Green Electronics

1. Anthropogenic Global Warming
Power/Energy Use [Joule/year, W]

- Total human energy use: \(0.5 \times 10^{21} \text{ J/y} = 500 \text{ EJ/y} = 15\text{TW}\)
- Total human electricity use: \(0.1 \times 10^{21} \text{ J/y} = 100 \text{ EJ/y} = 3\text{TW}\)

Unit of Energy:
1 Watt-hour (Wh) = 3600 J
## Current Primary Energy Sources

<table>
<thead>
<tr>
<th>Fuel (2016)</th>
<th>Energy Use %</th>
<th>Electricity Use %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil</td>
<td>30</td>
<td>5</td>
</tr>
<tr>
<td>Coal</td>
<td>30</td>
<td>40</td>
</tr>
<tr>
<td>Gas</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Wood &amp; Biomass</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>Uranium 235</td>
<td>5.0</td>
<td>15</td>
</tr>
<tr>
<td>Hydropower</td>
<td>2.5</td>
<td>15</td>
</tr>
<tr>
<td>Renewables</td>
<td>2.5</td>
<td>5</td>
</tr>
</tbody>
</table>

---

![Global Primary Energy Consumption 1830 - 2010](http://www.theoildrum.com)

Business insider
Fossil Fuels

\[ C + O_2 \rightarrow CO_2 \]  
\[ 4H + O_2 \rightarrow 2H_2O \]

- 33MJ/kg
- 140MJ/kg

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Weight % C</th>
<th>Weight % H</th>
<th>CO(_2)/J [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal (Anthracite)</td>
<td>100</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>Petrol, Diesel</td>
<td>87</td>
<td>13</td>
<td>61</td>
</tr>
<tr>
<td>Propane(C8H18)</td>
<td>84</td>
<td>16</td>
<td>55</td>
</tr>
<tr>
<td>Methane (CH4)</td>
<td>75</td>
<td>25</td>
<td>41</td>
</tr>
<tr>
<td>Hydrogen Gas</td>
<td>0</td>
<td>100</td>
<td>0</td>
</tr>
</tbody>
</table>
Anthropogenic Global Warming (AGW)

- Greenhouse effect
  - Black Body radiation
  - Temperature of Planets
  - Role of Atmosphere
    - N₂
    - H₂O
    - CO₂
- Evidence of anthropogenic global warming
  - CO₂ emission
  - Temperature increase
  - Feedback
Black Body Radiation (Sun)

- The radiation [W/m²] a body sends out is solely determined by its temperature
  - Energy is distributed over wavelength spectrum according to defined formula
    - Planck’s law
  - Total energy is integral over wavelength spectrum
    - Stefan-Boltzmann law
  - Peak wavelength is when derivative is zero

\[
I(\lambda, T) = \frac{2hc^2}{\lambda^5} \frac{1}{e^{hc/\lambda k_B T} - 1}
\]

\[
I(T) = \sigma T^4 \quad \sigma = 5.67 \times 10^{-8} \text{ Wm}^{-2} \text{K}^{-4}
\]

\[
\lambda(\text{peak, mm}) = \frac{2.90}{T} \quad \lambda(\text{sun}) = 483 \text{nm}
\]
Black Body Equilibrium Temperature

- Equilibrium between incoming solar radiation and outgoing earth radiation
- Incoming Energy in Visible/UV, Outgoing Energy in Infra-Red
- Planet heats up until equilibrium is achieved
Equilibrium temperature of planets

\[ I_{\text{sun}}(T) = \sigma T_{\text{sun}}^4 x 4\pi R_{\text{sun}}^2 = \frac{3.85 \times 10^{26}}{W} \]

\[ \Phi_{\text{in}} = \Phi_{\text{out}} \]

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Venus</td>
<td>0.72</td>
<td>2.64</td>
<td>328</td>
<td>0.75</td>
<td>232</td>
<td>730</td>
<td>498</td>
<td>116</td>
<td></td>
</tr>
<tr>
<td>Earth</td>
<td>1.00</td>
<td>1.37</td>
<td>279</td>
<td>0.30</td>
<td>255</td>
<td>287</td>
<td>32</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>Mars</td>
<td>1.52</td>
<td>0.59</td>
<td>226</td>
<td>0.16</td>
<td>216</td>
<td>218</td>
<td>2</td>
<td>1.01</td>
<td></td>
</tr>
<tr>
<td>Mercury</td>
<td>0.40</td>
<td>8.56</td>
<td>441</td>
<td>0.12</td>
<td>427</td>
<td>100/700</td>
<td>n/a</td>
<td>58.6</td>
<td></td>
</tr>
</tbody>
</table>

\[ a.u. = 1.5 \times 10^{11} m \]

- Albedo: direct reflection of sunlight (not absorbed); if black body albedo=0
Absorption by Atmospheric Gasses

- Vibrational modes exist in all molecules
- If these modes change the dipole moment of the molecule they can absorb radiation in the infra-red
- Linear di-atomic molecule (N₂, O₂): stretching: not Infra-red (IR) active

- Linear tri-atomic molecules CO₂:
  - Symmetric stretch
  - Asymmetric stretch
  - Bend

- Non-linear tri-atomic molecule (H₂O)
  - Symmetric stretch
  - Asymmetric stretch
  - Bend

- Water, Carbon Dioxide in atmosphere absorb radiation and re-transmit in random direction
Green House Effect

- Atmospheric gasses absorb and reflect some of the outgoing energy
- Earth temperature rises to compensate:
  - Equilibrium temperature at outer atmosphere: 255K
  - Equilibrium temperature at Earth surface: 287K
- Dry air: Nitrogen (79%), Oxygen (21%), and Argon (1%) do not absorb much of the spectrum
- Water Vapour (H$_2$O) (0-4%) mostly responsible for current greenhouse effect
  - Near full absorption in spectrum so does not matter if we add a little bit more more
  - But feedback as max concentration depends on temperature (see later)
- Carbon Dioxide (CO$_2$) adds further absorption
  - Creates new and higher equilibrium temperature
    - which might lead to some nasty side effects…….

- Earth IR radiation between 2-30 µm

Nasa: relative absorption of green house gasses in Infra-Red
Radiative Forcing

- Power of Radiation \([W/m^2]\) not escaping earth due to absorption by greenhouse gasses.

- If radiation already absorbed at that wavelength there is less additional forcing; depends on:
  - Position of vibrational levels
  - Amount of the greenhouse gas in the air
  - Amount of other greenhouse gasses at same wavelength
  - Details of the vibrational modes (shape around wavelength)

- Different formula for each greenhouse gas
  - Calculation for \(\text{CO}_2\) between 100 and 1000ppm

\[
\Delta F_{\text{CO}_2}[W/m^2] = 6 \ln \left( \frac{C_{\text{new}}}{C_{\text{old}}} \right)
\]

\[
\Delta F / dC (at 400 \text{ ppm}) = 0.015W/m^2 . \text{ ppm}
\]

\[
\Delta F / dC (doubling) = 4.2W/m^2
\]
CO₂ emission

\[ C + O₂ → CO₂ \]

- Total human energy use: \( 0.5 \times 10^{21} \text{ J/y} = 500 \text{EJ/y} = 15 \text{TW} \)
- Energy originating from Carbon: 50%
- Total human CO₂ emission: \( 3 \times 10^{13} \text{kg} \)
- Weight of the atmosphere: \( 5 \times 10^{18} \text{kg} \)
- CO₂ emission to the atmosphere: 6ppm (mass) = 4ppm (volume)
**CO₂ emission**

- CO₂ emission to the atmosphere: 6ppm (mass) = 4ppm (volume/mol)
- Absorption by the oceans: 50%
- CO₂ increase of the atmosphere: 2ppm (volume)

[Image of atmospheric CO₂ at Mauna Loa Observatory]

[Graph showing CO₂ levels over the last 10,000 years]

DOI: 10.1029/2009GL040613, Skepticalscience.com
Radiative Forcing

- Human emission from 280ppm to 400ppm= 120ppm CO₂ equivalent to 2.1W/m²

\[ \Delta F_{CO_2} \left[ \frac{W}{m^2} \right] = 6 \ln \left( \frac{C_{new}}{C_{old}} \right) \]

\[ \Delta F_{CO_2} = 6 \ln \left( \frac{400}{280} \right) = 2.1W / m^2 \]

- Radiation Sensitivity (Planck): 0.28K/Wm²
- CO₂ sensitivity: 4.2mK/ppm

- Anthropogenic Global Warming (AGW):
  - Current increase of 120 ppm CO₂ corresponds to 0.6K increase
  - Future doubling to 800 ppm CO₂ corresponds to 1.2K increase
Anthropogenic Global Warming (AGW):
• Simple physical calculation fro CO$_2$: 0.6K
• Actual observation: 0.8-1.2K
• Difference mainly due to:
  • Additional Greenhouse gasses (CH$_4$ and N$_2$O)
  • Other unrelated changes on Earth
  • Feedback: The response of the earth to global warming

Minor effects:
• Uncertainty in calculation: forcing
• Uncertainty in temperature measurements: local variations
• Other unrelated changes in Solar system

There is no scientific controversy about the AGW!
Earth Temperature over the years

Temperature of Planet Earth

- Eocene
- Ice Age

Wikipedia (Glen Fergus)
Feedback

- $g=1$ No feedback: calculations as is!
- $g<0$ Negative feedback: earth regulates itself: “Gaia”
  - Certainly true long term: Might not include human survival though
  - Short term:
    - Additional cloud raises albedo
    - Ocean will continue absorption of CO$_2$ from atmosphere
- $g>0$ Positive feedback:
  - Increased water concentration in atmosphere leads to further green house effect
  - Ice cover decreases which decrease albedo
  - Tundras melt releasing CH$_4$ (strong greenhouse gas)
  - CO$_2$ absorption of oceans stops or reverses strongly increasing CO$_2$ ppm

- What is the real $g$ factor ????
- Best estimate (long term): $g=1-3$
- Is there a tipping point (sudden increase in $g$ at certain temperature )???
Effects of global warming

• Higher temperatures: more droughts and heat waves,
  • frost free seasons (more yield or more diseases ?), ice-free artic, melting glaciers
• Change in weather patterns: precipitation, hurricanes
• Sea level rise of around 1m by 2100
  • due to melting land ice (Greenland and Antarctic)
• Local climate change
  • El Nino, la Nina
  • North-Atlantic Oscillation
  • Monsoons

<table>
<thead>
<tr>
<th>city</th>
<th>latitude</th>
<th>Min T [C] (this week)</th>
</tr>
</thead>
<tbody>
<tr>
<td>London</td>
<td>51.5 N</td>
<td>6°C</td>
</tr>
<tr>
<td>Montreal</td>
<td>45.5 N</td>
<td>-17°C</td>
</tr>
</tbody>
</table>

Further reading: climate.nasa.gov, metoffice.gov.uk, EPA, Wikipedia, Intergovernmental panel on climate change IPCC (physical science basis)
Prevention and Mitigation

• Reduce CO$_2$, CH$_4$, and N$_2$O emission
  • Renewable energy generation
  • Reduction in energy consumption

• Geo-engineering
  • Carbon dioxide capture and storage (CSS) / carbon sinks (trees)
  • Solar radiation management (stratospheric sulfate aerosols)
    • Additional volcano eruptions have similar effect
  • Iron fertilisation of sea to stimulate phytoplankton growth