Protecting Our Water Environment

Metropolitan Water Reclamation District of Greater Chicago

Global Warming Initiative

R&D Seminar
July 25, 2008
Presentation Overview

- General Information, Definitions
- Paleoclimate
- IPCC Perspective
- NIPCC Perspective
- Energy Outlook
- Carbon Regulation (?)
- Global Warming Initiative
- Carbon/ Energy Footprint (2005 Actual)
- Strategy/Discussion
Acknowledgements

MWRDGC Global Warming Initiative
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Greenhouse Effect

- The Sun heats the Earth’s surface and atmosphere.
- Half of the Sun’s heat is filtered, absorbed, or removed by other mechanisms in the atmosphere.
- Some gases temporarily absorb infrared light of specific wavelengths.
- This re-radiated energy is absorbed by the earth and consequently heats the surface and surrounding air.
- This phenomenon is known as the greenhouse effect, and the gases responsible are known as greenhouse gases (GHGs).
Definitions

- **Global Warming**
  - *Increase in average temp of earth’s atmosphere*
  - *Generally used in context of human influence*

- **Climate Change**
  - *Significant change temp, precip, wind, > decade*
  - *Natural factors: sun’s intensity, earth’s orbit*
  - *Natural fluctuations in climate system (ie, ocean circulation)*
  - *Human activity that changes atmospheric composition*
“Now overwhelming scientific consensus that fossil fuels are causing serious climate change”

(Science, December 2004)

“The climate is changing at an unnerving pace. Glaciers are retreating, ice shelves are fracturing, sea level is rising, permafrost is melting....How can we not cover the biggest geography story of the century?”

(National Geographic, September 2004 issue, which devoted 74 pages to the signs of climate change)
"WE ARE ANTICIPATING ANOTHER 8-12 INCHES OF GLOBAL WARMING TODAY."
Paleoclimatology

- Study of past climates
- Multidiscipline inquiry: history, anthropology, archaeology, chemistry, physics, geology, atmospheric, ocean sciences
- Past climate: Proxy indicators
  - *Isotopic Geochemical Studies*: The study of rock isotopic ratios, ice core bubbles, deep sea sediments, etc.
  - *Dendochronology*: the study of tree rings
  - *Pollen Distribution*: the study of plant types and prevalence from pollen found in sediments, ice, rocks, etc.
  - *Lake Varves*: (like dendochronology, with lake sediments)
  - *Coral Bed Rings*
  - *Fossils*: Studies of geological settings, etc.
  - *Historical documents, paintings, evidence of civilizations, etc.*
Climate Change

- Changes in solar output
- Changes in Earth's orbit
- Changes in the distribution of continents
- Changes in the concentration of Greenhouse Gases in the atmosphere
Past Temperature Correlation with Atmospheric Methane and Carbon Dioxide
Paleoclimate – 5 Billion Years/15 Billion Year Universe

- First 500 million years: H₂, H₂O, CH₄
- 400 billion years ago: oceans formed
- 2.5 billion years ago: archaea and cyanobacteria
- 2.3 billion years ago: photosynthesis creates first oxygen in atmosphere
- 900 million years ago: increased photosynthesis (rock record)
- 600 million years ago: first marine organisms & ozone layer
- 400 million years ago: first land plants
- ~ 3.2 million years ago: Lucy (A. afarensis)
- ~ 250,000 homo sapiens
Milankovitch Cycles

- Serbian civil engineer/geophysicist
- Ice Ages ~ 100,000 year cycle
- Theory proposed in 1924
- Published in English 1942
- doubted in 1950’s
- Supported in 1970’s with deep ocean core samples
Ice Volume
Planktonic Foram O-18 as Proxy

More Ice

Less Ice
Paleoclimate Summary

- The Earth's climate has changed dramatically in the past, apparently in response to natural changes in orbital characteristics and topography (plate tectonics).
- We are able to deduce past climates through multiple techniques but much of the progress in resolving Cenozoic (recent) climate change has resulted from oxygen and carbon isotope records.
- A paleoclimate record has been developed using different techniques, stretching back over 2 billion years. The Earth was warmer than at present for most of this time, punctuated by infrequent Ice Ages.
- The Great Ice Ages may have been caused by processes associated with continental drift and greenhouse warming.
- The interglacial periods are related to orbital changes described by the Milankovitch cycles, among other factors.
Intergovernmental Panel on Climate Change

- Convened in 1988 by
  - United Nations Environmental Programme
  - World Meteorological Organization
- Advisory Role (no research/data review)
- First IPCC Assessment Report – 1990
- Rio de Janeiro Summit – 1992
- Second IPCC Assessment Report – 1995
- Kyoto Protocol – 1997
- Third IPCC Assessment Report – 2001
- Fourth IPCC Assessment Report - 2007
Climate change is unequivocal
Observed changes

- Global average temperature
- Global average sea level
- Northern hemisphere snow cover
Heat waves have become more frequent over most land areas

-Heat wave in Europe, 2003: 35,000 deaths

-IPCC, 2008
Intense tropical cyclone activity has increased in the North Atlantic since about 1970

- *Hurricane Ivan*: 2004
- *Hurricanes Katrina, Rita and Wilma*: 2005

IPCC, 2008
Indicators of the human influence on the atmosphere during the Industrial era

- Carbon Dioxide concentration
- Nitrous Oxide concentration
- Methane concentration
- Sulfate aerosols deposited in Greenland ice

Radiative forcing (Wm$^{-2}$)

$SO_2$ emissions from United States and Europe (Mt yr$^{-1}$)
Comparison between GDP and CO₂ emissions for selected countries

CO₂ emissions (thin line)
Mt C yr⁻¹

GDP (thick line)
Billions of 1990 U.S. dollars PPP*

*PPP: Power Purchase Parity

SYR - FIGURE 5-6
Continued emissions would lead to further warming of 1.8°C to 4°C over the 21st century and induce many changes that would be larger than those observed during the 20th century.
Expected impacts on North America

Warming in western **mountains** is projected to cause decreased snowpack and reduced summer flows, exacerbating competition for over-allocated water resources

Increased number, intensity and duration of **heatwaves** will have potential for adverse health impacts

**Coastal communities and habitats** will be increasingly stressed by climate change impacts interacting with development and pollution
The urgent need for mitigation of greenhouse gases
Available tools for business

Voluntary agreements and actions
- Help increase profitability or protect competitive position in the event of future regulatory mandates

Management tools
- GHG Inventory
- Management Systems
- Benchmarking

Technology development & transfer
- Clean Development Mechanism
- Joint Implementation
- Research & development
Carbon markets

Growing price of carbon on EU carbon market has encouraged businesses to consider new opportunities, driving Europe towards technological leadership.

There are clear signs that other countries, including the USA, will follow the EU’s lead in the coming years.

For stabilization at levels between 450 and 550 ppm CO$_2$-eq, global carbon prices of up to 100 US$/tCO$_2$-eq need to be reached by around 2030.
Trends in energy investments

Sustainable energy investment was $70.9 billion in 2006, an increase of 43% over 2005

- Wind sector attracted the most investment (38% of the total) followed by biofuels (26%) and solar (16%)

Global renewable energy capacity grew at rates of 15-30% annually for many technologies in 2002-2006

Demand for global energy service has grown by 50% since 1980 and is expected to grow another 50% by 2030

There is a powerful signal to the arrival of a profitable market for low-carbon products.
Non-governmental International Panel on Climate Change (NIPCC)

2008 International Conference on Climate Change
New York, New York

Reasons:
- Climate models: curve-fitting
- Agree that climate is warming
- Humans responsible for 3.5 % CO₂
- Solar radiation responsible for warming
- Anthropogenic argument: politically motivated alarmism
White Spruce 100 km north of current tree line - Radiocarbon Date 4940±170:
Courtesy of Professor Ritchie
CO₂ Mitigation is Not Needed

**Cap & Trade**: pointless, political, expensive

**Ethanol**: ineffective and wasteful; subsidized

**Wind, Solar**: marginally useful, with subsidies

**Carbon Capture**: not needed and very costly.

*Instead:*

Generate **Electric power** from secure and low-cost coal/nuclear: phase out natural gas and use as transportation fuel, feedstock, etc

S. Fred Singer, Ph.D.

*The NIPCC Report: Nature, not Human Activity, Rules the Climate*
Present-Day Composition

- 78% Nitrogen – dilutes oxygen, protein
- 21% Oxygen – respiration, combustion
- 0.9% Argon – light bulbs
- 0.3% Carbon Dioxide – plants respiration, planet warming
- 0 – 4 % Water Vapor – essential for life, also warms planet
- Trace gases - neon, helium, krypton, xenon
Energy Outlook

- Fossil Fuels are finite
- Combustion: particulate emissions
- Coal: mercury, SOx, NOx
- Air Pollution
  - Health Impacts
  - Quality of Life
- Transportation: Oil
- Unprecedented transfer of wealth
- Social/ political implications
Worldwide Energy Outlook

Oil
Proven Reserves (billion barrels):
   1,201 (BP Stat Rev.)  1,317 (Oil, Gas Jour.)
Consumption: 30,660 million barrels/year
   ~ 40 years (at current rate of consumption)

Natural Gas
Proven Reserves (trillion ft$^3$)
   6,183 (Energy Information Agency, DOE)
Consumption: 100 trillion ft$^3$, 2005
   ~ 60 years (at current rate of consumption)
Energy Use at MWRDGC

- Energy Used in Plant Operations
- Energy Generated at Plant Operations
- Energy Used to Manage Waterways
- Energy Generated by Hydropower
Energy Footprint at Water Reclamation Plants - 2005 Actual

MWh Equivalent/ Million Gallons

Water Reclamation Plant

Stickney North Side Calumet Kirie Egan Hanover Park Lemont

Biogas Natural Gas Electricity

No Solids Processing
Calumet WRP Operations Electricity Demand

Blowers ~ 45%
TARP ~ 25%
Lockport Powerhouse: Hydropower

- Located: Main Channel Extension Lockport, IL
- Built in 1907
- Outflow of the Sanitary and Ship Canal
- Limit the diversion of water from the Lake Michigan Watershed into the Des Plaines River.
- Generated 38,017 MWh in 2005 ($1.7 million)
SEPA  Sidestream Elevated Pool Aeration
Energy Balance in WRP Operations and Waterway Management - 2005
Actual

MWh Equivalent

Electricity for Operations
Gas Consumption
Stream Aeration
Hydropower
Gas Production
Gross
Net

35% Recovery!
U. S. Policy (2002)

- Voluntary, Incentive-Based
- Slow Growth of Emissions
- Strengthen Science, Technology, Institutions
- Enhance International Cooperation
- Reduce GGI by 18% from 2002 - 2012
  - $GGI = \frac{GGE}{\text{Economic Activity}}$
  - Project 100MMT Annual Reduction by 2012
World Energy/Capita Consumption by Region

Energy Consumption (thousand Btu/capita)

- **Year 1997**
- **Year 2020**

- **ind.**
- **U S**
- **EE/FSU**
- **Dev.**

Year 1997:
- ind.: 150
- U S: 350
- EE/FSU: 175
- Dev.: 25

Year 2020:
- ind.: 185
- U S: 375
- EE/FSU: 200
- Dev.: 50
Carbon Flux Indicated by Arrows: Natural Flux = \[\text{Vegetation and Soils 2,000}\]\[\text{Ocean 38,000}\]\[\text{Atmosphere 730}\]

Anthropogenic Flux = \[\text{Global Gross Primary Production and Respiration 119}\[\text{120}\]\[\text{Changing Land-Use 1.7}\]\[\text{Fossil Fuel Combustion and Industrial Processes 6.3}\]

Greenhouse Gases

- Water Vapor (9 - 26%)
- Carbon Dioxide (CO$_2$) (36 -70%)
- Methane (CH$_4$) (4 - 9%) {WRPs #6}
  - 21 times the heat-trapping potential CO$_2$
- Ozone (O$_3$) (3 - 7%)
- Nitrous Oxide (N$_2$O) {Human Sewage #4}
  - 300 time the heat-trapping potential CO$_2$
Greenhouse Gas Emissions

- 75% Energy Related (Mostly CO₂)
  - 50% Stationary Sources (Power Plants)
  - 30% Transportation
- Industry
- US Inventory: million metric tons CO₂ equivalents (MMT CO₂e)
- CO₂ concentration in the atmosphere:
  - ~8,000 B.C. - Industrial Revolution: 280 ppmv
  - 200 years: + 50 ppmv
  - 33 years (1973 - 2006): + 50ppmv
MWRDGC Global Warming Initiatives

- Form a Workgroup to Inform Policy
- Conduct literature review
  - *Greenhouse gas emissions from wastewater treatment*
  - *Potential corrective action*
- Verify Fugitive emissions at MWRDGC facility
  - *Workplan complete*
  - *Sampling scheduled for summer ‘08*
- Pursue corrective action
- Determine carbon footprint of operations
“Control, Reduction and Utilization of Greenhouse Gases in Wastewater Treatment”

- GHG: Methane (CH$_4$), Nitrous Oxide (N$_2$O)
- CH$_4$ : sixth largest atmospheric contribution
  - 21 times the heat-trapping capacity
  - Anaerobic processes: low oxygen pockets, concentration tanks
- N$_2$O : fourth largest atmospheric contribution
  - 300 times the heat-trapping capacity
  - nitrification, sludge thermal drying

Kozak, 2007
“Control, Reduction and Utilization of Greenhouse Gases in Wastewater Treatment” (Con’t)

- Control Methane:
  - Beneficial use
  - Flare
  - Remove from centrate

- Control Nitrous Oxide
  - Intermittent nitrous oxide, bacteria genera

Recommend: Measure fugitive emissions
\[ CH_4 = \left[ \sum_{i,j} (EF_j) \right] (TOW - S) - R \]

\( CH_4 \) = Total methane emissions from domestic wastewater (kg/year)

\( i \) = Income group (rural, urban high income, urban low income)

\( j \) = Each treatment/discharge pathway or system, i.e. AEROBIC AND ANAEROBIC TREATMENT

\( EF_j \) = Emission factor (kg \( CH_4 \)/kg BOD)

\( TOW \) = Total organics in wastewater in inventory year (kg BOD/ year)

\( S \) = Organic component removed as sludge in inventory year (kg BOD/yr)

\( R \) = Amount of \( CH_4 \) recovered in inventory year (kg \( CH_4 \)/yr)
Let $E F_j = B_0 \cdot M F_j$

$B_0$ = Maximum CH4 producing capacity (kg CH4 /kg BOD)
- $= 0.6 \text{ kg CH}_4 /\text{kg BOD (IPCC)}$
- $= 0.4 \text{ kg CH}_4 /\text{kg BOD (NACWA)}$

$M F_j$ = Methane correction factor
- $= 0.1 \text{ (Aerobic Treatment of Wastewater)}$
- $= 1.0 \text{ (Anaerobic Treatment of Sludge)}$

DISTRICT EMISSIONS (2000)

$C H_4 = 32.37 \times 10^6 \text{ kg CH}_4 \text{ (IPCC)}$
- $= 679.7 \times 10^6 \text{ CO}_2 \text{ equivalents (IPCC)}$

$C H_4 = 12.35 \times 10^6 \text{ kg CH}_4 \text{ (NACWA)}$
- $= 259.4 \times 10^6 \text{ CO}_2 \text{ equivalents (NACWA)}$
**N₂O Emissions (IPCC)**

\[ N₂O_{Plants} = P \cdot T_{Plant} \cdot F_{IND-COM} \cdot EF_{Plant} \]

- \( N₂O_{Plants} \): Total N₂O emissions from plants, kg N₂O/year
- \( P \): Population, persons
- \( T_{Plant} \): Degree of use of wastewater treatment plants per capita, unitless
- \( F_{IND-COM} \): Fraction of industrial and commercial co-discharged protein, unitless
- \( EF_{Plant} \): Emission factor, kg N₂O/person/year

\[ N₂O_{Effluent} = N_{Effluent} \cdot EF_{Effluent} \cdot \frac{44}{28} \]

- \( N₂O_{Effluent} \): Total N₂O emissions from effluents, kg N₂O/yr
- \( N_{Effluent} \): Nitrogen in the effluent discharged to aquatic environments, kg N/yr
- \( EF_{Effluent} \): Emission factor, kg N₂O-N/kg N
- 44/28: Conversion of kg N₂O-N to kg N₂O
$N_2O$ Emissions (IPCC)

$$F_{IND-COM} = 1.25 \text{ (IPCC)}$$
$$= 1.0 \text{ (NACWA)}$$

DISTRICT EMISSIONS (2000)

$N_2O = 49,353 \text{ kg } N_2O \text{ (IPCC)}$
$$= 14.81 \times 10^6 \text{ CO}_2 \text{ equivalents (IPCC)}$$

$N_2O = 45,120 \text{ kg } N_2O \text{ (NACWA)}$
$$= 13.54 \times 10^6 \text{ CO}_2 \text{ equivalents (NACWA)}$$
Measurement of Fugitive CH₄, N₂O

- Commence July 28, 2008
- Collaboration with UIC, Dept of Earth and Environmental Science
- Verify IPCC/ NACWA estimates
- Sample unit process operations
- Sample fence-line during atmospheric inversion (speculative)
- Phase I
## Carbon Footprint by Source (2005)

<table>
<thead>
<tr>
<th>Source</th>
<th>Tons CO₂</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Electricity</strong></td>
<td>520,419</td>
</tr>
<tr>
<td><strong>Gas (Purchase)</strong></td>
<td>9,276</td>
</tr>
<tr>
<td><strong>Biogas Generated</strong></td>
<td>33,180</td>
</tr>
<tr>
<td><strong>Fugitive Methane</strong></td>
<td>747,670 (IPCC)/ 285,340 (NACWA)</td>
</tr>
<tr>
<td><strong>Nitrous Oxide</strong></td>
<td>16,280 (IPCC)/ 14,894 (NACWA)</td>
</tr>
<tr>
<td><strong>Carbon Conversion</strong></td>
<td>118,867*</td>
</tr>
<tr>
<td><strong>(biogenic)</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Hydropower</strong></td>
<td>25,490</td>
</tr>
<tr>
<td><strong>Biogas Utilization</strong></td>
<td>26,957</td>
</tr>
<tr>
<td><strong>Net</strong></td>
<td>1,274,378 (IPCC)/ 810,662 (NACWA)</td>
</tr>
</tbody>
</table>
# CAWS Water Use by Energy Sector – 2005 Actual

<table>
<thead>
<tr>
<th>CAWS WW Flow (MG)</th>
<th>Treatment (MWh Eq)</th>
<th>Energy Sector</th>
<th>Water Use (MG)</th>
<th>Energy Produced MWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>406,047</td>
<td>567,924</td>
<td>Fisk Gen Plant</td>
<td>81,100</td>
<td>1,602,180</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Crawford Gen</td>
<td>183,700</td>
<td>3,201,844</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Citgo</td>
<td>1,933</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Premcor</td>
<td>66</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td><strong>266,799</strong></td>
<td><strong>4,804,024</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hydropower</td>
<td>518,950</td>
<td>38,017</td>
</tr>
</tbody>
</table>
Reasons for Optimism

- Tian, Granato, Cox, Pietz, Carlson, Abedin (2008)  
  “Carbon Sequestration of Biosolids: Extrapolating from Fulton County Case Study to Evaluate its Potential for the United States and Worldwide”

- 1974 – 2004: 1 million tons applied
- Amorphous Fe, Al stabilize C
- Increase soil microorganisms that utilize CO2
- Additional 80,000 tons C sequestered
- “missing C sink?” ~ 2.1%
Reasons for Optimism

Direct Electricity for Hydrogen Generation from Wastewater and other Waste Biomass Using Microbial Fuel Cell Technologies, Professor Bruce Logan, Penn State University

Solar-powered Hydrogen Production via Water Splitting with Simultaneous Water Treatment, Professor Michael Hoffmann, Cal Tech