Climate Change – A Primer on Energy and the Environment

Or: See you real soon, I’m off to the Thirty Years War

Terry Surles
Hawaii Natural Energy Institute
November 14, 2007
“Everyone is not entitled to an opinion. If they lack knowledge, they do not deserve to have an opinion.”

Sir Winston Churchill
“Everybody wants to get into da act!”
Main Points

• Overview of greenhouse gas (GHG) effect - the basic science
• Output from the April, 2007 IPCC (Intergovernmental Panel on Climate Change) Report
• Options are available to manage the GHG problem
  – Both technical and institutional opportunities
  – There is no silver bullet and none of them will be easy
• We need to begin to address this problem seriously now
  – Hawaii has the potential to be a leader!!
Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global mean sea level.
Solving the Problem Ain’t Cheap or Easy

• Projections of economic benefits as a result of new laws (California models) based on wishful thinking – “Magic happens!”
  – Innovation can also come from other places
• Changes in consumer habits and spending necessary, but not sufficient
• “Miracle” of new technologies in telecommunications and computation is not transferable to energy and environmental technologies
  – These tech areas can, however, help to drive solutions
Some History

1800s to 2005
The Greenhouse Effect Was Quantified in 1861

“The solar heat possesses... the power of crossing an atmosphere; but, when the heat is absorbed by the planet, it is so changed in quality that the rays emanating from the planet cannot get ... back into space. Thus the atmosphere admits of the entrance of the solar heat, but checks its exit; and the result is a tendency to accumulate heat at the surface of the planet.”

John Tyndall
The Earth is a Greenhouse Planet

Mars
- 63°C

Earth (0.03% CO₂)
15°C

Venus (96% CO₂)
452°C

Average Surface Temperatures

The combination of solar irradiance and greenhouse effect determines the mean surface temperatures of Mars, Earth and Venus. In the absence of the natural greenhouse effect, the average surface temperature of Earth would be -19°C.

Source: C.T. Bowman, Mechanical Engineering, Stanford
Earliest Predictions of Global Warming Due to Burning of Fossil Fuels Were in 1800s

• Hogboom calculated emissions from anthropogenic sources and said that human activity was adding as much CO$_2$ to the atmosphere as natural processes

• Svante Arrhenius - Gradual accumulation over centuries could double atmospheric CO$_2$ concentrations

• Additional concerns in the 1930s (Callendar) and 1950s (Roger Revelle)
Charles David Keeling
CO₂, CH₄ and N₂O Concentrations
- far exceed pre-industrial values
- increased markedly since 1750 due to human activities

Relatively little variation before the industrial era
Water vapor is a GHG
Various Modeling Results for Historical Temperatures: The Infamous Inhofe/Barton/Crichton “Hockey Stick”

- Mann et al, 1999, reconstruction (annual mean, full hemisphere)
- Mann et al, 1999, reconstruction (annual mean, 30N-70N latitude band)
- Jones et al, 1998, reconstruction (summer, extratropical emphasis)
- Briffa, 2000, reconstruction (tree-ring density only, summer, extratropical)
- Instrumental data (annual mean, full hemisphere)
The Latest

- IPCC Report Issued April 2007
Drivers of Climate Change: It’s Getting Worse

• Annual fossil CO$_2$ emissions increased from an average of 6.4 GtC per year in the 1990s, to 7.2 GtC per year in 2000-2005
• CO$_2$ radiative forcing increased by 20% from 1995 to 2005, the largest in any decade in at least the last 200 years (since the start of the Industrial Era)
Global mean temperatures are rising faster with time.

Mainly decrease in rain over land in tropics and subtropics, but enhanced by increased atmospheric demand with warming.
Continued CO$_2$ emission will lead to warmer sea-surface temperatures

Warmer sea-surface temperatures have been associated with increase hurricane intensity.
Observed widespread warming

- extremely unlikely without external forcing
- very unlikely due to known natural causes alone
Attribution

- are observed changes consistent with
  ✓ expected responses to forcings
  ✗ inconsistent with alternative explanations
Global-average radiative forcing estimates and ranges

Radiative Forcing Components

<table>
<thead>
<tr>
<th>RF Terms</th>
<th>RF values (W m⁻²)</th>
<th>Spatial scale</th>
<th>LOSU</th>
</tr>
</thead>
<tbody>
<tr>
<td>Long-lived greenhouse gases</td>
<td>1.66 [1.49 to 1.83]</td>
<td>Global</td>
<td>High</td>
</tr>
<tr>
<td>N₂O</td>
<td>0.48 [0.43 to 0.53]</td>
<td>Global</td>
<td>High</td>
</tr>
<tr>
<td>CH₄</td>
<td>0.16 [0.14 to 0.18]</td>
<td>Global</td>
<td>High</td>
</tr>
<tr>
<td>Halocarbons</td>
<td>0.34 [0.31 to 0.37]</td>
<td>Global</td>
<td>High</td>
</tr>
<tr>
<td>Stratospheric ozone</td>
<td>-0.05 [-0.15 to 0.05]</td>
<td>Continental to global</td>
<td>Med</td>
</tr>
<tr>
<td>Tropospheric ozone</td>
<td>0.35 [0.25 to 0.65]</td>
<td>Global</td>
<td>Med</td>
</tr>
<tr>
<td>Stratospheric water vapour from CH₄</td>
<td>0.07 [0.02 to 0.12]</td>
<td>Global</td>
<td>Low</td>
</tr>
<tr>
<td>Surface albedo</td>
<td>-0.2 [-0.4 to 0.0]</td>
<td>Local to continental</td>
<td>Med</td>
</tr>
<tr>
<td>Black carbon on snow</td>
<td>0.1 [0.0 to 0.2]</td>
<td>Continental to continental</td>
<td>Med - Low</td>
</tr>
<tr>
<td>Total Aerosol</td>
<td>-0.5 [-0.9 to -0.1]</td>
<td>Continental to global</td>
<td>Med - Low</td>
</tr>
<tr>
<td>Direct effect</td>
<td>-0.7 [-1.8 to -0.3]</td>
<td>Continental to global</td>
<td>Low</td>
</tr>
<tr>
<td>Cloud albedo effect</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Linear contrails</td>
<td>0.01 [0.003 to 0.03]</td>
<td>Continental to global</td>
<td>Low</td>
</tr>
<tr>
<td>Solar irradiance</td>
<td>0.12 [0.06 to 0.30]</td>
<td>Global</td>
<td>Low</td>
</tr>
<tr>
<td>Total net anthropogenic</td>
<td>1.6 [0.6 to 2.4]</td>
<td></td>
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</tr>
</tbody>
</table>
Projections of Future Changes in Climate

1.8°C (likely range is 1.1°C to 2.9°C), and for high scenario (A1FI) is 4.0°C (likely range is 2.4°C to 6.4°C).
PROJECTIONS OF FUTURE CHANGES IN CLIMATE

• *Very likely* that hot extremes, heat waves, and heavy precipitation events will continue to become more frequent
  – Increased probability for droughts in tropics and sub-tropics

• *Likely* that future tropical cyclones (when formed) will become more intense, with larger peak wind speeds and heavier precipitation

• Heating will be more pronounced in the higher latitudes
  – Leads to release of methane from permafrost melting
  – One of the “positive” feedbacks due to global warming which worsens our situation
Paleoclimate information supports the interpretation that the warmth of the last half century is unusual in at least the previous 1300 years. The last time the polar regions were significantly warmer than present for an extended period (about 125,000 years ago), reductions in polar ice volume led to 4 to 6 meters of sea level rise.

Note that IPCC projects one meter sea level rise. BUT, melting of Greenland Ice Sheet can produce the higher levels.
Technology and Policy Instruments - Solutions

Technology options
Recent policies in other states and countries
Technology is a Key: Significant Advances Needed to Achieve the Base Case

To stabilize at 550 ppm, Carbon/$GDP must be <10% of today’s by 2100

Where today’s technology will take us

- 75% of electricity non-fossil
- End-use efficiency increases 1%/yr by 2050
- Electric generation 67% efficient
- Passenger vehicles average 50 mpg

Where more advanced versions of current technologies will take us

Path we need to be on to stabilize atmospheric CO$_2$
Portfolio of Options Available Today or in Near Future: No “Silver Bullet”

From Pacala and Socolow, *Science*, 2004
Worldwide PV Production 1990-2006

Rest of the World
Europe
Japan
United States

India
Taiwan
China

Total MW Production

Year
46.5 55.4 57.9 60.1 69.6 77.6 88.6 125.8 154.9 201.3 276.8 386.0 547.0 748.4 1193.5 1387.0 1540.0 2016.0 2521.4
Hawaii - Flat Plated Tilted at Latitude Solar Resource

The annual solar resource estimates shown are for a 1-axis tracking flat plate collector. It is a 8-year average (1998-2005) with 10 km resolution, produced by Richard Perez (SUNY) and adjusted by NREL.

Solar Resource kWh/m²/day
- > 9.0
- 8.5 - 9.0
- 8.0 - 8.5
- 7.5 - 8.0
- 7.0 - 7.5
- 6.5 - 7.0
- 6.0 - 6.5
- 5.5 - 6.0
- 5.0 - 5.5
- 4.5 - 5.0
- 4.0 - 4.5
- 3.5 - 4.0
- 3.0 - 3.5
- 2.5 - 3.0
- 2.0 - 2.5
- < 2.0

U.S. Department of Energy National Renewable Energy Laboratory
Geothermal Energy Increasingly Competitive

1980: 10-16 cents/kWh

2007: 5-8 cents/kWh

- Improved technology
- Reduced drilling costs
- Expanding resource base

2011 Goal: Less than 5 cents/kWh

Additional opportunities on the Big Island and Maui
Biomass Energy

Wood chips
Switch grass
Poplars
Fats and Oils
Municipal solid waste
Corn Stover

Hawaii Natural Energy Institute
School of Ocean and Earth Science and Technology
University of Hawaii at Manoa
Well-to-Wheels Analysis – Biofuel

Solar Energy

CO₂ - FIBREVehicle

Photosynthesis
Converts CO₂ to Fibre

Harvesting

Bio-Energy Facility
Converts Fibre to Ethanol, Electricity & CO₂

Bio-Energy Refining

Distribution

Cars Burn Ethanol to Release CO₂, Which is Recycled

Use as Fuel

CO₂
Wave Technology Examples

Oscillating Water Column; Energetech;

Point Absorbers

Aquabuoy

Attenuator; OPD Pelamis

OPT PowerBuoy

Overtopping; Wave Dragon
Ocean Tidal & Current Technology

Verdant; Horizontal Axis; East River, NY

Gorlov Helical Vertical Axis; Merrimack River,

Hydro; Open Center Turbine; Gulf Stream

Lunar Energy, Rotech Tidal Turbine

Underwater Electric Kite; Merrimack River,

MCT SeaFlow Experimental Test
## Ocean Energy: Demonstrations at Best, Uncertainty with O&M Issues

<table>
<thead>
<tr>
<th>Ocean energy type</th>
<th>Technology types</th>
<th>Estimated global resource</th>
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<tbody>
<tr>
<td>Ocean wave</td>
<td>Attenuator, Collector, Overtopping, OWC, OWSC, Point absorber, Submerged pressure differential, Terminator, Rotor</td>
<td>8 000-80 000 TWh/year</td>
</tr>
<tr>
<td>Tidal current</td>
<td>Horizontal/Vertical-axis turbine, Oscillating hydrofoil, Venturi</td>
<td>800+ TWh/year</td>
</tr>
<tr>
<td>Salinity gradient</td>
<td>Semi-permeable osmotic membrane</td>
<td>2 000 TWh/year</td>
</tr>
<tr>
<td>OTEC</td>
<td>Thermo-dynamic ranking cycle</td>
<td>10 000 TWh/year</td>
</tr>
</tbody>
</table>

- 81 wave, tidal, OTEC, and salinity devices in development worldwide
- 2x industry growth from 2003 to 2006
- Only 14 full scale devices deployed at sea.
- Only 3 in the USA
Growth of Wind Energy Capacity Worldwide

Jan 2007 Cumulative MW = 71,476
Rest of World = 11,043
North America = 13,054
U.S. – 11,603MW
Canada – 1,451MW
Europe = 47,379

Sources: BTM Consult Aps, March 2005
Windpower Monthly, January 2007
*NREL Estimate for 2007
GE WindEnergy
3.6 MW Turbine

Arklow Banks Windfarm
The Irish Sea

Photo: R. Thresher
The annual wind power estimates for this map were produced by TrueWind Solutions using their Mesomap system and historical weather data. It has been validated with available surface data by NREL and wind energy meteorological consultants.
Renewable (Particularly Wind) and Other Distributed Energy Systems Stress the Grid

Systems RD&D Required
- Technical Standards and Testing
- Power Conversion and Conditioning
- Protection and Load Control
- Communications
- Metering
- Training and Education
- Modeling and Simulation

Communication RD&D – Information Flow, Data Management, Monitor/Control

Substation
2.0 Performance Analysis (PSLF)
One-hour Validation on April 3, 2007

Frequency

Wind Farm Output
Power (disturbance)

Following slide
Energy Storage Technologies for Varied Applications Must be Commercialized
What is Possible for Renewable Electricity

Renewable Energy Expected From State Standards

Total Estimated Solar Capacity Driven by State RPS Set-Asides (assuming full compliance with mandates)

2010: 400 MW to 500 MW
2015: 1,200 MW to 1,400 MW
2020: 2,800 MW to 3,200 MW
2030: 3,700 MW to 4,300 MW

Western Governor’s Association 2015 Goal

Clean Energy – 30,000 MW

- Solar – 8,000 MW
- Wind – 5,000 to 9,000 MW
- Geothermal – 5,600 MW
- Energy Efficiency – 40,000 MW
Energy Efficiency: Annual Rate of Change in Energy/GDP for US Already Approximates the Administration’s “Voluntary” Program

International Energy Agency (IEA) and EIA (Energy Information Agency)

IEA data
EIA data

Average = -0.7%

- 3.4%

- 2.7%

Electricity Generating Capacity Savings for 150 Million Refrigerators + Freezers in the US: 40 GW Equal to 80 500MW Coal-Fired Power Plants
Zero Energy Homes Design Leads to Reduced Peak Demand

- Average 2003 New Home
- "ZEH" Demand – July average
- PV Prod. SW-facing (Nominal 2 kW)
- "ZEH" Net Demand – July average
Sequestration: Continued Coal Use While Addressing Climate Change

- Two major challenges for economically viable, environmentally acceptable CCS
  - Lower cost capture
  - Reduced uncertainty of storage permanence, safety, etc.
- Need resolve both to gain acceptance → keep coal as option
- Regional Carbon Sequestration Partnership program
  - Focus on saline aquifers, EOR
  - Basalt formations as R&D activity
Sleipner Project, North Sea

- 1996 to present
- 1 Mt CO$_2$ injection/yr
- Seismic monitoring

Picture compliments of *Statoil and LBNL*
Weyburn CO$_2$-EOR and Storage Project

- 2000 to present
- 2.7 Mt/year CO$_2$ injection
- CO$_2$ from the Dakota Gasification Plant in the U.S.

Photo’s and map courtesy of PTRC, Encana, and LBNL
Nuclear Should Remain an Option
BUT

- **Cost**
- **Waste disposal**
- **Health and safety**
- **Proliferation**
Looking Forward: Integration of Transportation and Electricity

• Plug-In Hybrid Electric Vehicles: Integration of transportation and electricity sectors can provide solutions
A Number of Policy Activities Are Underway to Address the Problem

• Kyoto Protocol - now in effect
  – European Union response to Kyoto
  – Can we learn from Montreal Protocol?

• RGGI – Northeastern US states
  – Good news: nine states and institutions coming together in a bi-partisan fashion, offsets in place (SF6, landfill gas, end use efficiency, methane from animal waste, etc.)
  – Bad news: very real concerns about “leakage,” only one sector (electricity) is planned for regulation

• AB 32 (California)
  – Good news: bi-partisan approach to address the problem
  – Bad news: little prior knowledge of how to link aggressive public policies to technological realities
Carbon “Markets” - Need Source/Sink Baselines

- **Allowance markets** – “Cap and trade” programs that allocate GHG emissions that can be traded to achieve compliance goals.
  - EU Emissions Trading Scheme (EU-ETS)
  - Worked effectively for sulfur dioxide and nitrogen oxides in the USA
- **Credit markets** – “Baseline and credit” schemes in which GHG “offsets” or “credits” are awarded for GHG abatement projects that reduce emissions against a project baseline and are traded and used for compliance purposes.
  - Kyoto Protocol’s Clean Development Mechanism (CDM) and Joint Implementation (JI) program
  - Chicago Climate Exchange (CCX) and other voluntary schemes (RECs)
- **Carbon Tax** - can government create level playing field
  - Must be “fair” to all economic sectors - utilities, transportation, etc.
  - Must be societally “fair” - carbon taxes will tend to be regressive taxes
Government is a Critical Part of the Equation

- Financial instruments must be available to overcome “Valley of Death”
- Laws should promote the insertion of new, environmentally-acceptable technology
- Should be in the lead for public education and information dissemination
- Must link public policies with technology development and scientific findings
Hawaii Can Be a Leader: Sustainability
Hawaii Can Be a Leader - Sustainability

Identify technology solutions that, with economic viability, reduce the inputs & outputs to the state control volume.
HNEI Links R&D and Public Policy to Commercialization Process

- **Basic Research & Development**
- **Collaborative Technology Development Integration Application**
- **Technology Commercialization**

- **Institutional Issues Regulations Incentives**
- **National Laboratories Universities**
- **Industry R&D**
- **Suppliers Vendors End Users**
- **Government**
Driving to a Sustainable Future: Hawaii Can Be a Leader

- Environment
- Energy
- Economics
- Equity
- Education
Warming Won’t Wait. Will We?

Since 1979, more than 20% of the Polar Ice Cap has melted away.