


Module 6: Infrastructure Networks

THE CHANGING CLIMATE'S IMPACT ON THE TRANSPORTATION AND ENERGY SECTORS

Overview

1. What are the primary impacts of climate change on infrastructure networks?
2. What are the key climate-related challenges and issues to consider in transportation and energy infrastructure planning?
3. Have there been recent, successful municipal efforts to create more resilient infrastructure networks?
4. Are there any resources to assist infrastructure planners?
5. Presentations by municipal experts:David McLeod, Vesna Briatico, City of Toronto

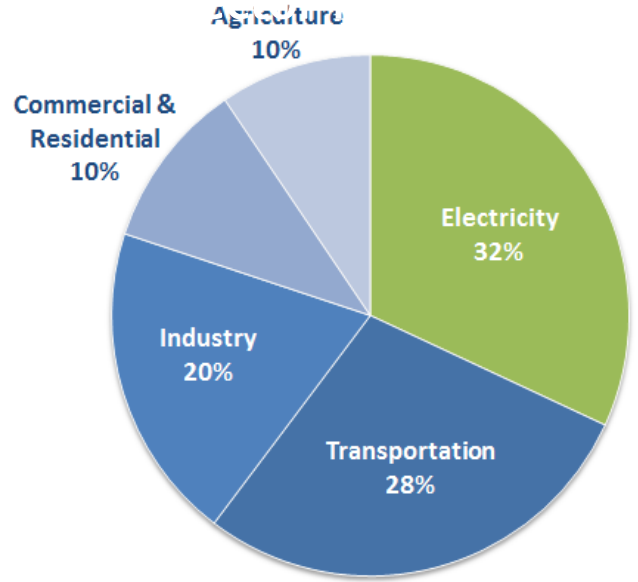
Transportation and Electricity Contribution to GHG Emissions

Total GHG emissions in the US in 2012 were 6,526 million metric tons of CO2 equivalent.

Combined, the electricity and transportation sectors contribute 60% of all GHG emissions in the US, which contributes to climate change, which then impacts the performance of the electricity and transportation sector even further.

Mitigation of these emissions must be part of any adaptation strategy.

TOTAL US GHG EMISSIONS, 2012



Overview of Municipal Infrastructure Impacts

Climate change-related challenges to infrastructure networks

✓Infrastructure may be exposed to weather extremes not accounted for in original design. Construction often assumes past climate extremes will represent future conditions

✓Severe weather causes shorter infrastructure life span and reduced overall performance, as well as increased maintenance and operating costs

✓Climate change may disrupt municipal transit and power operations, compromising public safety

✓Severe and unanticipated economic losses can occur due to damaged/overwhelmed infrastructure

✓Climate related risks are further aggravated by:

- Aged infrastructure that has exceeded normal service life
- Frequent co-location and interdependency of multiple structures
- Decline in public spending
- Ballooning populations

Climate-Specific Factors to Consider

1. Extreme rain and flooding events
2. Hotter & drier summers
3. Accelerated freeze and thaw cycles, with snow & ice variability
4. Problems stemming from increased salt usage
5. More pronounced repercussions in small communities (example: Wawa, Ontario)

For freeze and thaw forecasts for your area, visit the Midwestern Regional Climate Center's website, http://mrcc.isws.illinois.edu/, or check out NOAA's National Weather Service Climate Prediction Center at http://www.cpc.ncep.noaa.gov/index.php to find seasonal temperature and precipitation forecast data. The Great Lakes Hydro-Climate Dashboard is another useful site that shows real-time data for Great Lakes water levels, as well as offering historic climate and hydrological information. Visit it here: http://www.glerl.noaa.gov/data/dashboard/GLHCD.html

Climate Change and Transportation

Extreme Rain and Flooding

Increase in frequency and severity of:

- Drainage issues and erosion threats to road and bridge structures
- Collapsed culverts, wash out/ inundation of causeways, bridges, low-lying roads
- Pavement and bridge joint expansion and road asphalt softening; compromised bridge structure integrity, due to high winds and channel flow
- Soil moisture, unstable slopes and landslides that cause road and bridge damage, along with service disruption

Modeling and projections can be predictive:

A DOT-funded vulnerability assessment for transportation systems in New Jersey, completed in 2011, was predictive of many of the areas actually flooded by Hurricane Irene and Superstorm Sandy. Similarly, the transportation sections of the City of New York's adaptation plan, completed in 2010, anticipated much of the flooding and damage that actually occurred, particularly the disastrous consequences of flooding highway and subway tunnels into Manhattan.

Climate Change and Transportation:

Hotter and drier summers

Increase in frequency and severity of:

- Pavement softening and buckling; distortion in wheel paths
- Reduced maximum loads among municipal, transport and residential transport vehicles on paved surfaces
- Reduced ride quality and performance, increased maintenance costs
- Reduced overall life span of roads, rail, bridges and culverts

Accelerated freeze and thaw cycles

Accelerated freezing and thawing cycles have been implicated in destabilizing paved and built structures. This may impede automotive, railway, and other forms of transportation, and can undermine motorist, passenger and pedestrian safety. The following infrastructure elements may be negatively impacted:

- Ditches, culverts and drains
- Ramps, bridges, highways, railway lines and tunnels
- Sea walls, locks, lighthouses and water retention structures
- Power lines, generators and digital service towers

This may result in :

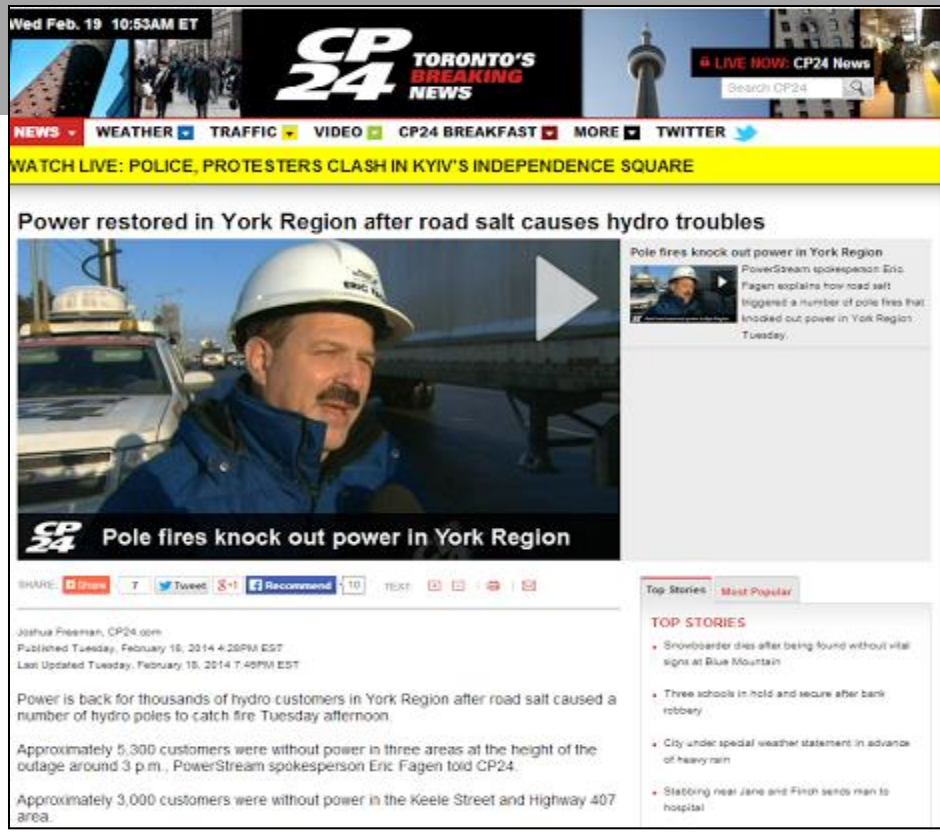
- Increased maintenance, repair and reconstruction costs
- Pavement bleeding, cracking and rutting, leading to traffic redirection
- Deterioration of motor, rail and seaways; damage to underground subway lines
- Electricity outages and cell phone service disruption

Road crews in Toronto attempt to clean up cracked pavement in January 2014

Road Salt Usage

Road salt is an effective and affordable way to manage winter road conditions, but has impacts:

- Chloride in road salt is toxic to aquatic vegetation, wildlife, soils, waterways.
- Anti-caking agents in salt often contain cyanide, which the EPA classed as a toxic pollutant in 2003.
- Cold-weather states use 10-15 million tons of road salt every winter.
- Salt alternatives include sand, molasses, beet juice and cheese brine – some of which can cause their own set of environmental impacts.
- Public drinking water security and private wells are at risk of salt contamination, and concrete infrastructure and railway crossings are often corroded by salt.
- Excess salt accumulation can cause traffic signal box malfunctions and contribute to roadway congestion and accidents.



In York, Ontario, over 5000 customers were without power due to salt-created fires on utility poles.

Roads, Maintenance and the Law

In April 1, 2003, Giuliani lost control of her vehicle on an icy road and travelled into oncoming traffic, colliding with another vehicle. In the three hours prior, 2cm of snow had fallen. The courts found that municipal authorities were lax in their roadway monitoring and clearing duties, and further, that the municipality was not in compliance with Minimum Maintenance Standards (2002) as they relate to snow accumulation and icy roadways.

In 2014, a Lambton County farmer was awarded more than $100,000 in damages in a potentially precedent-setting lawsuit involving a municipal government's use of road salt.
The farmer claimed the farm had suffered crop losses leading to the depreciation in value of their 96-acre farm as a result of the County of Lambton's use of road salt.

Impacts to public health

The US Department of Commerce estimates that 70% of automobile accidents resulting in death are snow or ice-related.

Driving conditions in severe weather can be extremely perilous. Evidence from climate models suggests that an increase in overall severe storm and weather events is likely.

- Damage to paved surfaces from extreme heat, cold and excessive water may result in:
  - Increased danger to motorists from potholes, less stable bridges, visibility impairments (from blowing snow/dust), lessened vehicle traction, lane obstructions and/or submersion
- Increased rainfall can heighten flooding, leading to traffic delays, health risks, erosion, infrastructure washout, landslides
- Temperature extremes (fast freezes, etc.) and flooding can also damage vehicles themselves

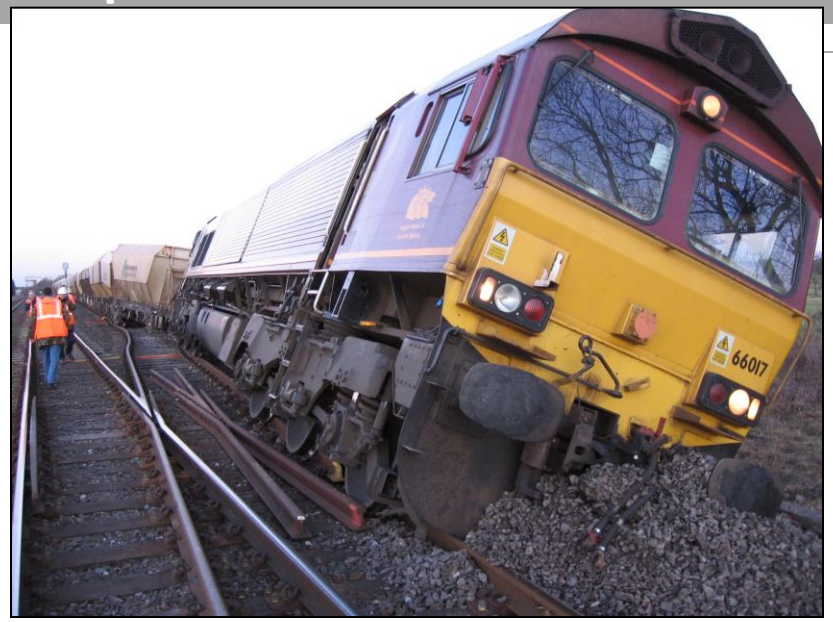
Pronounced Effects in Smaller Communities

Wawa, Ontario

- October 25th 2012, excess rainfall of 100 mm in 12 hours
- Total flood damage exceeded $10 million, with greatest damage to transportation infrastructure
- Severe damage to 3 bridges, plus one collapsed culvert
- Destroyed sections of a popular municipal biking and snowmobile trail

Photos by Chris Benka

Impacts to Rail Networks



Challenges posed to railway infrastructure

Climate affects railroad safety and operations, efficiency, scheduling and demand. The viability of railway transit impacts many passengers, as well as businesses whose bottom line depends on timely delivery of goods.

Railway tracks can buckle in instances of extreme temperatures, causing repair delays and even derailments. Crossings and bridges are particularly vulnerable. Severe weather may require sudden stops and even re-routing of common train routes.

High-speed crosswinds can be particularly hazardous for train operators and travelers. Hazardous cargo may spill if trains derail.

Adaptation strategies may include:

- Increase forecasting capability with real-time data and additional monitoring stations. Improve operational responses to severe weather (avalanches, etc.)

- Identify high-risk earthworks, flooding sites, extreme temperature and high wind zones, and aging infrastructure. Example actions; raise sea walls, increase drainage capacity, increase vegetation of surrounding areas.

Impacts to Air Travel

Severe flooding at Chicago's O'Hare International Airport in July 2014 caused the delay and cancellation of many flights.
(Source: abc7Chicago.com)

Challenges posed to airlines

- Extreme weather can lead to the grounding of flights
- Runway and aircraft damage may occur with extreme temperatures and excessive precipitation
- Increased business costs (fuel, electricity, insurance, service disruption, ground transportation and lodging for displaced or stranded passengers)
- Sudden (or gradual) changes in demand
- Unhappy customers (and consequent economic losses)

Adaptation strategies may include:

Infrastructure reinforcement, such as sea walls and coastal protection, diversified local supplies/resources (fuel, electricity, water), storm water improvements (like better drainage, pumping, storage), enhanced response programs for disruptions, and Emergency Management Plans.

Impacts to Public Transit

Climatically hazardous conditions pose a threat to transit operators/drivers as well as passengers.

Emergency vehicle operators are particularly at risk, and vital emergency services may slow or stop completely.

Increased precipitation may flood bus and train storage lots, and power outages could disrupt traffic control signals for all transit types.

Subways and below-ground transportation infrastructure are especially prone to risk of flooding.

Low-income populations, seniors and disabled citizens, who may be disproportionately reliant on public transportation, will be more affected by transit interruptions

Adaptation strategies may include:

- Sealing street-level vents and manholes; protecting underground pump rooms, circuit breaker houses and other underground facilities that provide power to subways;
- Purchasing buses or ferries that are able to withstand adverse weather conditions, and upgrading emergency communication systems.

Impacts to Marine Transport and Shipping

Challenges posed to waterway systems

80 percent of the world's volume in trade is carried by sea (UNCTAD). Harbors and docks are vulnerable to rising coastal water levels and higher storm surges.

Combined with the St. Lawrence Seaway and the Mississippi River system, the Great Lakes are the mid continent's tradelink to markets around the world, handling 180 metric tons of cargo per year, at a value of $35billion, employing 227,000 people.

Higher temperatures and/or increased sediment deposition from flooding may lead to reduced lake and port depth. With shallower waters, less cargo can be carried. Additionally, the operability of locks is influenced by floods and droughts.

Adaptation strategies may include:

Identification and reinforcement of vulnerable areas (by adding breakwaters, for example, or increasing dredging), increased monitoring and data collection at the local level, and compilation of case/studies & best practices.

Climate Change, Energy and Electricity

An Introduction

The National Resource Council and U.S. Global Change Research Program (USGCRP) found that **U.S. energy infrastructure is vulnerable to a range of climate change impacts-**--particularly infrastructure in areas prone to severe weather, blackouts and water shortages.

When assessing, forecasting, and responding to potential impacts of climate change and extreme weather on the energy sector, must consider lower probability, higher impact scenarios characterized by thresholds or 'tipping points' beyond which there are irreversible changes or changes of higher magnitudes than expected based on previous experience.

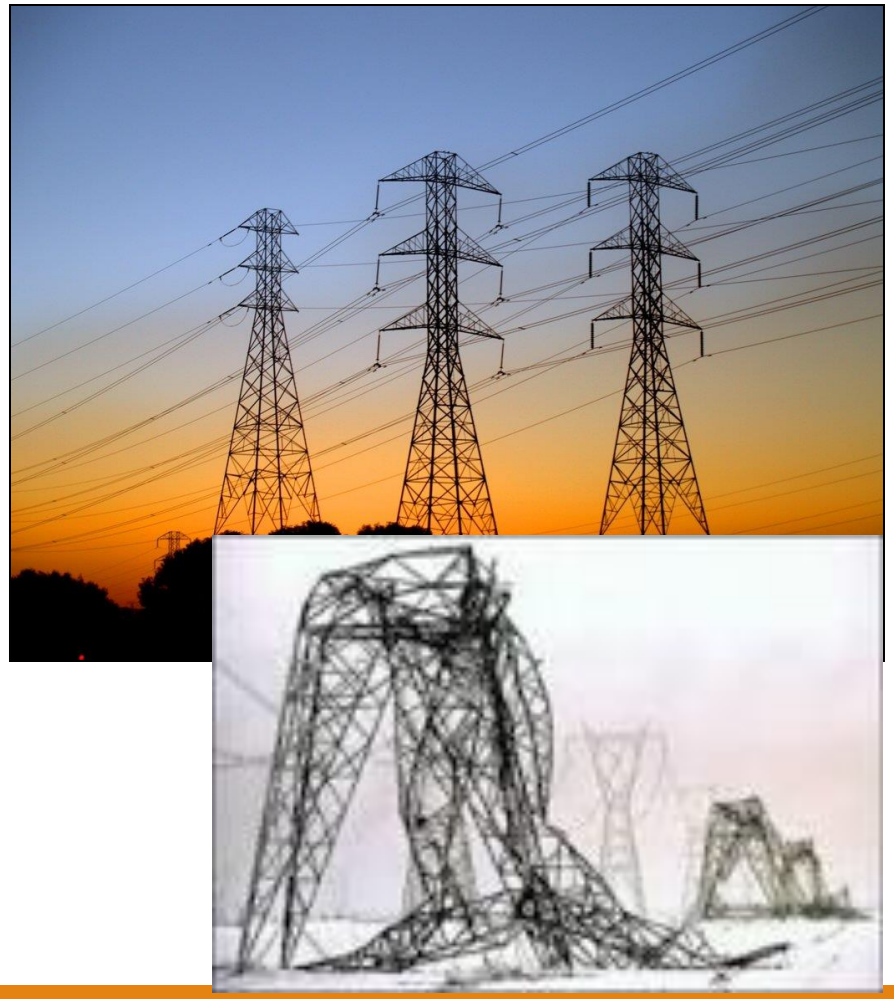
Air traffic control hubs are one example of where climate change could impact the energy and transportation sectors.

Energy Infrastructure:

Impacts and Management Strategies

Risks to infrastructure:

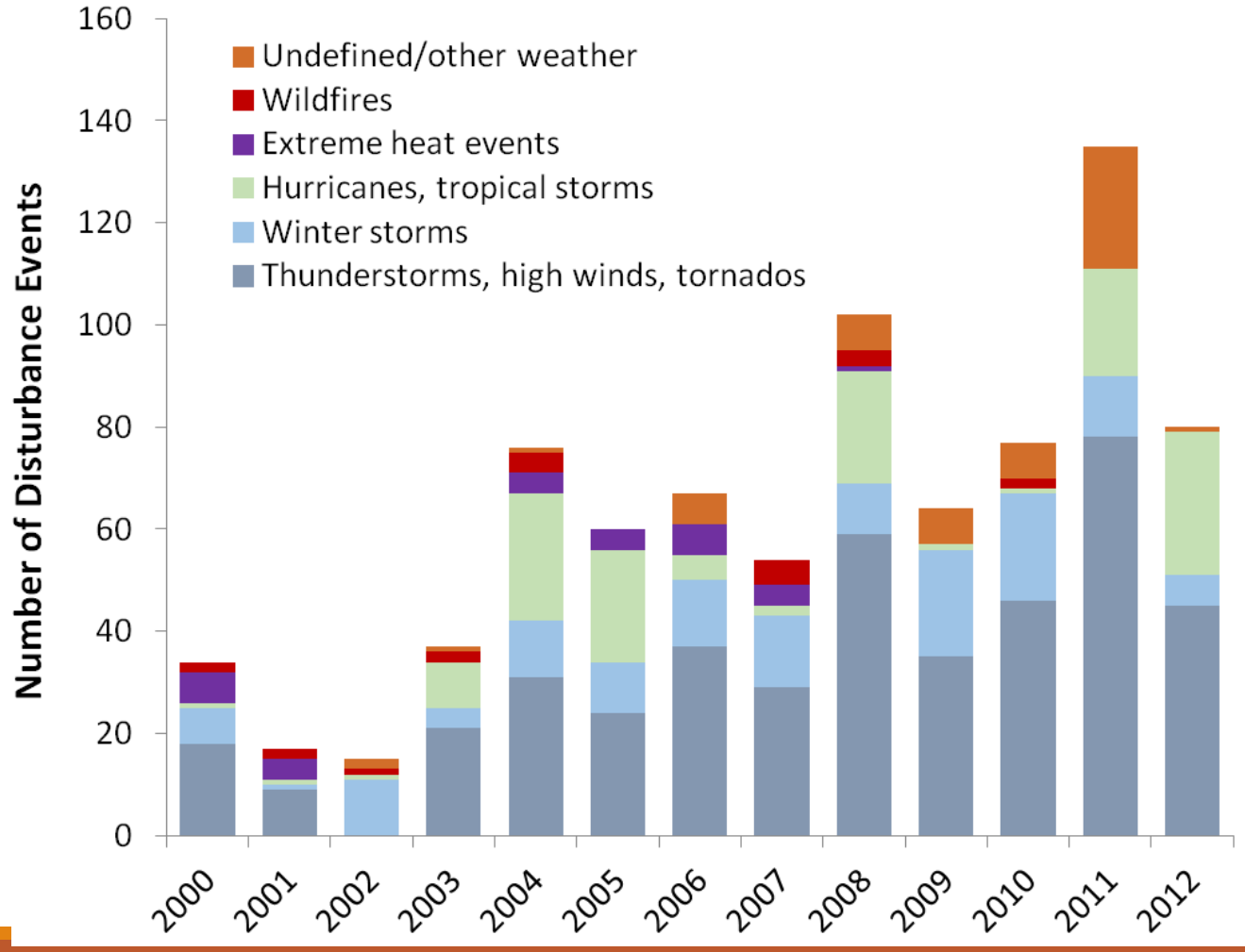
Energy supplies and usage may all be affected by climate change, via stress on the power grid during hotter summers and colder winters. Additionally, crucial energy infrastructure elements may be damaged by extreme weather.



Adaptation strategies include:

- Manage power vulnerability;
- Diversify current energy sources to improve resiliency of existing system;
- Incorporate better ventilation, reduced energy use (efficiency, renewables);
- Manage fleet vulnerability with varied purchasing strategies and rotating maintenance schedules;
- Include climate change in new development and renovation planning;
- Set appropriate codes and standards.

Weather-related grid disruptions, 2000–2012



Climate change-related strategies to consider in transportation and energy infrastructure planning

Adaptation Meets Mitigation

Walking and Bicycling

Alternative Transit Modes

Individual-level changes in transportation choices can add up to big impacts, improving local air quality and minimizing the urban heat island effect, for example.

- Private combustion engine automobiles are responsible for 62% of transportation-related CO2 emissions (EPA 2006).
- Non-polluting forms of transportation such as biking and walking can reduce emissions and improve public health.
- Electric vehicles reduce GHGs if source of electricity is renewable or nuclear, convert about 59–62% of the electrical energy from the grid to the wheels. Conventional vehicles convert 17–21% of the energy stored in gasoline to power their wheels.

Energy Sector Faces Major Challenges from Climate Change

Without strong mitigation policies, the global average temperature is likely to rise above the internationally agreed 2°C target. As a major source of carbon emissions, the energy sector will be affected by mitigation policies as well as by climate impacts in multiple ways.

Global warming, changing regional weather patterns and extreme weather events will affect demand and impact energy production and transmission. Strong global policy action would also have major implications on investments.

Impacts and Adaptations

Power Stations

Thermal power plants will be affected by the decreasing efficiency of thermal conversion as a result of rising ambient temperatures. Reduced water for cooling and increasing water temperatures could lead to reduced power operations or temporary shutdowns.

Pipelines

Energy transport infrastructure is at risk, with oil and gas pipelines in coastal areas affected by rising sea levels and those in cold climes by thawing permafrost. May require new land zoning codes and risk-based design and construction standards and structural upgrades to infrastructure.

Power lines

Extreme weather events, especially strong wind, could damage power lines. Standards can be amended to implement appropriate adaptation measures, including re-routing lines away from high-risk areas.

Renewables

Changes in regional weather patterns threaten to impact the hydrologic cycle that underpins hydropower. An increase in cloudiness in some regions would affect solar technologies, while an increase in the number and severity of storms could damage equipment.

Nuclear

Lack of water and extreme weather events may threaten nuclear plants by disrupting the functioning of critical equipment and processes.

Emission Reduction Options

Carbon Capture & Storage

Adoption of carbon capture and storage (CCS) for fossil fuel plants can reduce emissions. CO_2 storage capacity is large and all parts of the technology have been demonstrated. CCS units burning bioenergy (BECCS) can draw CO_2 from the air. But barriers to CCS and BECCS remain, including cost.

Increasing Efficiency

Energy efficiency can be improved by retrofitting existing plants and adopting efficient new ones; improving transmission and distribution and through technology improvements in fossil fuel extraction and conversion.

Switching Fuels

Switching to lower-carbon fuels (eg from coal to gas) can reduce emissions. Moving from world-average efficiency coal plant to state-of-the-art gas can halve emissions if fugitive methane release is controlled, and can act as a 'bridging technology'.

Alternatives

Increasing use of renewables such as solar, wind and biofuels. Increasing use of nuclear power. Hydropower is currently the largest single RE contributor, but solar, wind and bioenergy are expected to experience the biggest incremental growth.

Reducing Demand

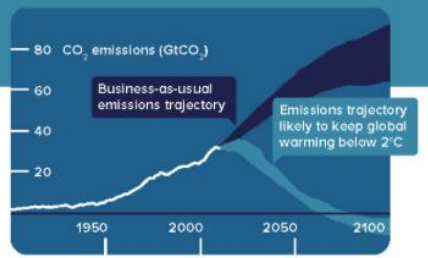
Reducing consumer demand is a key mitigation strategy. The level of demand reduction determines the size of the mitigation challenge facing the energy sector. Potential limitations from 'rebound effect' to be taken into consideration.

Policy Framework

Additional investments, which could be bolstered by fiscal measures and/or subsidies are required in the energy supply sector to keep the global temperature increase below 2°C.

Largest GHG Contributor

The energy sector is the largest source of greenhouse gas (GHG) emissions. Meeting the 2°C target implies swiftly halting the rise in emissions for the full energy system and bringing them to zero before the end of the century, with a likely need for 'negative emissions' technology such as BECCS.



Regulatory Frameworks

Governments may facilitate an increased use of emission reduction options by creating an attractive fiscal and regulatory framework.

Investment in Technology

New technologies can be used for efficiency improvements, power generation, extraction, storage, transmission and distribution.

Carbon Pricing

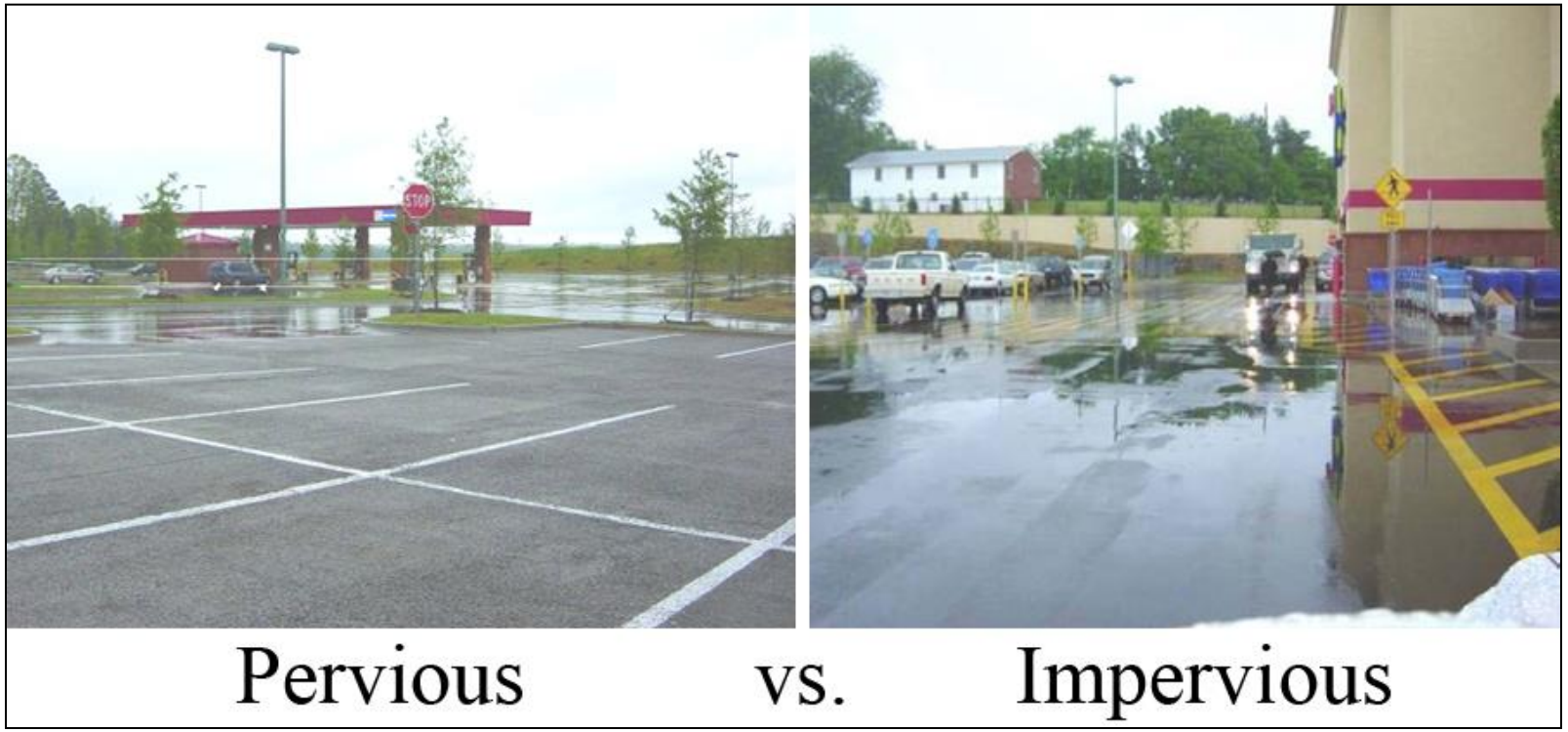
For government and regulators, a key challenge will be to ensure a price of carbon that incentivises extra investment in low-carbon technologies.

Adaptation Meets Mitigation

The role of building codes

Zoning is a key important regulatory tool which can:

- Ensure that more pervious surfaces are created, which reduces water inundation of roadways and submersion of key infrastructure
- Increase mixed land use to shorten vehicle trips, thereby reducing wear and tear on road surfaces
- Require landscaping, mature tree preservation, and open spaces to mitigate temperature extremes that may damage infrastructure networks



Adaptation Meets Mitigation

Maintenance, the Low-Hanging Fruit

Routine maintenance of energy and transportation infrastructure is one of the easiest and most cost-effective strategies for dealing with the impacts of a changing climate. Additionally, providing information and training to employees can be beneficial in this regard as well.

- Establish a schedule for reviewing ingress and egress patterns, and identify highest priority repairs needed to culverts, power lines, roadways and facilities
- Identify areas at highest risk for flood and weather hazards
- Install warning signs and, when possible, barriers
- Conduct emergency drills and ensure evacuation plans are up to date and personnel are trained in emergency response measures
- Revise plowing guidelines, add emergency routes and revise weight and speed limits for winter road, bridge and railway use

Presentation by municipal experts

David McLeod, Senior Environmental Specialist, Environment Office, City of Toronto

Vesna Stevanovic-Briatico, Transportation Coordinator, Transportation Service Division, City of Toronto

Thank you for joining us.

Please register on-line for our Next Webinar February 25th, 2015 Shorelines, Ports and Harbours

Case Study: Transportation

Ann Arbor, Michigan

Issues

- 24.7% of Ann Arbor's citizens use alternative transit modes to commute to work. This is higher than the national average (8%), but the City wished to do even better.
- Goal: discourage highway traffic, connect the City's existing bike paths, reduce traffic congestion and pollution, and encourage a healthier and more sustainable lifestyle among residents.

Adaptation Measure: Enhanced Bicycling Infrastructure

- Part of City's Climate Action Plan to incentivize residents to live within 2 miles of work
- City added over 4 lane miles of on-road bike lanes in 2012, bringing the total to over 71 lane miles.
- Offers ample bike parking, with 400+ bike hoops, 26 secured bike lockers and on-street bike parking racks, as well as fix-it stations
- Will begin offering bike sharing program, "ArborBike", in 2014

Bike lane, fix-it station and storage locker in Ann Arbor.

Case Study: Energy

Power Grid "Hardening" in New York State

Issues

Severe weather, geothermal disturbances, even terrorist threats make power grids vulnerable to disruption. In the wake of Hurricane Sandy and other extreme weather events, New York is embarking on an ambitious plan to "harden" – or make more resilient- their existing energy infrastructure. The state has suffered nine federally-declared disasters in the last three years.

Adaptation Measures:

- New York Governor Cuomo has allocated $1.37 billion to harden the state's energy grid and create 10 "microgrids" at the community level
- Part of the "Reimagining New York for a New Reality" master plan
- The plan includes replacing and repairing aging bridges, installing an advanced weather detection system, and creating a Statewide Strategic Fuel Reserve that will enable gasoline-powered backup energy generation in the event of outages
- New coastal surge protection infrastructure will be built
- Citizens will be trained to become part of a Citizen First Responder Corps

Resources to assist infrastructure planners

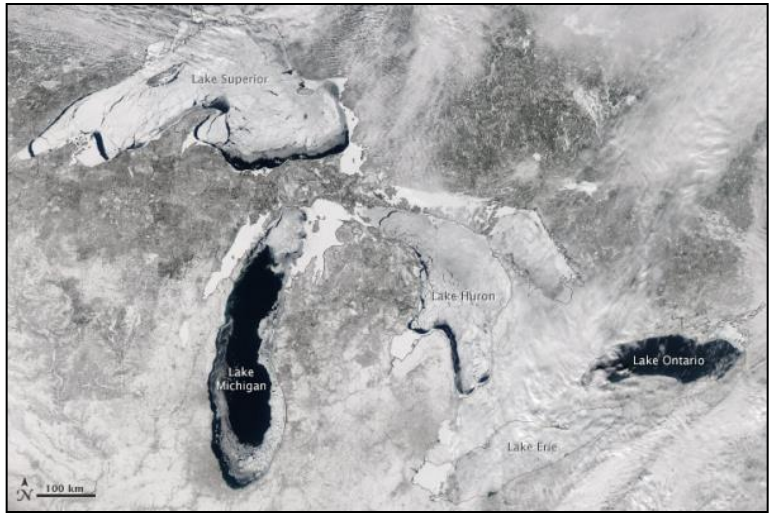
Reports

GLISA:

1. http://glisa.umich.edu/media/files/NCA/MTIT_Transportation.pdf
   a. Assesses current literature on potential impacts of climate change on transportation systems in the Midwestern region of the United States. Four sections follow:
   b. Synopsis of recent research on general transportation impacts
   c. Current climate projections for different parts of the Midwest, to assess levels of risk for transportation impacts from climate change
   d. Assessment of ongoing transportation adaptation measures
   e. Gaps in knowledge and research are discussed

2. Impacts discussed: Temperature and precipitation change, snow, water levels.

3. Ongoing efforts were highlighted, in areas including Chicago, Wisconsin, Iowa and Michigan



Reports

EPA United States Environmental Protection Agency

EPA: Climate Impacts on Energy

1. http://www.epa.gov/climatechange/impacts-adaptation/energy.html
2. Impacts discussed:
    1. Temperature, energy demand and energy supply
    2. Water availability and energy
    3. Sea level rise, storm surge and extreme events
    4. Wind speed, cloud cover and renewable energy
3. Climate changes will affect energy production, delivery, distribution and consumption in the US.
4. Problems like the cost of creating new infrastructure or updating old fixtures and facilities, as well as lesser known issues of competition, economic and population growth, and land use are addressed.
5. Useful links to many additional reports are provided.

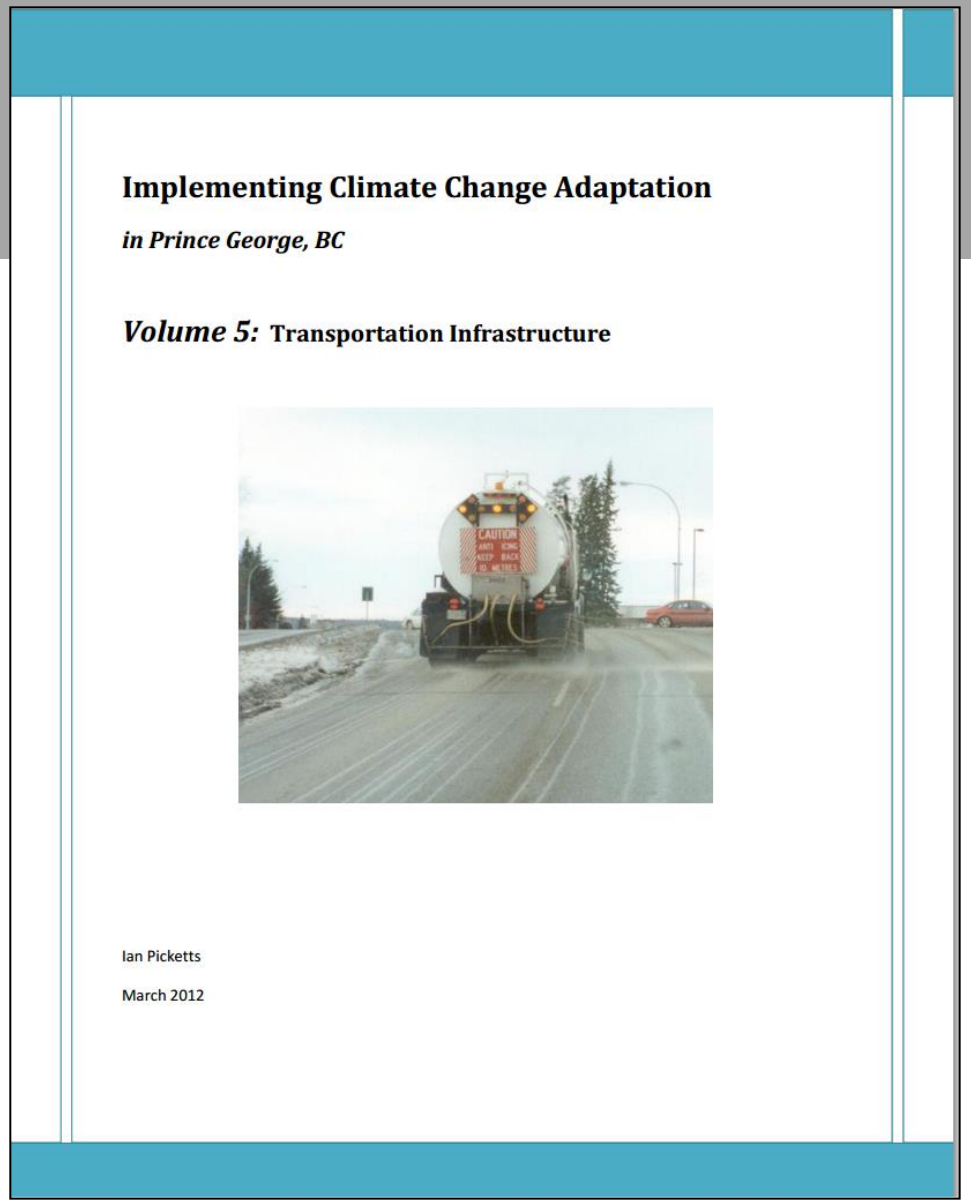
Reports

Municipal:

Implementing Climate Change Adaptation in Prince George, BC: Transportation Infrastructure

https://www.ccadaptation.ca/en/component/k2/item/2794-implementing-climate-change-adaptation-in-prince-george-bc-transportation-infrastructure

- Explores how Prince George is adapting its transportation infrastructure to climate change
  - Assesses climate change's impacts on road safety, conditions and vehicle crashes
  - City is considering using pervious paving to improve conditions



Reports

GLISA:

Freezing-Rain in the Great Lakes

http://glisaclimate.org/media/Freezing%20Rain%20in%20the%20Great%20Lakes%20(6.7.13)_0.pdf

a. A winter adaptation plan focused on Chicago
b. Highlights the significant impacts from freezing-rain (issue stems from Chicago's proximity to Lake Michigan)

Additional Reports

Improved Data and Tools for Integrated Land Use-Transportation Planning in California Project

http://ultrans.its.ucdavis.edu/projects/improved-data-and-tools-integrated-land-use-transportation-planning-california

Up-to-date California-specific data on built environment-travel relationships allows decision-makers to consider the effects of transportation infrastructure and land use investment choices

FHWA's Climate Change and Extreme Weather Vulnerability Assessment Framework

https://www.ccadaptation.ca/en/component/k2/item/2674-the-federal-highway-administrations-climate-change--extreme-weather-vulnerability-assessment-framework

Guide for transportation agencies interested in assessing their vulnerability to climate change and extreme weather events. Provides overview of key steps in conducting vulnerability assessments and uses examples to demonstrate a variety of ways to gather and process information. The framework is comprised of three key steps: defining study objectives and scope; assessing vulnerability; and incorporating results into decision making.

Supplemental Slides:

Green Infrastructure Tools (EPA)

Green Infrastructure Tools available from EPA

Source: http://water.epa.gov/infrastructure/greeninfrastructure/index.cfm#tabs-3

1. **Cost-Benefit Resources**
   Help conduct cost benefit analyses of green infrastructure approaches. Includes completed analyses which demonstrate that green infrastructure's benefits and overall benefits can be well worth the investment.

2. **Funding Opportunities**
   Green infrastructure serves many community purposes, and is thus eligible for an array of federal funding.

3. **Policy Guides**
   Offers policy and planning strategies to encourage / require green infrastructure.

4. **Design and Implementation Resources**
   Green infrastructure is most effective when the design is tailored to the context, when the installation follows the design, and when routine maintenance is performed.

5. **Modeling Tools**
   Modeling tools are available to help assess the performance, costs, and benefits of green infrastructure, on a range of scales.

6. **Federal Regulatory Programs**
   EPA encourages the use of green infrastructure in stormwater permits and Combined Sewer Overflow (CSO) enforcement agreements.

Supplemental Slides:

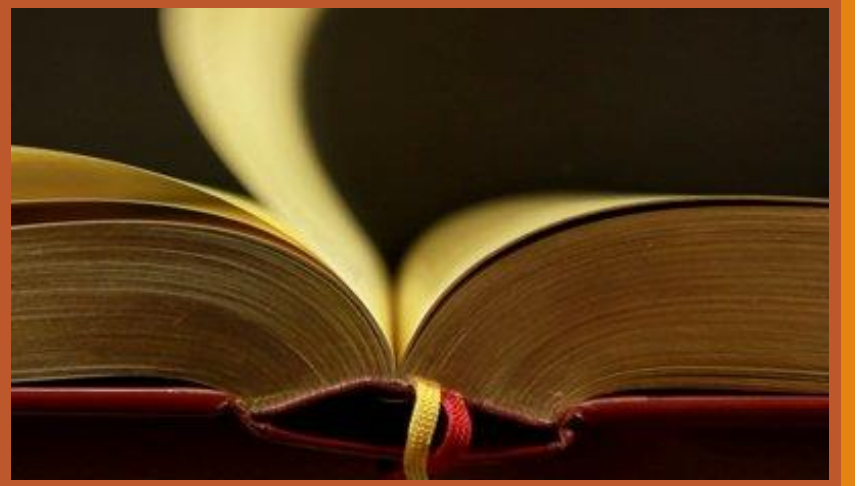
Green Infrastructure Tools – Valuation Tools Assessment

http://publications.naturalengland.org.uk/publication/6264318517575680

A report that highlights tools including:

- CAVAT: Capital Asset Value for Amenity Trees
- Green Infrastructure NorthWest‟s Green Infrastructure Valuation Toolkit
- Guide to valuing Green Infrastructure from the Centre for Neighborhood Technology Chicago
- Health Economic Assessment Tool for walking and cycling (HEAT);
- Helliwell
- i-Tree Design
- InVEST: Integrated Valuation of Environmental Services and Tradeoffs

Additional Resources



NOAA Factsheets:

•Civil Infrastructure:
http://www.ncdc.noaa.gov/sites/default/files/attachments/Civil%20Infrastructure_Low%20Rez.pdf

•Construction:

•http://www.ncdc.noaa.gov/sites/default/files/attachments/Construction_Low%20Res.pdf

•Transportation:

•http://www.ncdc.noaa.gov/sites/default/files/attachments/Transportation_Low%20Res.pdf

Other resources:

•NRC (2008). *The Potential Impacts of Climate Change on U.S. Transportation.* Research Board Special Report 290. National Research Council (NRC). http://onlinepubs.trb.org/onlinepubs/sr/sr290.pdf Contains an in-depth study of the impacts of climate change on land, marine, and air transportation in the United States. The report recommends that state and local governments, as well as private infrastructure providers, incorporate climate change into long-term improvement plans, design, and operations and maintenance activities. It also discusses the potential benefits of using "smart" technologies for monitoring infrastructure, re-evaluating infrastructure design standards, updating maps used for flood insurance, and integrating climate change into transportation and land use planning.

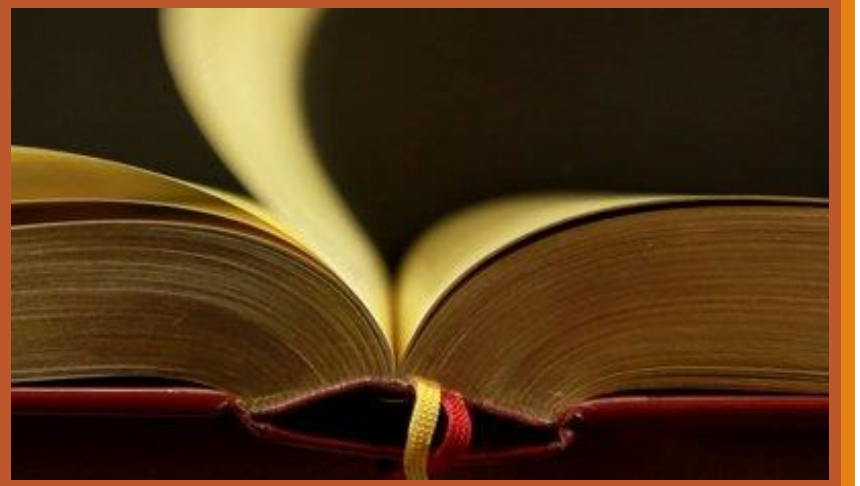
•FCM/ CSA Infrastructure Adaptation Training:

http://shop.csa.ca/en/canada/infrastructure-solutions/adapting-your-infrastructure-to-climate-change/invt/2703207wt/&bklist=icat,4,shop,training,infrastructuretrain

•IISD Literature Review on Climate Adaptation and Canadian Infrastructure:

http://www.iisd.org/publications/pub.aspx?pno=2854

Additional Resources



Other resources:

- City of Toronto Vulnerability Assessment Info & RFP for project

http://www.merx.com/English/SUPPLIER_Menu.asp?WCE=Show&TAB=1&PORTAL=MERX&State=7&id=183752&print=Y&src=osr&ForceLID=&HID=&hcode=psexcgqiP32jggDNO6ttqA%3D%3D

- Road Construction Standards in Kingston:

http://www.thestar.com/news/gta/transportation/2014/01/15/potholefree_roads_yes_its_possible_with_better_asphalt_says_queens_university_professor.html

http://www.chem.queensu.ca

http://www.cbc.ca/news/canada/ottawa/kingston-asphalt-program-takes-aim-at-potholes-1.2505845

- Case Study of PIEVC Road Infrastructure Assessment in City of Sudbury:

http://www.pievc.ca/e/doc_list.cfm?dsid=3

- LID road retrofits in Peel Region

http://www.creditvalleyca.ca/low-impact-development/showcasing-water-innovation-2/road-right-of-ways/

- Case study of Prince George

http://princegeorge.ca/environment/climatechange/adaptation/Documents/2012_PGRAC_Transport_volume%20with%20Exec%20Sum.pdf

- York Region De-Icing Strategies

http://www.cleanairpartnership.org/files/2%20Case%20Study.pdf