may be termed a "visioning process."

The focus of the process has been manifold: an examination of technologies that might prove scalable and of those that might be dead ends, of technical issues that must be addressed, of policies that favor or constrain GHG reductions, and of management and societal changes needed to reduce emissions. Of course, policies that favor GHG reductions must be implementable. But for a time horizon so far distant, at this early stage, technical feasibility and cost considerations can be considered only in broad-brush terms. This paper treats them accordingly.

Our scenarios suggest that, in concept, the 80x50 goal is technically possible. The overall visioning process makes clear that incremental, short-term planning alone cannot meet the goal and that even a sophisticated long-term approach must surmount serious challenges. This in turn underscores how important it is that climate change vulnerability analyses and adaptation planning proceed on equal footing with mitigation efforts.

But the scenarios reveal a world of opportunities, too, that hold tremendous potential for the state's economy and its citizens' well being.

THE APPROACH TO ENVISIONING A LOW-CARBON 2050

The technical work groups that are contributing to development of the State's Climate Action Plan process are responsible for recommending specific strategies, policies, and actions for the Council's consideration. The visioning process, defined above, was designed to complement their work. Scenarios are a uniquely valuable tool for this purpose. Scenarios have been widely and routinely used, for many years, in many fields, as a tool for exploring options and contingencies. The three scenarios we developed for the State's January visioning workshop investigated the technical feasibility of the 80x50 goal and identified some technology options and best practices that could achieve the goal. The scenarios also helped us identify some significant technical barriers and policy issues that might facilitate or constrain those options.

To model and gain insight into possible futures, we "worked backward" from an imagined mid-century New York that has far lower GHG emissions. Making assumptions about future energy demand, patterns of energy use, what technologies might be available to supply energy and reduce emissions and what their levels of performance might be, we estimated emissions for each major sector of the economy, considering many interchangeable elements that might be dictated by policy implementation, technology breakthroughs, or market developments in the US and abroad.

The value of the scenarios is in providing a framework for thinking concretely about how energy efficiency, new energy technologies, fuel switching, best practices, and other matters might shape the path to a low-carbon future. Scenario modeling can also provide insight into performance levels for new energy technologies such as plug-in hybrid electric vehicles (PHEVs), or emission-reduction technologies such as carbon capture and storage (CCS).

All three of the 80x50 scenarios share important characteristics:

- An end state is postulated for each major energy-consuming sector of the economy: Transportation, Electricity Production and Distribution, Residential Buildings, Commercial Buildings, and Industrial. These end states are largely characterized by their technological characteristics, such as low carbon-emitting central generation of electricity, electric vehicles, and net-zero carbon emission buildings.

- Next, the ramifications of these technology options are examined. For example, if the state were to depend on hydrogen as a transportation fuel, how would the hydrogen be produced? Similarly, if the goal is low-carbon electricity central generation, what are the technology options for generating that power?

- Finally, the resulting scenario is referenced to a projection of what the energy use may be in absence of carbon abatement policies; that is, in the "business as usual case" (BAU). This comparison illuminates, for example, the magnitude of energy-efficiency gains that might be required, or the extent to which projected transportation needs that light duty vehicles would otherwise meet could be met by expanded mass transit instead.

THREE SCENARIOS FOR 2050

Models, assumptions, and limitations

The three scenarios were designed to answer these basic questions:

- What are possible, illustrative scenarios in which NYS GHG emissions would be ~80% lower than the 1990 level of ~251.4 million metric tons (MMt) of CO_2 equivalent (CO_2e)? (a goal of about 51 MMt)
- What are the implications of such scenarios?

To support the modeling exercise, a macro model of statewide GHG emissions was developed. Data are presented in Table 1, below. Emissions data for 2007 are the most recent available and are considered "current" for the purpose of this paper. NYSERDA projects that 2025 annual GHG emissions will be 266 MMT CO2e, a relatively small increase from current levels. The relative contributions of the various sectors remain unchanged, except that the "Other Source" category (non-fuel combustion) is projected to surpass residential emissions by 2025. ("BAU" is the "business as usual projection.")

Table 1. Sector GHG Emissions for Select Years (in Million Metric Tons CO_2e)

	1990 (actual)	2007 (actual)	2025 (forecast)	2050 (BAU Projection)
Transportation	72.9	88.4	93.4	114.3
Electric	64.5	49.2	42.9	75.5
Electric Imports	1.7	7.4	7.6	-
Residential	34.1	37.6	34.7	40.8
Commercial	26.8	27.3	30.1	35.4
Industrial	25.0	19.2	18.7	21.9
Other	26.5	28.7	38.5	39.0
TOTAL	251.4	257.7	266.0	326.6

Scenario modeling was a rigorous process that began by estimating the total energy demand that might have to be met in 2050 in each sector. This was done by extrapolating current forecasts and assuming modest growth in state GDP and hence energy demand.

These assumptions create the future "business as usual" (BAU) emissions scenario – the case that perpetuates the path we are on. BAU energy demand projection estimates the energy supply needed to support the state's economy in 2050 given our current patterns of transportation, energy use and efficiency.

The foundation of our scenario development is a state-level, coupled-sector macro model of energy supply flows and corresponding (calculated) emissions for each sector of the economy. In addition, possible reductions in non-energy related emissions (the "Other", non-energy related category) were estimated.

Table 2. Estimated Energy Demand by Sector

	2007 (actual)	2025 (forecast)	2050 (BAU Projection)
Transportation			
LDV/HDV VMT	136B Miles	170B Miles	224B Miles
Aviation	210 Mbtu	222 Mbtu	240 Mbtu
Electric	165,000 GWh	187,000 GWh	270,000 GWh
Residential	591Tbtu	629Tbtu	721Tbtu
Commercial	533Tbtu	557Tbtu	587Tbtu
Industrial	191 Tbtu	180 Tbtu	180Tbtu

In the table above "LDV" means ‘light duty vehicle; "HDV" means "heavy duty vehicle; "VMT" means "vehicle miles traveled."

We then took the energy demand forecast for each sector, presented in Table 2, above, and traced energy flows through each sector as primary energy (e.g., coal, biomass) and energy carriers (e.g., gasoline, #2 and #6 oil, coal, etc.) would be used for such purposes as creating electricity, heating homes, providing power for businesses and manufacturing sectors, and fueling light duty and heavy duty vehicles. For each of those uses, we calculated corresponding emissions. Fuel energy content and emissions factors for combustion come from US EPA data tables.

Significantly, unlike conventional "wedge" models, which treat sectors as freestanding, the coupled-sector model we employed reflects the fact that switching technologies in one sector may raise or lower demand in another. For example, two scenarios (the "Yellow" and "Ultraviolet") depend on widespread use of PHEVs in the transportation sector, resulting in a decrease in gasoline demand and an increase electricity demand; thus, primary energy demand switches to the electricity sector.

A note of caution: The scenario modeling provides insights into how technologies and patterns of energy use may have to change to meet emissions targets. But there are limitations to using the scenarios. This sort of modeling is not a practical planning tool, as it does not account for the crucial factor of scalability, or for economic, regulatory, and other barriers to the implementation of any given technology, including the availability of the raw material required. Nor does it take into account lifecycle analyses of nuclear power and renewable energy technologies. The models also do not consider the future interaction between a changing climate and energy use and impacts on the performance of different technologies.

The models do include estimates of the performance of new and emerging energy technologies for which the predicted development time scales are commensurate with the State's 40-year planning timeframe. Assumptions about the performance of new, emerging energy technologies are based on credible estimates from available literature, though there can be no guarantee that as-built systems will meet the estimated levels of performance, be economically viable, or penetrate the market at rates needed to meet assumed levels.

A note on methodology and references: For more information on methodology and data sources used in our modeling, please see Appendix A. For more detail on the scenarios, see Appendix B.

Basic strategies for reducing emissions

Developing scenarios that illustrate potential approaches to meeting the 80x50 emissions target of ~50 MMT CO2e requires recognition of the fact that those emissions result from activities that power our society and our economy, providing food, shelter, heating and cooling, communications, transportation, and innumerable other things essential to well-being. Cutting GHG emissions could have real-world consequences if low-carbon or no-carbon energy sources don't adequately replace fossil sources.

The scenarios rely on four key strategies to reduce GHG emissions:

- The simplest and the most cost-effective is energy conservation through energy efficiency.

- Reducing combustion from fossil fuels is another obvious strategy, as that combustion accounts for about 87% of all GHG emissions in New York State, with the largest fraction coming from the transportation sector (38%), followed by on-site combustion in the residential, commercial, and industrial sectors (37%), and then from electricity generation (22%). All scenarios assume that combustion of fossil fuels should only be used when and where necessary, or where controls such as CCS effectively limit emissions. Minimizing point sources of combustion such as vehicles and use of oil and natural gas for heating, and switching to electricity, coupled with simultaneously reducing the GHG footprint of the electricity supply, thus constitutes the second strategy.

- The third strategy is to drive fuel switching where combustion must still be used, as in aviation and cement production, to minimize the GHG footprint.

- Using local, point-of-use renewable energy technologies such as solar to reduce the reliance of homes and businesses on centrally generated electricity is the fourth strategy.

By varying these strategies and devising portfolios of energy technologies and practices that could implement them, we created three scenarios that we named "Yellow," "Deep Blue," and "Ultraviolet." The Yellow scenario falls far short of the 80x50 goal; the other two scenarios meet it, in different ways.

The Yellow scenario

The Yellow scenario does not meet the ~50 MMT CO2e GHG emissions challenge. It is intended to be a "first cut" at reducing GHG emissions through increased efficiency: the adoption of more efficient energy technologies that are largely available today, or will be soon. This scenario assumes a significantly different mix of light-duty vehicles (LDV) in use in 2050, with 30% being conventional internal combustion engines with an average of 37 mpg, 30% being hybrid electric vehicles (HEV) with an average of 50 mpg, and 40% being plug-in hybrid electric vehicles (PHEV) with 95% all-electric miles. This produces a modest increase in demand in the electricity sector of about 20,000 GWh. The use of intermodal freight shipping is assumed to reduce vehicle miles traveled (VMT) for HDV by about 30%.

In the electricity sector, it's assumed that New York State wind and hydro-electric generation will be built out to meet the maximum forecasts developed by NYSERDA, and that there will be a very significant increase (up to 100,000 GWh) of utility-scale solar electric generation or other renewable source such as off-shore wind. Where combustion is used for electricity, a switch to higher-efficiency natural gas combustion turbine (NGCT) and integrated gasification combined cycle (IGCC) power plants with CCS at 90% is assumed. It's also assumed that present levels of nuclear power generation can be maintained. Transmission and distribution losses are reduced by 50% to an average of 4% for the entire system. Residential, commercial, and industrial sectors reduce electricity demand via Energy Star+ efficiency gains.

This scenario includes elimination of 75% of all fossil fuel combustion in the residential and commercial sector, with natural gas and liquid fuels replaced by electricity, some generated on-site via solar (about 10% of the energy demand), and the balance generated at utility plants. Industrial emissions are reduced by curtailing fossil fuel combustion overall by 75% and using only natural gas and #2 oil; coal is eliminated in favor of natural gas.

Reductions in non-energy emissions (the "Other" category) assume elimination of sulfur hexafluoride (SF_6) dielectric from the transmission and distribution grid. Per molecule, SF6 has the highest GHG warming potential, about 23,900 times that of CO2. Reducing natural gas line leaks (by 50%), implementing a broad and aggressive *reduce, reuse, and recycle* policy, and eliminating leaks of alternative refrigerants (hydroflourocarbons [HFCs]) would reduce emissions from these sources significantly.

The Yellow scenario results in about 114 MMT CO2e emissions, a reduction of 55 percent below the 1990 level. It thus falls far short of the 80x50 goal – a sobering fact, given how much it differs from today's energy patterns.

The Deep Blue scenario

The Deep Blue scenario meets the ~50 MMT CO_2e GHG emissions challenge. It begins with the efficiency savings outlined in the Yellow Scenario and then explores alternatives if fossil fuel combustion in the residential and commercial sectors were to be eliminated, thereby driving an increase in electricity demand. Some of the increased electricity demand is assumed to be met with a larger fraction of point-of-use solar.

The Deep Blue scenario explores the impact of widespread adoption of hydrogen-powered light-duty vehicles for 100% of the LDV VMT with an equivalent of 65 mpg. The scenario assumes that hydrogen is produced through high-temperature steam electrolysis using gas-cooled high-temperature nuclear reactors. Because this approach employs a carbon-free electricity source, emissions are minimized. The calculations suggest the need for ~5 to 7 GW of nuclear capability for electrolysis. Gas-cooled reactors are well known conceptually, but significant technological and regulatory developments are needed. An alternative source of electricity could involve the use of IGCC or natural gas combined cycle (NGCC) with CCS. High-temperature steam electrolysis is an unproven technology at this time. The scenario does not address infrastructure issues associated with the transformation to a hydrogen-based transportation system.

The scenario assumes that 100% of all fossil fuel combustion in the residential and commercial sectors is eliminated and that the use of natural gas and liquid fuels is replaced by electricity, some generated onsite via solar (about 40% of the energy demand), the balance generated at utility plants. Industrial emissions are reduced by curtailing fossil fuel combustion overall by 75% and using only natural gas and #2 oil; coal is eliminated in favor of natural gas. Importantly, 8.4 MMT of the 13 MMT in emissions in the industrial sector are residual emissions from asphalt, petrochemical production, etc. It will be important to devise methods for curbing emissions from asphalt production to make further reductions.

Electricity demand is met from carbon-free sources, including 30% from nuclear (including 2 new plants that would increase nuclear power generation by 25,000 GWh, not counting the additional reactors required for hydrogen generation), 30% from renewables (maximum hydro, wind, and 100,000 GWh of solar), and 40% from NGCC plants with 90% CCS. It is important to note that the emission levels from NGCC limit generation from this source unless CCS is achievable at levels higher than 90%. This would make the future use of natural gas or coal for the electricity sector dependent upon the viability of CCS for locations and geologies within the state, and upon the amount of CO2 that can ultimately be stored.

In addition, the Deep Blue scenario assumes that emissions in aviation and the residential, commercial, and industrial sectors could be significantly reduced through the use of in-state, bio-derived oils for transportation (diesel), aviation (jet fuel), and heating. Given the potential for reduced emissions in the aviation, residential, and commercial sectors – as well as for HDV transportation – these replacement fuels warrant serious consideration, as do studies of the feasibility of supplying bio-derived oils for fuel from within the state. At present, net carbon emissions from these sources are assumed to be zero or close to zero, as carbon emitted by combustion of the biofuel is offset by carbon sequestered by plants grown to supply fuel. (See EPA's 2009 U.S. Greenhouse Gas Emissions Inventory Report.) Further study regarding the total carbon cycle associated with the use of these fuels is warranted to validate the emissions assumptions.

The Deep Blue scenario estimates emissions at 53 MMT. It thus achieves a 79 percent reduction in GHG emissions below the 1990 level.

The Ultraviolet scenario

Another possible future was devised that would also meet an 80 percent reduction by 2050. Like Deep Blue, the Ultraviolet scenario is much more aggressive than the Yellow scenario. It too begins with the efficiency savings outlined in the Yellow scenario and explores alternatives if fossil fuel combustion in the residential and commercial sectors were eliminated, thereby driving an increase in electricity demand. A part of this electricity demand is met through local, point-of-use solar.

The Ultraviolet scenario explores the impact of shifting to widespread use of PHEVs where 95% of VMT are all-electric miles, with 5% of VMT coming from bio-ethanol at 50 mpg. This is an aggressive goal, well beyond current predictions for most studies of PHEV market penetration and performance improvements through 2030. Significant increases in electricity demand are postulated via elimination of fossil fuel combustion in the transportation sector for LDV.

The scenario assumes that 100% of all fossil fuel combustion in the residential and commercial sector is eliminated and that the use of natural gas and liquid fuels is replaced by electricity, some generated onsite via solar (about 40% of the energy demand), the balance being generated at utility plants. Industrial emissions are reduced by curtailing fossil fuel combustion overall by 75% and only using natural gas and #2 oil; coal is eliminated in favor of natural gas. As in the Deep Blue scenario, 8.4 MMT of the 13 MMT in emissions in the industrial sector are residual emissions from asphalt, petrochemical production, etc.

The significant increase in electricity demand is met largely with carbon-free sources: 35% from nuclear (including ~10-12 new plants), 35% from renewables (maximum hydroelectric, maximum on-shore wind, and 100,000 GWh of solar or other utility scale renewable such as offshore wind), and 17% from NGCC plants with 90% CCS. This scenario employs as much NGCC with CCS as is practical to meet overall emissions targets, thereby requiring a larger fraction (and level) of carbon-free sources. They are assumed to be met with new nuclear plants.

As with the Deep Blue scenario, this scenario relies on the use of low carbon-intensity bio-derived fuels (in-state ethanol) to supply the liquid fuel needed for non-electric miles in the LDV category, and on the use of biofuels in the aviation sector.

The Ultraviolet scenario estimates emission at 55MMT, a 78 percent reduction in GHG emissions below the 1990 level.

SERIOUS CHALLENGES POSED BY THE LOW-CARBON GOAL

The scenarios, presentations, and discussion at the January 5 workshop illuminated issues and challenges facing the Council. In particular three sectors – transportation, electricity generation, and buildings – emerged as particularly challenging and significant. At present, the transportation sector produces 34.3% of the state's GHG inventory; electricity generation, 19.1%; residential uses, 14.6%; commercial uses, 10.6%. The "business as usual" (BAU) case for 2050 projects that the transportation sector will produce 35%; electricity generation, 23.1%; residential, 12.5%; commercial, 10.8%; and industrial, 6.7%.

The text below discusses the challenges those sectors present.

Serious Challenge: Transportation

Mobility is essential to social and economic welfare. By all measures, New York is one of the most mobile states in the nation. It has over 11 million licensed drivers, 10.5 million motor vehicles – virtually all of them operating on fossil fuel, and joined by similar vehicles that travel to New York from other states – and 113,000 miles of roads, along with 4,800 miles of railroads, 18 commercial airports, and 495 public use and private airports. Ensuring a safe, secure, reliable, efficient, low-carbon transportation system is vital to the state's future. (See Strategies for a New Age: New York State's Master Transportation Plan for 2030.)

Today's transportation systems are defined by technological, socioeconomic, land use, and public policy factors. Transportation demand is growing, and patterns of travel are changing and increasingly reliant on multiple, interdependent modes of transportation. Congestion in urban areas is growing, and transportation systems in these areas are bounded by the built environment. Over the next 40 years, the transportation system will have to support the same or greater levels of mobility while lowering emissions dramatically. And the importance of transportation security to national and economic security is expected to increase.

Over the past three decades, tremendous growth in the transportation sector and the decline in US oil production have made the US and New York increasingly dependent on foreign supplies of petroleum. Today, about 60% of the oil consumed in the US is imported. In New York, transportation accounts for about half of petroleum consumption, the equivalent of about 300 million barrels per year, or about 4% of the US total. As the potential for disruptions in world oil supply and production of refined petroleum products increases, so does the risk of disruption to the state's transportation system. Given projected growth in demand for oil in emerging markets, notably China and India, the cost of oil and the reliability of supply are important risk factors to consider.

Within the transportation sector, road transport is the largest consumer of energy and the largest source of emissions. The major contributors to emissions are light duty vehicles (LDV), a category that includes automobiles, SUVs, motorcycles, and light trucks, and heavy duty vehicles (HDV), which includes trucks for road freight as well as buses. After road transportation, aviation is the next biggest contributor. Another important factor is the impact of the design and construction of the local built environment on mobility and patterns of use of available modes of transportation.

Addressing transportation requires a holistic look at all the factors that can improve efficiency as well as reduce emissions. In general, approaches to transportation examine (1) society's future mobility needs, (2) the technical efficiency of a given mode of transportation and the potential for improvements, (3) the effects of the operating environment, and (4) the mix of transportation modalities and potential systems performance improvements via changes in the mix of modalities.

Transportation and the built environment

The New York metropolitan area enjoys an extensive public transportation system that is well integrated into the region. Some 4.8 million passengers use public transportation on a daily basis. The high density of housing, proximity to public transportation, and its relative ease of use contribute to this high level. Aspects of the region have attributes of "compact, mixed-use development" – also known as "smart growth."

In all of the mitigation scenarios, a significant reduction in projected VMT level for 2050 (240 billion miles) is assumed. The assumption is that smart growth can promote greater reliance on public transportation and/or increase walking and bicycle travel. At the January 5 visioning workshop, success stories about smart growth in urban and suburban areas were recounted – notably for Arlington, Virginia, and Portland, Oregon. They offer models for New York's suburbs and for cities other than New York City; for example, the corridors in Long Island along the Long Island Railroad and major traffic arteries.

Over the 40-year horizon of the Climate Action Plan, many urban and suburban centers will very likely be rebuilt or redeveloped. This will create opportunities to reshape the state's transportation system and its use – if transportation planning and redevelopment efforts are approached holistically and use smart-growth practices. As redevelopment in urban and suburban areas occurs, more compact, mixed-use development that includes higher population and employment densities, competitive alternatives to automobile use such as pedestrian and bicycle paths, street networks that provide connectivity between destinations, and easy access to public transportation can all reduce residential and commercial energy use, GHG emissions, and VMT.

A recent and comprehensive study by the Transportation Research Board of the National Academies explores the impact of and correlation between driving behavior and the built environment. It concludes that compact, mixed-use development can reduce VMT by differing means and amounts depending on where the development in a region occurs. The study reports that the literature suggests "that doubling residential density across a metropolitan area might reduce VMT by about 5-12%, and perhaps as much as 25% if coupled with higher employment concentrations, significant public transit improvements, mixed uses, and other supportive demand management measures." It also notes that more study is needed to better understand the causal links between specific design elements in land use, transportation pathways, high density housing, employment centers, and other factors and reductions in VMT and increased use of public transportation.

To significantly reduce VMT would require changes in current practices and patterns of development in suburban areas. In home-rule states like New York, land use is largely a function of local governments, which can be reluctant to zone for higher-density housing because local residents often resist it. Statewide change would require that state-level policies be enhanced with incentives that encourage and support compact, mixed-use developments that would result in greater energy efficiency, increased use of public transportation, and reduced VMT and GHG emissions.

These efforts would be facilitated by communitywide design standards (the equivalent of LEED certification); the development of partnerships among State and local governments and private developers; tax incentives; coordinated State, federal, and local infrastructure investments; coordination with regional transportation authorities and operators; and rezoning to support appropriate transit development.

Light duty vehicles

In 2007 New York State residents drove over 140-billion VMT and consumed some 7.6 billion gallons of gasoline [EIA, Energy Consumption 2007], largely through the use of personal vehicles. As our mitigation scenarios reveal, significant emission reductions are possible in the transportation sector. The scenarios explore three alternative future vehicle fleets: one a mix of conventional, hybrid, and plug-in hybrid electric vehicles (PHEVs) (Yellow scenario); one dominated by hydrogen vehicles (Deep Blue); and one dominated by PHEVs (Ultraviolet). The latter two scenarios show that fuel switching will drive increased demand for electricity production, either for vehicle re-charging or electrolysis of steam for hydrogen production. Of course, emissions reductions would only be realized by the use of nearly carbon-free electricity sources such as renewables, nuclear, or natural gas or coal-fired plants with CCS.

What will it take for the US to realize 100% PHEV or 100% all-hydrogen powered cars on the road in 2050? Significant changes to automobile technology, of course. However, replacing New York's entire fleet of automobiles will take time. The lifetime of a car is long; the mean lifetime is about 15 years: half the cars sold today will still be on the road in 15 years, and it will take about 25 years for 95% of the autos sold today to be retired. (See the ORNL Transportation Energy Data Book [2009 ORNL-6984]). Thus, to achieve a fleet composed of 100% PHEV cars in 2050, 100% of the cars sold in 2025 and every year thereafter would have to be PHEVs. The same case applies to hydrogen-fueled cars.

Another reason why changing the entire fleet will take time is that it takes time for transportation equipment and automobile manufacturers to adopt new technology and integrate it into their product lines and manufacturing processes. At present, automobile models undergo a complete redesign approximately once every 8 years, and new designs are locked in about 2 years in advance. Thus, it could take from 5-10 years for a new automobile design to be brought to market, and another 25 years to completely change over the fleet.

For PHEVs, this penetration rate is more aggressive than what experts are predicting. For example, a recent study by the National Academy of Sciences (NAS), Transitions to Alternative Transportation Technologies – Plug-in Hybrid Electric Vehicles, concluded that PHEVs are "unlikely to achieve cost effectiveness before 2040 at gasoline prices below $4.00 per gallon," given the higher costs when compared to conventional vehicles. Further, the NAS PHEV study concluded that "at a maximum practical rate, as many as 40 million PHEVs could be on the road by 2030, but various factors (e.g., high cost of batteries, modest gasoline savings, limited availability of places to plug in, competition from other vehicles, etc.) are likely to keep the number low."

PHEVs are scheduled to enter the US market in the 2011-2013 timeframe. They will have an all-electric range of ~30-60 miles. For mass-market penetration, a greater all-electric range of around 100 miles or more would be needed – underscoring the need to develop higher performance battery technologies. Costs must come down, too. Drivers include electronic controls, drive trains, and batteries. Lithium-ion battery technology has been developing rapidly, though costs are still high and, according to the NAS study, expected to decline only by about 35% by 2020. Further technology development will likely reduce costs below these levels, as well as increase storage density and reliability, possibly by using alternative chemistries to lithium ion batteries.

Other notable barriers include the need for suitable charging stations or battery exchange facilities and consumer acceptance of PHEVs, especially if PHEVs cost more than similar functioning hybrid electric vehicles and require daily (or more frequent) recharging. Adoption of PHEVs by large vehicle fleets, such as federal, state, and local government fleets, may be an appropriate first step to increase adoption, if costs are reasonable.

The Deep Blue scenario explores the potential impact of fuel switching from gasoline to hydrogen for vehicles. Hydrogen vehicle technologies largely follow two paths: direct burning of hydrogen in a suitably modified internal combustion (IC) engine or use of electrochemical fuel cells (proton-membrane exchange fuel cell [PMEFC]) which, in turn, drives an electric motor. Hybrids of electric and combustion processes are also conceivable – PMEFC with batteries, for example. It is important to note that hydrogen-based ICs and PMEFCs have applications in local point-of-use generation of electricity. It's conceivable that ICs and PMEFCs could be used for hot water, lighting, and heating in residential and commercial applications, as well. Studies of the energy efficiency of hydrogen (such as the National Academies of Science's *The Hydrogen Economy*) find that the hydrogen vehicles would not substantially reduce total energy use per mile driven (the "wheels to wheels" energy per mile driven) unless the hydrogen were produced from wind or solar power.

The Deep Blue scenario relies on nuclear power with high temperature electrolysis of water to produce hydrogen, with electricity and heat generated from a nuclear reactor. Alternate approaches include steam reforming of methane using process heat provided by a very-high temperature nuclear reactor, or through a thermochemical cycles, such as the sulfur iodine process. Steam reforming of methane is widely used in industry to make hydrogen today, and this process is well established. Carbon release from steam reforming of methane would compromise emissions gains through the use of nuclear power and is a potential showstopper, though carbon capture is not inconceivable.

Beyond nuclear-based approaches that rely on steam reforming, several technologies are envisioned for large-scale or central generation of hydrogen. Coal and natural gas integrated gasification combined cycle (IGCC) or natural gas combined cycle (NGCC) plants could also serve as a heat source for steam reforming of methane – and for much smaller hydrogen generation scales, solar PV or wind could be used for electrolysis. Of these sources, only nuclear and renewable-based hydrogen production have a zero-carbon footprint, and with the advent of carbon capture and storage (CCS) technologies, central-station hydrogen production from coal or natural gas plants would have a carbon footprint five to ten times smaller than that of gasoline. The price of hydrogen is highly dependent on the way hydrogen would be produced and associated emissions from the generating source. Thus, today, nuclear-based, as well as NGCC or IGCC with CCS, appear to be cost-competitive with gasoline, while the higher cost of electricity generated by renewable sources is two to five times more expensive.

At best, hydrogen represents a long-term option. Significant technological and infrastructure breakthroughs are needed before it's considered viable. Significant improvement in the energy density of hydrogen storage, reductions in fuel cell costs, increased lifetime and reliability, as well as cost reductions in hydrogen production are needed. Safety is also an important factor. Initially, transportation and distribution of hydrogen would entail transport by truck to regional distribution centers, using compressed gas cylinders. Over time, the use of hydrogen to fuel vehicles would require construction of infrastructure such as pipelines and fueling stations.

To overcome some of the barriers to adoption of hydrogen fuel for PHEVs, New York State would have to work with other states and the federal government to develop requirements that drive the market toward new vehicle technologies. In the meantime, fuel efficiencies and carbon reductions will be realized through improvements to conventional vehicle technologies and greater market penetration of hybrid electric vehicles.

Heavy duty vehicles

Trucks carry the bulk of freight transport. In New York State, 90 percent of commodities by weight are moved by truck, while only 3 percent are moved by rail - a more efficient and less GHG-intensive mode. Freight traffic is expected to grow significantly, with a concomitant growth in VMT. More-efficient, less GHG-intensive modes of transport are clearly needed. In general, there are two ways to reduce HDV emissions: directly reducing truck emissions, and shifting freight from trucks to more efficient and less GHG-intensive modes.

The factors that affect truck emissions and efficiency include (1) the nature of the fleet mix (the size of the trucks), (2) the fuel-efficiency of the trucks, (3) the operating environment (built environment, road conditions, traffic and congestion, etc.), (4) how trucks are operated (speed and idling), (5) the nature of the cargo and truck loading (weight, density, containerized vs. open-bed freight, etc.).

The mix of trucks and their patterns of use are extremely heterogeneous. Efforts to reduce emissions should focus on the largest fuel consumers: tractor-trailers and straight trucks. Tractor-trailer efficiency improvements should start with retrofits to reduce truck frame drag. Estimates indicate that truck retrofit packages (such as aero-cab, front flaring, side skirts, rear tail flaring, low rolling-resistance tires) can improve truck efficiency on the order of 5-10%. Retrofit packages can be readily adopted for existing fleeting. (The Union of Concerned Scientists offers information on green trucks. Scroll down that web page for a link to a study by the technology firm TIAX, Heavy-Duty Truck Retrofit Technology: Assessment and Regulatory Approach.)

In addition, future truck fleets will rely on advanced truck engine designs, such as hybrid-electric engines, with an estimated efficiency increase of 7-9%. Adoption of new engine technologies will take time, as the market is conservative and fleet turnover is much slower than for LDVs: the median lifetime of a HDV is well over 20 years. This implies that the penetration of a new technology will take significantly longer in the HDV market than in the LDV market. Consideration should be given to policies that may speed adoption of new technologies.

Biodiesel is the first advanced biofuel in large-scale commercial production. Biodiesel produced from domestic soybean oil is assumed by the EPA to reduce GHG emissions by 57% compared to petroleum diesel fuel, and the EPA's lifecycle analysis recognizes that the GHG reduction could be as high as 85%. (See http://www.epa.gov/otaq/renewablefuels/420f10006.pdf.) In the US, biodiesel production is now expanding rapidly (see http://www.biodiesel.org/pdf_files/fuelfactsheets/Production_Graph_Slide.pdf). In 2005, production was 75 million gallons; in 2007, 450 million gallons; in 2008, approximately 700 million gallons. By 2011, 1 billion gallons of biodiesel will be produced. An assessment of the resource available to produce biodiesel indicates that feedstock available today could produce more than 1.7 billion gallons per year.

Intermodal

Convenience and cost are the key factors that determine the mode of transportation for the shipment and distribution of goods. In New York State, the predominant method for transport of freight is by truck, with up to 90% by weight shipped by truck. Truck transportation is the most energy and GHG intensive modes of the movement of freight. A key challenge to reducing GHG emissions in the transportation sector is then to reduce emissions from truck transport of freight. This can be most readily accomplished by reducing GHG emissions from trucks and/or shifting freight to other modes of transport with lower emissions. New York State will have to investigate policy options to bring about modal shifts. These would include:

- Financial assistance to develop more efficient organization of supply-chains, including advanced logistics capabilities and optimal positioning of trans-shipment points and distribution centers.

- Increasing fuel and economy standards for trucks, speed limit reduction/enforcement, and development of anti-idling policies and electrification of rest-stops.

- The development and adoption of advanced technologies, particularly the development of no or low net-carbon bio-diesel fuels and waste heat recovery systems to power air conditioning/electronics.

- Reducing congestion by increasing non-truck modes of transportation; provide incentives and build infrastructure to encourage switching from truck to rail or water transport.

Aviation

Emissions reductions in the aviation sector can come from advances in three areas: improved efficiency through advances in technology, development, and adoption of suitable bio-derived fuels, and improvements to operations and air traffic management.

Significant emissions reductions in the aviation system will come from new composite materials that result in airframe weight reductions, as well as improvements to engine design. For example, as much as 50% of the primary structure of the new Boeing Dreamliner is made from advanced composite materials. Coupled with advanced engine designs, this will increase fuel efficiency as much as 20% over similar sized aircraft, while permitting air speeds characteristic of the fastest wide-bodies, mach 0.85.

The National Academies' Airports Cooperative Research Program is examining alternatives to fossil fuels, as is a coalition that includes the Federal Aviation Administration. Industry interest in the subject is growing. Currently, new biofuels – "biojet" are being developed for the military. This represents a significant opportunity for reduction of net carbon emissions from the aviation sector if a sufficient supply of biofuels can be developed for wide-scale adoption and use.

Changes to air traffic management are expected to lead to ~10% reductions in fuel use, through better management of holding patterns, more efficient take-off and landing trajectories, and minimization of suboptimal routes. Switching modes of travel can reduce emissions, too. Many short-distance flights could be replaced by inter-city high-speed rail; for example, between New York City and Albany, as well as Buffalo.

Serious Challenge: Electricity Supply

Electricity generation is currently among the largest sources of GHG emissions and is projected to remain so under the BAU case. New York's current electricity generation system is a diverse mix of primary energy sources, with about 53% of net generated electricity coming from fossil fuel-fired electric generating units. With a diverse resource mix and a solid base in renewable energy, the state's electric sector is expected to contribute approximately 75.5 million tons of CO2e to the GHG emissions inventory in 2050

The electricity sector presents a serious challenge for a set of reasons:

- *All mitigation scenarios place increased demand on the electricity sector.*

  All three 80x50 scenarios assume total electricity demand in excess of 400,000 GWh, a 50% increase over the BAU case. This is typical of mitigation strategies – for example, see the results of the Global Technology Strategy Project. The reasons are several. The most important is that it is much easier and more cost effective to manage any residual carbon emissions at a central electric generation facility than in highly distributed sources like vehicles or buildings. In the 80x50 scenarios, energy demand is driven to electricity by the almost complete conversion of the building sector to electricity, the substitution of electricity for liquid fossil fuels as an energy carrier in the transportation sector (most notably in the Yellow and Ultraviolet scenarios), and a general shift from fossil fuels to electricity in the industrial sector.

  The flexibility of electricity as an energy carrier has led to continued growth in its use. The electricity sector has been well studied, and many technological improvements are made every year. These improvements are quite important: efficiency improvements in the conversion of energy stored in fossil fuels to electricity has a direct impact on the capital cost of all electricity generation resources. Even more important, improvements in the efficiency of end-uses of electrical energy reduce total demand for electricity. The scenarios for each of the major end-uses begin with an assumption of large improvements in end-use efficiency, ranging from 20-30%. Generally, it's expected that the electric generation sector could be decarbonized more easily than distributed uses of energy could be.

- *Renewable resources within the state are not adequate to meet the challenge.*

The major renewable sources of electric power that are carbon free are wind, solar, and hydropower. With the exception of large hydroelectric facilities, these resources are distributed: they collect a local resource. Moreover, in comparison with, for example, a large thermal electric facility like coal or nuclear, they generate far less energy per unit of land. The Yellow scenario includes practically all of the available renewable energy resources in the state, and it includes only resources from within the state. The renewables are over and above the renewable sources assumed to be integrated with buildings.

Wind is a relatively mature technology, and it's relatively easy to estimate how much wind energy is available. The current analysis includes both on-shore and off-shore wind resources. On-shore wind deployment is increasing around the world, but every deployment faces challenges. The first is the actual siting of the turbines, which is often resisted locally for aesthetic and environmental reasons. Second, wind is an intermittent resource and places special demands on the grid, as discussed below. The scenarios are fairly optimistic about success in siting turbines, and they assume wind power's straightforward integration into the grid (as estimated in a 2003 study). They also assume that the current 873 GWh of wind can be expanded to 42,000 GWh by 2050, meeting just over 10% of total projected demand.

Solar is a far less mature technology in terms of both efficiency of conversion and experience with actual installation. The Yellow scenario assumes that 100,000 GWh of demand will be met by grid-installed solar (~25% of 2050 demand); currently in New York the value is zero. This makes the Yellow scenario quite aggressive in several regards. First, this amount of solar energy requires a large amount of land, probably far more than is commonly assumed. For the current generation of solar PV sited in New York, it would take about 1% of the area of New York to generate 100,000 GWh of electricity. Second, it requires a massive improvement in the ability to manufacture photovoltaic (PV) devices. Most current solar technology is based on silicon, and despite large increases in PV cell production, global consumption of silicon for solar applications only recently passed consumption of silicon for semiconductor devices such as computers. Without low-cost, mass production of solar cells on the scale of products like paper or steel, large-scale deployment of solar energy is unlikely. Finally, solar, like wind, is an intermittent resource with special requirement for integration with the grid.

New York has significant hydropower resources, thanks to Niagara/Horseshoe Falls and the St. Lawrence Seaway. Further upgrades and expansions, with a small component of new dams, could significantly increase electric output to the grid and reduce GHG emissions. The Yellow scenario assumes that 10,300 GWh of hydropower will be added to the 25,500 GWh, satisfying nearly 10% of projected 2050 electricity demand.

In summary, the relatively aggressive goals included in the Yellow scenario, which are incorporated in the other two scenarios, meet less than 50% of projected 2050 demand, and indeed in the future they may not be met. But other sources of renewable energy might improve the prospects of success. The largest is probably offshore wind. In addition, full-scale testing of kinetic, in-river hydropower applications is under way in the East River and St. Lawrence River. These projects and maximum build-out were not considered in our analysis, but they could add slightly to the total hydropower package of emission reduction technologies and strategies.

- *Low carbon-emitting central generation options all entail serious issues.*

The discussion of renewable electrical energy options above underscores the fact that demand for central generation of electricity will continue. This demand must be met with low-carbon or no-carbon conversion technologies. Currently in New York, large central generation relies on fossil fuel and 42,500 GWh of nuclear power. Options considered in detail in the scenarios are expanded use of nuclear generation and use of fossil fuels with carbon capture and storage (CCS).

The future of nuclear power generation is uncertain, but nuclear power could satisfy a good portion of a future electricity demand or hydrogen production demand (as discussed above). All of the scenarios assume a continuation of the existing level of nuclear power generation; each takes a different approach to nuclear. The Yellow scenario meets the low-carbon generation option without expanding the current nuclear fleet. The Deep Blue scenario assumes expansion of nuclear power generation by 2 new plants that would generate 25,000 GWh, not counting the additional reactors required for hydrogen generation. The Ultraviolet scenario expands the nuclear supply of electric power by 118,000 GWh, meeting a total of 40% of 2050 electric demand with nuclear power, comparable to the amount planned by Japan.

The scenarios do not speak to the resolution of specific issues associated with nuclear power. Expanding nuclear power will require substantial capital investments and federal loan guarantees. It would require investment in scientific research into and technological advances in alternative fuel cycles and nuclear waste management. It would require public acceptance of license renewals for existing nuclear power plants, expansion of current plants, and siting of new plants.

Fossil fuel combustion with CCS is a significant component of all three scenarios, accounting for 190,000 GWh of energy in the Yellow scenario, 170,000 GWh in Deep Blue, and 70,000 GWh in Ultraviolet. Both coal (IGCC) and natural gas are included in differing amounts in the scenarios. While important in implementation, the fuel choice is non-substantive in comparison with other challenges associated with CCS. They include efficiency of capture and storage, establishment of storage reservoirs, and construction of infrastructure to transport CO2 from its point of generation to the point of storage. Notably, CCS is not yet commercially available and in fact has not yet been successfully demonstrated on a commercial scale. Moreover, the regulatory scheme that would govern it remains to be defined, and the capacity for large scale CCS in New York is not presently known.

Probably the most important CCS challenge is efficiency of capture and storage. The scenarios assume a capture efficiency of 90%, with the electricity sector contributing 24, 13, and 10 MMT CO2e for the Yellow, Deep Blue, and Ultraviolet scenarios respectively. For the latter two scenarios, which do meet the 80x50 goal, CCS still produces 20-25% of total emissions. The improvement of CCS technology to, for example, 99% would significantly reduce emissions.

Storage and transport of CO2 present closely related issues. The capacity to store CO2 is not homogeneously distributed throughout the state. Further, little is yet known about the suitability and capacity of those sites to store CO2. There will be a trade-off between siting of generation sources and siting storage facilities. Certainly, concentrating emissions sources near large-capacity storage reservoirs would simplify implementation and reduce costs. But it could also further increase the burden on the grid. NYSERDA's studies of New York's potential for CCS are important to defining the long-term potential.

Finally, it should be noted that as 2050 approaches, nuclear fusion may become a viable zero-carbon source of electricity. The scenarios assume it won't be sufficiently well developed to meet energy demand in 2050, but as the State looks beyond its 2050 target to continuing emissions reductions, this technology may be important. Decisions made between now and 2050 can impact its availability in the long run.

- *Infrastructure for electricity transmission and distribution must evolve to meet demand and other services the grid must provide.*

Fortunately, growing demand for electricity is accompanied by substantial research into and development and deployment of new technologies, which are shaping the grid of the 21st century – and at a time when capital improvements to New York's aging grid infrastructure are needed. The smart grid will deliver substantial benefits: greater reliability, enhanced security, "smarter" use of information technology, integration of renewable power generation, better storage technology, and sophisticated demand-management strategies. The ability to manage demand can yield another benefit: avoidance of the huge costs of building more power-generating plants.

The 80x50 scenarios assume three significant demands on the grid. One is the need for increased capacity to carry energy. The capacity increases can be met in two ways. The most straightforward is to install higher-capacity transmissions lines and to increase capacity through upgrades to substations, transformers, and distribution lines. Since all three scenarios call for a 50% improvement in transmission and distribution (T&D) efficiency (which contributes as much to emission reductions as all of the hydro enhancements), the upgrades will both increase capacity and reduce T&D losses. Another method is changing from conventional T&D lines to high-temperature superconductors. This technology both increases capacity and decreases losses, and it's already employed in two locations in New York State. However, it's complex to manufacture, and manufacturing capabilities must be radically scaled up and costs shrunk before it can be widely deployed.

The second demand on the grid arises from reliance on large amounts of solar and wind: their intermittency must be managed and compensated for. As intermittent loads grow, this becomes a larger and larger problem. In general, the approach been viewed as a question of "what do you do when the sun goes down, or the wind stops blowing?" This implies the availability of a backup energy resource. Because baseload power from thermal resources (nuclear and fossil with CCS) performs best if it operates continuously, increasingly the view is that energy storage might be the best option for intermittent sources.

Hydro resources have some limited storage capacity, allowing their output to be increased when demand grows. However, without "high" dams like those in western US states, this storage is limited. NYSERDA is studying the potential of below- ground compressed air storage potential in New York. The next step is to introduce storage technology, such as batteries, or in the long run, superconducting magnetic energy storage (SMES). This kind of storage has the added value of serving as a convenient means of helping to manage transients in the system, as well. Managing storage to compensate for intermittency will be greatly enhanced by incorporating information technology into the smart grid.

The smart grid also facilitates another strategy for managing intermittency: demand response, in which loss of generation is compensated for by a sophisticated demand-reduction strategy that targets flexible and non-essential loads, shutting them off for a short period of time. These loads can be at the commercial and industrial level, but recent and ongoing demonstrations also show success in the residential sector through use of smart meters and smart appliances.

Finally, the changing mix of end uses on the demand side will alter the temporal demand for electricity on time scales ranging from daily to seasonal. In general, this is a design and load-dispatch problem. What generation resources do you bring on, when, to minimize the cost of generation? To satisfy peaks in demand with the more-expensive generation resources and, through pricing strategies, encourage end-users to not use resources during peak demand periods? Switching of peaks among seasons, from summer peaking to winter peaking, for example, can create resource mismatches for resources that may have a strong seasonal variability, such as hydro and solar.

The scenarios assume the largest new demand will come through vehicle electrification. Studies have shown that smart electronics in, for example, PHEVs can manage that demand to fill in periods of otherwise lower demand. This allows baseload plants to operate more or less continuously, with consequent greater efficiency. Charging the PHEV "appliance" can also become part of the demand-response network used to manage intermittency – another benefit of the emerging smart grid.

Challenge: The Building Sector – Residential & Commercial

A critical challenge to reaching the 80x50 goal is in the performance of residential and commercial buildings. Reaching mid-century GHG reduction goals will require that buildings function with minimal or no net-energy input (input from the electric grid or from onsite use of high-carbon fuels). New residential, commercial and industrial building systems will need to significantly reduce, and eventually eliminate, onsite fossil fuel combustion for space heating, water heating, cooking, and other needs, and supply electricity through onsite generation from low-carbon energy sources.

The strategy suggested in this vision requires that buildings function with minimal or no net-energy input from onsite use of high-carbon fuels and that to the extent possible their energy demand not be shifted to the grid.. These new residential, commercial and industrial building systems will reduce, and eventually eliminate, onsite fossil fuel combustion for space heating, water heating, cooking, and other needs, and will supply electricity through onsite generation from low-carbon energy sources.

The relationship of the building sector to other sectors is a critical aspect of the 80x50 challenge. These relationships fall within four broad areas:

- End uses: Residential and commercial buildings represent a growing sector of energy demand. This demand is a central part of the standard of living we enjoy. An example is the growing use of personal electronics in residences and the development of large datacenters that support the new internet enabled economy, particularly the global financial industry based in New York. The critical first step in any carbon reduction strategy will be increasing the end use efficiency of the equipment and devices within structures. Reductions of 30% in each electricity and natural gas use is rather straightforward through the adoption of more efficient end-use technologies, such as more efficient lighting, space heating/cooling, water heating, computers, and televisions – as well as through the use of modern controls.

- Structures – A substantial component of the energy demand in the buildings sector is for space conditioning. End use efficiency has an important impact on this demand, particularly in the commercial sector where the cooling demand created by waste heat from devices and equipment. In New York the challenge of structures is exacerbated by the fact that much of the building infrastructure already exists. This will lead to important challenges in improvements of the performance of building envelopes and the creation of cost effective retro-fit options for key building systems such as windows and increased sealing and insulation.

- Distributed generation – One real option for building is the promise of distributed generation. The use of both photovoltaics and passive solar heating as well as the exploitation of geothermal resources through such technologies as ground source heat pumps offers real promise. The greater the contribution of these technologies to both efficiency and meeting electric demand the less the buildings sector will contribute demand to the already growing burden on the grid. There are many policies options that can help reduce the capital costs barrier could be strong enablers of broader adoption of distributed generation technologies in residential and commercial sectors.

- Communities and the promise of smart growth – Probably the most important trend will be the increased view of the buildings sector as a component of communities. Many of the elements above are even more valuable when one considers collections of structures and seeks to manage energy for these aggregations. Distributed generation for communities can include wind and local biomass conversion for heat and power. The community can become part of a micro-grid that not only effectively manages the electric demand of the community but also can be the basis of using the community as a dispatchable demand response resource for the wider grid. Finally, if the communities take on the "smart growth" approach both in new construction but also in re-development, the communities themselves can have appositive impact on other sectors, most notably transportation.

There has been extensive work on energy efficiency in buildings, done by the World Business Council on Sustainable Development, the National Academy of Science, the Pew Center on Climate Change, and Lawrence Berkely National Laboratory, which offer key data and insights to the energy savings potential. A difficulty in comparing the energy efficiency potential across studies is the variation in methodologies and measures within each of them. However, there are some common themes worth noting.

BOTTOM-LINE ISSUES AND CONSIDERATIONS

The scenarios that inform the visioning process can be further manipulated to yield more insights into interrelationships among mitigation strategies for various sectors. But even at present, and the benefit of insights and knowledge gained at the January 5 visioning workshop and from yet other sources, it's clear that major decisions are necessary to achieve the 80x50 goal.

Many of those decisions must be made sooner rather than later, as they affect long-lead-time matters such as infrastructure investments and research and development strategies that can help or hinder progress. Moreover, the early adoption of some measures won't preclude later adoption of others. Thus, identifying pivotal future decisions and sequencing them becomes a serious challenge in its own right.

The text below discusses issues that follow from the discussion of serious challenges above, and that emerged from the visioning process and other sources. Some concern single economic sectors; some span two or more. While it can be difficult to differentiate technical issues from policy issues, we've tried: the points immediately below are primarily technical in nature; policy considerations follow.

Technical considerations

- Gains in energy efficiency are critical to achieving a low-carbon future. The scenarios don't specify mechanisms, technologies, or practices necessary to achieve these gains, but their importance is clear.

- Very soon, a risk assessment table for critical technologies, such as CCS, nuclear, and solar, should to be developed. This table would highlight the barriers to and compare the types of uncertainty associated with each technology, facilitating the identification of both policy measures and research investments.

- Electrification is an essential strategy, too, and a move to electrification is consistent with the energy needs of a 21st-century economy based on information technology, biotechnology and nanotechnology. If New York's demand for electricity nearly doubles by 2050, a number of issues arise. For one thing, electrification transcends selecting non-carbon emitting central generation technologies and arranging for their siting and financing. Demand on transmission and distribution systems will increase, too. This means that ongoing planning for the smart grid and associated technologies must be part of the Climate Action Plan strategy.

  And growing demand will alter not only the amount of electricity needed but when demand peaks, on timescales ranging from daily to annually. How the load duration curve, one measure of changing demand, is managed will be an important part of the smart grid. This may include the use of storage to facilitate handling of larger quantities of intermittent renewable resources, and the use of active demand management technologies like demand response.

- Electrification of buildings could create a stranded asset in the gas distribution system. The existing infrastructure for gas and its continued expansion may create a structural barrier to the goal of reducing highly distributed point sources of GHG emissions. On the other hand, pipelines moving CO2 from gas combustion facilities to storage reservoirs may be co-located along rights of way, provided they are appropriately located.

- All scenarios call for the phase-out of fossil fuel generation that free-vents carbon to the atmosphere. The schedule for retiring or converting existing facilities thus becomes an issue.

- Similarly, existing nuclear power plants are on the critical path for a future that continues to rely on nuclear power. These plants would have to be replaced or re-licensed. If relicensed, it would probably be for a maximum of 20 years; they'd then be replaced.

- Nuclear and/or fossil fuel combustion with CCS, which is largely undemonstrated, are important for decarbonization of centrally generated power. Both require long lead times and large capital outlays. CCS also requires significant infrastructure for storage, which will include site selection and certification as well as some pipeline infrastructure. The regulatory scheme that would govern siting and operations of CCS facilities and storage locations remains to be defined.

- The transformation to a hydrogen economy would require a new infrastructure for producing and delivering hydrogen to consumers. The development of gas-cooled, high-temperature nuclear reactors to produce hydrogen would require new plant designs, which would require licensure. Safety regulations for transportation and storage of hydrogen would also be needed.

- In our scenarios we've included some technologies that are emerging but not yet commercial, such as CCS. Others are unproven, such as large energy storage. We omitted nuclear fusion, an unproven technology, and direct air capture of carbon dioxide, which is speculative at this time. These all have theoretical potential to help achieve the 80x50 goal, but the timeline for making changes requires technologies that are in development today, and ready for deployment at scale within approximately a decade. The current international roadmap for fusion would have the first demonstration reactor online in about 2040.

- The scenarios assume complete success; for example, total conversion of the building sector to electricity, or to net-zero carbon emissions. Inevitably, there will be "leakage," which will place further limitations on emissions from other sectors or technologies.

- Renewable resources play a major role in all three scenarios. But even with expected gains in renewable energy technology efficiencies, the state's renewable resources can't meet all of projected future energy needs. And, distributed resources used on a large scale would require large tracts of land for solar arrays, wind farms, and biomass cropping. The scenarios assume all renewable resources would come from within the state. This is consistent with the State's desire to develop its own resource and energy industry. But out-of-state renewable resources could be used, too, and perhaps in some cases more cheaply. Opening the market could take pressure off in-state only resources.

- Sustainable biomass is a limited resource. What's the best allocation for its use? Should it be used for transportation (as in our scenarios), to heat buildings, or for power with CCS, which could create a carbon sink?

- The grid-installed solar electric assumption in the scenarios is quite optimistic and may not be met without significant energy conversion improvements in photovoltaic panels and systems. Distributed solar awaits gains in scalability, reductions in cost, and the creation of large-scale installation capabilities. The scenarios don't include some renewable technologies that may be fungible and that could help reduce emissions, such as geothermal and hydrokinetic energy sources.

- The transportation sector is an extremely large, diffuse source of GHG emissions. All of the scenarios largely call for eliminating gasoline and diesel as energy carriers and replacing them with bio-fuels, hydrogen, or electricity. The sector is diverse, with each of the subsectors – light duty vehicles (LDV), heavy duty vehicles (HDV), mass transit, and aviation – having its own special needs. Key issues include these:

  -- Transportation options create an infrastructure demand that must be accounted for in planning. The current network of fueling stations for LDV and HDV is pervasive, with one or more fueling station in virtually every community and neighborhood in the state. Pushing vehicles to electricity adds demand to the distribution system, while a hydrogen-based vehicle system would necessitate replacement of key components of this extensive refueling network.

  -- The specifics of how to reduce VMT aren't addressed in the scenarios. They're important: e.g., reducing VMT means increased demand on and expansion of mass transit, as well as potential impacts on community design, development, and redevelopment.

  -- Significant improvements in vehicle fuel efficiency are important to the mitigation scenarios. Whether national standards will be sufficient to drive this change is questionable.

  - The state's residential and commercial sectors are a major source of emissions, and the scenarios call for substantial improvements in energy efficiency and the source of energy used for space conditioning, hot water, and cooking. At the January workshop, the point was made that many building professionals have little concept of how much buildings contribute to GHG emissions, and how little it costs to mitigate them. New York City's new Green Codes, a major effort commissioned by the Mayor and City Council Speaker, may offer a useful guide for other cities in the state, for starters.

But even if all building owners, managers, and tenants were committed to greening the existing building stock, the workforce needed to install energy retrofits may not be adequate to the job: training may be required, along with financing schemes that facilitate retrofits.

- All three scenarios assume use of distributed renewable energy in the building sector. This resource is over and above transmission-connected resources accounted for in the electricity sector. The Deep Blue and Ultraviolet scenarios call for the residential sector and commercial sector to be zero emissions, not net-zero. If the strategy evolves to a net-zero standard, other emissions not accounted for in the scenarios will have to be offset.

- Serious methodological questions must be addressed. For example, how well understood are interconnections among complex physical systems—the networks of energy inputs and feedback loops—that drive emissions? That link energy use and water use? Should estimates of GHG emissions include embedded energy, which produces emissions beyond the state's borders? How far should lifecycle analyses go?

- With a goal of 51 MMT CO2e, even small sources of emissions become important. Emissions reductions strategies for several sources (e.g. asphalt production, SF6 leakage, etc.) are not immediately clear. Work is needed to develop strategies for management of emissions from all sources.

- *Interdependencies.* The interdependencies, and consequent vulnerabilities, of transportation, water, energy, and communication systems have direct consequences for system performance and thus for climate change adaptation and mitigation. System managers and operators must be helped to understand and manage those interdependencies.

Policy considerations

- *Incipient policy conflicts and synergies*. The Climate Action Plan has pervasive ramifications for the state's economy and social fabric. Many existing State policies may facilitate or hinder achievement of the 80x50 goal. Policies made by other states and the federal government can affect New York's ability to pursue its chosen path. For example interstate commerce (tourism, freight, and aviation) is shaped by federal policy. Large-scale renewable energy involves significant land-use choices, for siting of wind and solar facilities and use of biomass resources; local choices and policies may affect the State's ability to meet its renewables goals.

- *Policy gaps*. What regulatory scheme will be required to cover the siting for CCS facilities, pipelines, and storage sites, and the permitting of CCS operations? For gas-cooled, high-temperature nuclear reactors that would produce hydrogen? For new technologies yet to emerge? Designing and implementing regulatory "infrastructure," so to speak, might be no small undertaking in its own right.

- *The need for partnering.* Related to policy conflicts and synergies is the great need for partnering among all levels of government and between the public and private sectors, with regional collaboration being a point strongly urged at the January 5 workshop. The inclusiveness and openness already demonstrated by the NYS Climate Action Council and the State's many other climate and energy initiatives, including the State's aggressive partnering with local governments through the Climate Smart Community Pledge, augurs well for this. Obviously, close partnering with the business community will remain a long-term necessity.

- *Long-term consequences of near-term decisions, and lack of decisions.* Decisions made, and not made, about matters that require long lead times, such as major infrastructure projects, and that have long-term consequences, such as land-use policy and a commitment to CCS, cast long shadows into the future. Whatever the choice of low-carbon sources of electricity (CCS, nuclear, solar) and of energy carrier for transportation (electricity or hydrogen), the electricity sector *must* plan for the expansion of the grid and improvement of transmission and distribution. Some early actions, such as improving energy efficiency, have value regardless of other choices made; others may have value only in relation to specific choices of technology, such as development of CCS infrastructure. It's important to remember that achieving a low-carbon future requires a portfolio of actions, and that "easy" decisions aren't substitutes for hard ones.

- *The* rate *at which policies drive change matters to success.* But this important factor is difficult to manage. The Climate Action Council is working in a field in motion, as technologies evolve, economic conditions change, and other parties, including the federal government, make decisions that have consequences for New York.

- *Stranded capital investments*. Practically all energy-related technologies require both infrastructure and capital investment from the private sector, and those investments are generally large. If they are foreclosed because of decisions that support the 80x50 goal before they've delivered a full return on investment or reached the end of their useful lifetimes, the result will be stranded capital investments – both a major hidden cost of carbon mitigation and a source of resistance to future change.

- *Investments by the State*. The current performance of many technologies assumed by the mitigation scenarios – such as PV, offshore wind, large-capacity/low-cost batteries, PHEVs, CCS, zero-energy commercial buildings and LEDs – is inadequate to meet the 80x50 goal. Those technologies will require investment to boost performance. Sources like DOE-National Lab Roadmaps and the National Academies' study, America's Energy Future, identify step-function improvements in technology and major investments in infrastructure needed to achieve a low-carbon economy.

- *Motivating change.* The scenarios make no explicit assumptions about individual behavior. How to motivate individuals to modify their energy consumption and patterns of use, drew considerable interest at the January workshop, and warrants the attention the State Climate Action Council.

CODA

Insidiously, carbon emissions are cumulative: they persist in the atmosphere for up to thousands of years. This means that as levels of emissions grow, reducing them to levels deemed acceptable becomes ever harder. And because New York is already more energy-efficient than most states, reducing emissions from what is already a low baseline is harder, still.

Against this physical reality, the momentum of *business as usual* is not to be underestimated: it's one of the most powerful forces in the world. And yet, the nature of *business as usual* continually evolves. The "installed base" of current energy technologies represents trillions of dollars in sunk costs and powerful special interests. Fossil fuels are cheap, abundant, and convenient. Options for scaling up alternatives to them, affordably, are not yet in hand. Yet history tells us that technologies, and markets, continue to change. The brutal realities of fiscal deficits are certain to constrain important efforts to achieve the 80x50 goal. And yet they also make the very real economic opportunities generated by that goal even more compelling.

Notably, the assets and advantages that the State enjoys can be game-changers, too. Executive Order 24 is soundly and sensibly conceived. The Climate Action Council's approach to its task is exemplary. It enjoys the benefit of committed top-down leadership; many motivated state employees who possess technical expertise, policy savvy, and insight into how government and the political system work; a broad-spectrum approach that engages a large number of committed stakeholders in the NGO and private sectors; and a deep commitment to achieving environmental justice.

Crucially, the Council is rapidly gaining insight into the staggering magnitude of the challenge it has been tasked to address and the nature of the strategies it can employ.

Over coming decades, New Yorkers – long celebrated for being tough, resourceful, and creative – may well prove to be the equal of the 80x50 challenge. Every megaton of GHG emissions avoided will be a gain, and the societal and economic transformation achieved in vigorous pursuit of sustainability will create a future for our children and grandchildren and generations beyond that is *better* than the present we inhabit.

APPENDIX A

Supplemental Information on Methodology & Data Sources for the Baseline Forecast of Energy Demand and the "Business as Usual" Case

The input to the macro coupled-sector modeling is the baseline projection for energy demand by sector and fuel type in 2050. These values were estimated by a constant growth (% per year) extension of the modeling conducted in the development of the New York State Greenhouse Gas Emissions Inventory and Forecast for the 2009 State Energy Plan, which estimated the GHG emissions by sector and fuel type to 2025.

Forecasts of petroleum and coal use for residential, commercial, industrial, and non-highway transport sectors were based on U.S. Energy Information Administration (EIA) forecasts for Mid-Atlantic fuel demand, along with natural gas projections provided by Energy and Environmental Analysis, Inc. (ref: Energy Demand and Price Forecast, 2009 State Energy Plan).

Forecasts for fuel use for the electricity sector and net imports of electricity were based on output from ICF International's Integrated Planning Model® (IPM), an electricity sector modeling software used to support the development of the 2009 State Energy Plan. Energy demand by sector and fuel type was modeled to 2025. From 2025 to 2050, a constant annual rate of growth or decline was assumed. In addition, emissions projections for 2025 and 2050 are also estimated and presented in Table 2 above. These projections include estimated emission reductions due to RGGI and partial implementation of New York's 15x15 energy efficiency goal.

Forecasts of NYS vehicle miles of travel (VMT) were estimated from historical NYS Department of Transportation VMT data (https://www.nysdot.gov/divisions/policy-and-strategy/darb/dai-unit/ttss/repository/vmt_0.pdf). NYDOT estimates that VMT will continue to grow at a 1.1% per year growth rate out to 2030, and is assumed to grow at this pace to 2050. The annual rate of growth of VMT was 2.5% between 1975 and 1990, and 1.7% between 1990 and 2005 (See Strategies for a New Age: New York State's Transportation Master Plan for 2030.) On-highway diesel and gasoline fuel use was based on NYS VMT along with the Department of Energy's Energy Information Agency-projected vehicle economy, and was the basis the estimate of emissions from the transportation sector.

Finally, non-fuel combustion GHG emission forecasts for the industrial sector were based on the projected growth of New York industries. These forecasts were created using Policy Insight® version 8.0, macroeconomic modeling software from Regional Economic Models Inc. Estimates for emissions from hydrofluorocarbon (HFC) refrigerant substitutes are scaled from EPA projections for national emissions by New York State's relative use of air conditioning, refrigerators, and freezers. Emissions from electricity transmission and distribution were assumed to continue to decline, following the long-term historical trend.

A more detailed explanation of the forecasting methods can be found in the NYS State Energy Plan Energy Demand and Price Forecast Assessment. GHG emission forecasts are in large part based on these energy-use forecasts. A more detailed explanation of the sources and methodologies for GHG emissions can be found in the New York State Greenhouse Gas Emissions Inventory and Forecast for the 2009 State Energy Plan.

Appendix B

GHG Emissions Scenario Assumptions

Sector	Yellow	Deep Blue	Ultraviolet
Transportation	Smart growth reduces VMT Demand 10% for LDV Fleet mix composed of CV/HEV/PHEV* = 30/30/40 CV reaches 37 mpg; HEV miles at 50mpg 95% of VMT for PHEV are all-electric 50% of HDV miles switch to freight transport by rail 30% efficiency gains in aviation ~51.3 MMT CO2e	Smart growth reduces VMT demand 40% for LDV 100% of VMT for LDV from hydrogen (nuclear-based) @65 mpg equivalent 50% HDV VMT switch to freight transport to rail; 40% of balance of miles from biodiesel 30% efficiency gains in aviation, 50% reduction of aviation emissions from biofuel ~15 MMT CO2e	Smart growth reduces VMT demand 40% for LDV 95% of VMT from LDV are all-electric miles Balance of LDV VMT 50 mpg with in-state E85/biodiesel 50% HDV VMT switch to freight transport to rail 30% efficiency in aviation sector; 50% reduction of aviation emissions from biofuel ~20 MMT CO2e
Electricity	25% electricity efficiency in Residential 25% electricity efficiency in Commercial 10% electricity efficiency in Industrial Minimize combustion; what is left switches to IGCC, NGCC w/ CCS Max hydro, wind No new nuclear NO NEW OUT OF STATE RENEWABLE ELECTRICITY ~24 MMT CO2e	Significant efficiency gains as in Yellow Scenario Eliminate all combustion Maximize hydro 30% from carbon-free (nuclear [+2 new plants producing 25K GWh] + hydro) 30% from renewables (utility-scale solar (100,000 GWh), max wind) 40% from NGCC and CCS (@90%) H2 via electrolysis of high-temperature steam using high-T gas-cooled reactors (5-8 plants) NO NEW OUT OF STATE RENEWABLE ELECTRICITY ~13 MMT CO2e	Significant efficiency gains as in Yellow Scenario Maximize hydro, max wind 35% from carbon-free (nuclear [15 new nuclear plants; 24 total], max hydro) 35% from renewables (utility scale solar (100,000 GWh), wind) 17% from NGCC and CCS (@90%) 35%- 40% energy demand in Res./Comm from local solar NO NEW OUT OF STATE RENEWABLE ELECTRICITY ~10 MMT CO2e
Residential	20% efficiency gains in energy demand for heat/hot water 10% of electricity needs met from local solar Reduce combustion by 70-80% ~7.5 MMT CO2e	30% reduction in energy demand through efficiency 50% delivered gas/liquid fuels from biomass 40% of balance of energy demand left met by local solar generation Balance to energy demand from grid ZERO MMT CO2e	50% reduction in energy demand through efficiency Eliminate all combustion of gas, oil 40% of balance of energy demand met by local solar PV ZERO MMT CO2e
Commercial	Reduce natural gas/oil combustion by 75% 10% of electricity needs met from local solar Balance of energy need shifted to central electricity ~4.5 MMT CO2e	20%-30% efficiency gains 50% delivered liquids fuels from biomass ~30% of electricity demand from local solar Balance of energy need shifted to central electricity ZERO MMT CO2e	20%-30% reduction in energy demand through efficiency Eliminate all combustion of gas, oil ~ 50% of energy demand from local solar Balance of energy need shifted to central electricity ZERO MMT CO2e

Industrial	Eliminate all coke/coal use Reduce natural gas/oil combustion by 50% Switch coke/coal to natural gas Balance of energy need shifted to electricity ~14 MMT CO2e	20%-40% reduction in energy demand through efficiency Eliminate natural gas, oil combustion Eliminate coke at cement/boilers; switch to natural gas Residual of emissions from asphalt, petrochemical, other (8.4 MMT) ~13MMT CO2e EMISSIONS	20%-40% reduction in energy demand through efficiency Eliminate natural gas, oil combustion Eliminate coke at cement/boilers; switch to natural gas Residual of emissions from asphalt, petrochemical, other (8.4 MMT) ~13MMT CO2e EMISSIONS
Other	Eliminate SF6 dielectric from T/D grid 50% reduction in line leaks in natural gas RRR policy Eliminate HFC leaks Reduce process CO2 ~12 MMT CO2e	Eliminate SF6 dielectric from T/D grid Eliminate hydrofluorocarbon emissions Eliminate 90% line leaks in natural gas RRR policy to eliminate 100% municipal methane/waste emissions Eliminate HFC emissions ~12 MMT CO2e EMISSIONS	Eliminate SF6 dielectric from T/D grid Eliminate hydrofluorocarbon emissions Eliminate 90% line leaks in natural gas RRR Policy to eliminate 100% municipal methane/waste emissions Eliminate HFC emissions ~12 MMT CO2e EMISSIONS

CV = Conventional Vehicle; HEV = Hybrid Electric Vehicle; PHEV = Plug-in Electric Hybrid Vehicle; LDV = Light Duty Vehicle; HDV = Heavy Duty Vehicle; VMT = Vehicle Miles Travelled; MMT CO2e = Million Metric Tons CO2 Equivalent