Water Challenges - Past, Present, and Future

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Stanford University
Early 20th Century Problems

Pathogens

Oxygen Depletion

Industrial Wastes

Nutrients
Water Supply and Distribution

Listed by the National Academy of Engineering as among the Greatest Engineering Achievements of the 20th Century
50 Years Ago -

The arrival of new problems - bring a paradigm shift
Cuyahoga River, Cleveland, Ohio - 1952 - “Burn on, Big River, Burn on”

Photographer - James Thomas
San Francisco - 1971 Oil Spill

National Geographic magazine photographs
Aerobic - Activated Sludge Treatment

Toronto
San Jose
Chicago
Los Angeles County
ABS Synthetic Detergents – 1950s

Photographer - Bruce M. Wyckoff
Chanute, Kansas, 1956-57 Drought Zero flow in river, resulted in reuse of wastewater

Water Treatment Plant

Drinking Water

D. F. Metzler, et al., JAWWA, 1021(1958)
Whittier Narrows, CA
1962 Wastewater Reuse
SILENT SPRING

Rachel Carson

The author of THE SEA AROUND US and THE EDGE OF THE SEA questions our attempt to control the natural world about us.

1962
1965 - South Lake Tahoe
Advanced Wastewater Treatment
1968 - Direct Potable Reuse, Windhoek, Namibia
Orange County, California
1976 - Water Factory 21
Super Fund - 1980
Global Annual Production of Synthetic Organic Material (Source UNEP, 1987)
Emerging Chemicals of Concern

- Perchlorate (ClO$_4^-$)
- Nitrosodimethylamine (NDMA)
- 1,4-Dioxane
- Fire retardants
  - PBDE
  - Perfluoros
- Pharmaceuticals
- Endocrine disrupters
  - Fish Feminization
**Worldwide Problem**

- Over 1 billion people lack access to safe drinking water
- 2.4 billion lack access to adequate sanitation facilities
- In 1998, 2.2 million people estimated to have died of diarrheal diseases
- Millions suffer from parasitic worm infections
The New Paradigm Shift - CO₂ and Greenhouse Gases

The Keeling Curve

Dr. Charles D. Keeling was the first to measure carbon dioxide in the atmosphere on a continuous basis and was the first to report that global atmospheric concentrations of carbon dioxide were rising.

CO₂ (parts per million)

Long-term Trend

Monthly Mean

“Most of the observed increase in averaged temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations.”
“The combined radiative forcing due to increases in carbon dioxide, methane, and nitrous oxide... is very likely to have been unprecedented in more than 10,000 years”
IPCC 2007
Changes in Greenhouse Gases from Ice-Core and Modern Data

- Methane (ppb) vs. Time (before 2005)
- Carbon Dioxide (ppm) vs. Year
- Nitrous Oxide (ppb) vs. Time (before 2005)
IPCC, Climate Change 2007: The Physical Science Basis, Summary for Policymakers
“…Supreme Court ruled that carbon dioxide and other so-called greenhouse gases are air pollutants…”

Wall Street Journal, April 3, 2007
Global Carbon Cycle, GtCeq

[Diagram showing the carbon cycle with various fluxes and reservoirs including vegetation, oceans, atmosphere, and fossil fuel combustion.]

Carbon Flux Indicated by Arrows: Natural Flux = \( \rightarrow \) Anthropogenic Flux = \( \rightarrow \)

Source: Intergovernmental Panel on Climate Change, Climate Change 2001: The Scientific Basis (U.K., 2001)

http://www.eia.doe.gov/oiaf/1605/ggccebro/chapter1.html
Question

What is impact of wastes and waste treatment on greenhouse gas emissions?
# Global Warming Potential

\[ \text{CO}_2 = 1 \]

<table>
<thead>
<tr>
<th>Gas</th>
<th>GWP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon Dioxide ((\text{CO}_2))</td>
<td>1</td>
</tr>
<tr>
<td>Methane ((\text{CH}_4))</td>
<td>21</td>
</tr>
<tr>
<td>Nitrous Oxide ((\text{N}_2\text{O}))</td>
<td>310</td>
</tr>
</tbody>
</table>
Global Anthropogenic Greenhouse Gas Emissions

CO₂ 76%
CH₄ 15%
N₂O 8%
Other 1%

Anaerobic Pathways to Methane Formation

[Diagram showing the process of anaerobic digestion, starting with complex organics, leading to higher organic acids through hydrolysis and fermentation (Stage 1), then to acetic acid through acetogenesis and dehydrogenation (Stage 2), and finally to methane through methanogenesis (Stage 3).]

Anaerobic Digestion, Elsevier (1981)
Anaerobic Treatment
Anaerobic Treatment in China
2000 Non-CO₂ Emissions - % of Total CO₂eq

US EPA, Global Mitigation of Non-CO2 Greenhouse Gases, June 2006, EPA 430-06-005
2000 Waste $CH_4+N_2O$ Emissions - % of Total $CO_2eq$

US EPA, Global Mitigation of Non-CO2 Greenhouse Gases, June 2006, EPA 430-06-005
That’s not manure. That’s gold.

In our continuing search for clean, renewable energy, we’ve found ourselves in some unlikely places. Like your local dairy farm. We’re developing a program that takes manure from dairies and converts it into enough clean energy to power over 150,000 homes. And that’s just the start. Cow power – one more way to fight global warming.

Find out how cow power works at pge.com/wecandothis.
Water-Related Energy Consumption in California (2001)

### kWh/Million Gallons for Urban Water in California

<table>
<thead>
<tr>
<th>Service</th>
<th>North</th>
<th>South</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply &amp; Convey</td>
<td>150</td>
<td>8,900</td>
</tr>
<tr>
<td>Water Treatment</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Water Distribution</td>
<td>1,200</td>
<td>1,200</td>
</tr>
<tr>
<td>Wastewater Treat.</td>
<td>2,500</td>
<td>2,500</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>3,950</td>
<td>12,700</td>
</tr>
</tbody>
</table>

Rene Dubois

“Think globally, act locally”

Question

How can we reduce energy consumption and greenhouse emissions from wastewater treatment?
Palo Alto Wastewater Treatment Plant

- Primary settling
- Aerobic BOD removal
- Nitrification
- Sludge incineration
San Jose Wastewater Treatment Plant

- Primary settling
- Aerobic BOD removal
- Nitrification
- Sludge digestion
Drying Beds
Primary Tanks
Flotation
Digesters

CO₂ + CH₄
BOD Conversion to Algae

\[ 5O_2 \rightarrow 5CO_2 + 2H_2O + NH_3 \]

BOD to Particulate C$_5$H$_7$O$_2$N

Particulate C$_5$H$_7$O$_2$N to BOD

Soluble C$_5$H$_7$O$_2$N
Cogeneration at Sunnyvale Wastewater Treatment Plant
Gases Generated by Aerobic and Anaerobic Systems

Aerobic

- CO₂
- Power
- Air
- Wastewater

Anaerobic

- CO₂ + CH₄
- Wastewater
CO₂ & N₂O Release in Nitrification

NH₃ + 2O₂ + NaHCO₃ = NaNO₃ + 2H₂O + CO₂

Plus trace of N₂O
### CO₂ Equivalents (1000 kg/day)
#### Treatment of 10,000 kg BOD₅ /day

<table>
<thead>
<tr>
<th></th>
<th>Aerobic + Incineration</th>
<th>Aerobic + Digestion</th>
<th>Algae + Digestion</th>
</tr>
</thead>
<tbody>
<tr>
<td>BOD Removal</td>
<td>3.6</td>
<td>3.6</td>
<td></td>
</tr>
<tr>
<td>Incineration</td>
<td>20.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Digestion-CO₂</td>
<td></td>
<td>2.6</td>
<td>3.4</td>
</tr>
<tr>
<td>CH₄ Oxidation</td>
<td></td>
<td>5.4</td>
<td>6.8</td>
</tr>
<tr>
<td>CH₄ Loss (1%)</td>
<td></td>
<td>1.1</td>
<td>1.4</td>
</tr>
<tr>
<td>Nitrification</td>
<td>2.8</td>
<td>2.8</td>
<td>1.2</td>
</tr>
<tr>
<td>Energy Usage</td>
<td>2.2</td>
<td>(3.3)</td>
<td>(6.6)</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>29.0</strong></td>
<td><strong>12.2</strong></td>
<td><strong>6.2</strong></td>
</tr>
</tbody>
</table>
## Energy Costs - US$1000/year

*Treatment of 10,000 kg BOD$_5$ /day*

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<th>Aerobic + Digestion</th>
<th>Algae + Digestion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxygen Supply</td>
<td>178</td>
<td>178</td>
<td></td>
</tr>
<tr>
<td>CO$_2$ Penalty</td>
<td>58</td>
<td>24</td>
<td>12</td>
</tr>
<tr>
<td>Excess Power</td>
<td>(299)</td>
<td>(378)</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>236</td>
<td>(97)</td>
<td>(366)</td>
</tr>
</tbody>
</table>

CO$_2$ penalty = US$20/tonC
Water Reuse in Monterey County
Monterey Regional Water Pollution Control Agency

- Largest wastewater recycle in U.S. for irrigated crops
- Irrigates 12,000 acres
- 34.2 billion gallons produced since 1997
Water Reuse in Monterey County
Conclusions for Sustainability

• A reevaluation of waste treatment alternatives is needed because of climate change concerns
• Methane from wastes must be contained
• Desired alternatives are those that reduce both greenhouse gas emissions and power consumption
• Anaerobic treatment is likely to be an attractive component of the alternatives
• Wastewater is a resource for water, energy, and plant nutrients
Rene Dubois

"Trend is not destiny"
Ancient Chinese Proverb

"Unless we change our direction, we are likely to end up where we are headed"
Thank you!