London Array - 630 MW
Gunfleet Sands - 172 MW
Kentish Flats - 90 MW
Thanet - 300 MW

http://earthobservatory.nasa.gov/IOTD/view.php?id=82844
Biomass

Chris Davis
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29 September 2014
Energy Balance of the Earth

2) World energy consumption
fossil + nuclear fuels
3.2×10^{20} J/yr

sun radiation
5.6 \cdot 10^{24} J/a = 100 \%

albedo
64.8 \%
long wave radiation

border of atmosphere

heat of the earth
0.02 \%

gravity and rotation
0.002 \%

absorption in atmosphere
17.4 \%

31 \% reflection

earth surface

14.4 \%

33 \%

biomass 0.1 \%

energy resources
fossil ca. 3.5 \cdot 10^{22} J
nuclear ca. 4.4 \cdot 10^{24} J

continent
6.1 \%

sea
5.4 \%

2.7 \%

12.5 \%

radiation 17.9 \%

evaporation 20.7 \%

convection 8.8 \%
Energy Balance of the Earth

2) World energy consumption
fossil + nuclear fuels
3.2 \times 10^{20} \text{J/yr}

sun radiation
5.6 \times 10^{24} \text{J/a} = 100\%
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biomass 0.1\%

continents

6.1\%

5.4\%

2.7\%

17.8\%

sea

12.5\%

radiation 17.9\%

evaporation 20.7\%

convection 8.8\%

absorption in atmosphere

69\%

31\% reflection

0.02\%

0.002\%

47.4\%

4.2\% reflection

17.4\%

0.005\%

energy resources
fossil ca. 3.5 \times 10^{22} \text{J}
nuclear ca. 4.4 \times 10^{24} \text{J/a}
Biomass Fuels - Waste Derived

• Agricultural waste:
  • Straw (e.g. Denmark)
  • Greenhouse and fruit farming waste
  • Rice husks (e.g. Indonesia)
  • Nut shells
  • Sugar cane bagasse (e.g. Brazil)
  • Animal waste

• Organic wastes:
  • Household waste and swill (from restaurants etc.)
  • Waste paper
  • Food & beverage industry
Biomass Fuels - Waste Derived

- Wood:
  - Thinnings
  - Prunings (park and public garden)
  - Industrial and demolition waste wood
- Sludges:
  - Waste water treatment
  - Maintenance of waterways
Biomass Fuels - Agriculture/Forests

• Agriculture:
  • Energy crop cultivation of e.g. Miscanthus, sweet sorghum, switchgrass etc.
  • Sugar beet
  • Oil seed plants – palm oil, jatropha, etc.
• Forests:
  • Short rotation coppice, like e.g. willow and poplar
Biomass Considerations

- Decomposes quickly
- Low energy density, widely spread → transport issues
- Various processing steps needed before use
- Seasonality → storage
- Land, water, fertilizer requirements
- Contents – ash, etc, dioxins
- Depletion of soil nutrients
Coupling of Power Production to Water Consumption

Vulnerability of US and European electricity supply to climate change

Michelle T. H. van Vliet¹*, John R. Yearsley², Fulco Ludwig¹, Stefan Vögele³, Dennis P. Lettenmaier² and Pavel Kabat¹,⁴

Summer A2 2040s

Figure 3 | Changes in usable capacity of thermoelectric power plants. a. Projected changes in summer mean usable capacity of power plants in the US and Europe for the SRES A2 emissions scenario for the 2040s (2031–2060) relative to the control period (1971–2000). b. Mean annual cycles of usable capacity and return periods of production reductions for the New Madrid power station in the US (coal power plant with installed capacity of 1,200 MW using once-through cooling with water from the Mississippi River) and Civaux power station in France (nuclear power plant with installed capacity of 3,122 MW using recirculation (tower) cooling with water from the Vienne (Loire) River).

"Water becoming a serious constraint for power generation" Aditi Nigam, The Hindu, July 18, 2012
Welcome to the Anthropocene

- More Nitrogen fixed by factories than all plants/microbes
- More material moved by humans than by rivers, floods, landslides
- Proposed geological boundary layer of fallout from atomic bomb tests
Welcome to the Anthropocene
## Biomass Conversion Techniques

<table>
<thead>
<tr>
<th>Conversion Technique</th>
<th>Temperature Range</th>
<th>Pressure</th>
<th>Main Products</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combustion</td>
<td>800 - 1200 °C</td>
<td>atm - high</td>
<td>Heat, CO₂, H₂O</td>
</tr>
<tr>
<td>Pyrolysis</td>
<td>400 - 800 °C</td>
<td>atm - high</td>
<td>Char, oil, gas</td>
</tr>
<tr>
<td>Gasification</td>
<td>650 - 1100 °C</td>
<td>atm - high</td>
<td>CO, H₂, CH₄, CO₂</td>
</tr>
<tr>
<td>Hydrothermal Upgrading</td>
<td>250 - 600 °C</td>
<td>very high</td>
<td>Oil, char, gas, CO₂</td>
</tr>
<tr>
<td>Aerobic Fermentation</td>
<td>&lt;100 °C</td>
<td>atm.</td>
<td>Ethanol, CO₂</td>
</tr>
<tr>
<td>Anaerobic Fermentation</td>
<td>&lt;100 °C</td>
<td>atm.</td>
<td>CH₄, H₂O</td>
</tr>
</tbody>
</table>
Main Bio-energy Conversion Routes

Thermochemical Conversion:
- Direct combustion
- Gasification
- Pyrolysis liquefaction

- Steam turbine, BigCC, gas engine
- Fuel cell
- Methanol, hydrogen synthesis
- Upgrading
- Diesel
- Gas engine

Biochemical Conversion:
- Anaerobic digestion
- Fermentation

- Biogas
- Gas engine
- Distillation

Extraction (oilseeds):
- Transesterification
- Bio-diesel

Outputs:
- Heat
- Electricity
- Fuel
**Figure TS.2.3** | Schematic view of the variety of commercial (solid lines) and developing bioenergy routes (dotted lines) from biomass feedstocks through thermochemical, chemical, biochemical and biological conversion routes to heat, power, CHP and liquid or gaseous fuels. Commercial products are marked with an asterisk. [Figure 2.2, 2.1.1]
Energy Production from Biomass - Efficiencies

Solid Biomass

- (CO-) Combustion
  - Coal / Gas Power Plant: 30 - 45 %
  - Steam Turbine: 15 - 20 %
  - Stirling Engine: 10 - 15 %
  - Combined Cycle: 20 - 35 %
  - N.G. Combined Cycle: 45 - 55 %

- Gasification
  - Gas-Engine (CHP): ca. 25 %

- Pyrolysis
  - Fuel Cell: 30 - 45 %

* Lower output range than steam turbine.
** Dependent on fuel cell type.
Anaerobic Digestion
Gasification

Indirect Conversion Synthetic Fuels Manufacturing Processes

Coal → Gasification → Syngas Cleanup → Syngas (H2 & CO)

Biomass

Natural Gas → Steam Methane Reformation → Syngas Cleanup → Syngas (H2 & CO)

Fischer Tropsch Conversion → Diesel Fuel

Wax Hydrocracking → Jet Fuel

Methanol Synthesis

Methanol To Gasoline conversion (Mobil process) → Gasoline

https://en.wikipedia.org/wiki/Synthetic_fuel
Gasification
Thermal Biomass Utilization Considerations

- Kind of biomass: wood, straw, wastes
- Fuel conversion: gasification, combustion
- Power generation: combustion motor, gas turbine, steam turbine, Stirling engine, fuel cell
- Products: electricity, heat, heat and power (CHP)
- Mono- or Co-utilization
Centralized/Decentralized Biomass Utilization

- Pure biomass power restricted to about 50-100 MW at one location (availability, logistics)
- Centralized electricity production: only reasonable with co-firing
  - high electric efficiency
  - low investment costs
- Decentralized CHP (Combined Heat & Power)
  - High fuel utilization
  - Economical advantage of two products
Centralized/Decentralized Biomass Utilization

[Diagram showing various power plants and their efficiencies]

Direct + Indirect Co-combustion

Pretreatment by pyrolysis/gasification

Biomass → Burnout Air

Fuel gas → Coal + Biomass

Ash
Direct co-combustion E.On Maasvlakte

- 2 x 540 MWel
- Pulverized coal
- 183 bar/ 47 bar, 540 °C
- Efficiency 40.6%
- Co-firing of different biomass/wastes up to 6.8% (energy)
- Future up to 20%
Direct versus Indirect Co-combustion

**Indirect Co-combustion**
- Only milling/drying required
- Solids/ gases pass the boiler
- Possible effects on
  - Slagging, corrosion
  - DENOX, FGD (Flue Gas Desulfurization)
  - Emissions, by-products
- Increase of operational costs

**Direct Co-combustion**
- Additional process steps
- Critical components can be removed by process steps
- Ash is separated (gasification)
- Increased investment costs
Ethanol

Ethanol production in a nutshell

Corn +
Water +
Yeast +
Wait for
Fermentation
Figure 9.9.7-2. Corn wet milling process flow diagram.14
(Source Classification Codes in parentheses.)
Maize – A Hero of Industrial Ecology?

ENDOSPERM

GLUTEN
Cattle Feed

RAW STARCH

Corn Meal
Cereals

GERM

OIL CAKE
(OR MEAL)
Cattle Feed

CRUDE CORN OIL

SOAP

GLYCERIN

PLASTIC RESIN
Rubber Substitutes
Erasers
Elastic Heels

SOLUBLE CORN OIL
Textile Sizing
Cloth Coloring

REFINED CORN OIL
Salad Oils
Cooking Oils
Medicinal Oils

HULL
BRAN
Cattle Feed

DEXTRIN
Mucilage
Glue
Textile Sizing
Food Sauces
Fireworks

INDUSTRIAL STARCH
Laundry Starch
Textile Sizing Manufacture
Filler in Paper
Cosmetics
Explosives

EDIBLE STARCH
Corn Starch
Jellies
Candies

COR N SYRUP
Mixed Table
Syrups
Candies
Confectionery
Ice Cream
Shoe Polishes

COR N SUGAR
Infant Feeding
Diabetic Diet
Caramel Coloring
Vinegar
Lactic Acid
Tanning Mixtures
Brewing
Artificial Silk

Corn Syrup

Corn Sugar

Byproducts of Biofuel production

- Wet Distillers Grains (WDG)
- Dried Distillers Grains with Solubles (DDGS)
- Soybean meal (biodiesel production)

Machine for turning corn into meat
54 kcal energy input = 1 kcal protein

http://www.flickr.com/photos/agrilifetoday/5011936092/
“Generations” of Biofuel Technologies

- 1\textsuperscript{st} - Sugars, oils (ethanol, biodiesel)
- 2\textsuperscript{nd} – Cellulosic ethanol
- 3\textsuperscript{rd} – Algae, bacteria, GMOs

Energy from Cellulose

Algae

- Algae using CO$_2$ from power plants, limited in scope
- Higher photosynthetic efficiency
- Easier to harvest (just add plumbing)
- Works in desert lands
- Water usage?

Biochar

Biochar - Benefits

- Char produced from pyrolysis process
- Carbon Negative Fuel
- Improved soil water/nutrient retention, soil ecology
- Increased soil fertility
- Reduction in fertilizer (natural gas, env issues)
- C Sequestration time – 1000's years

http://www.biochar-international.org/biochar/faqs#q10
http://www.pnas.org/content/104/47/18866.long
http://www.whrc.org/global/carbon/
Biochar - Potential Impact

- 9 Gt CO$_2$ from humans, about 4 Gt CO$_2$ increase in atmosphere yearly
- 0.25 Gt – 27% of forest/crop waste
  - Same, but use energy to offset fossil fuels - 0.6 Gt
- 2.2 Gt – 80% all forest/crop waste – assumes:
  - Energy replaces energy from coal
  - Reduction in N$_2$O emissions
  - Increase in biomass production, biochar in soil
- Lehmann – 12%, 1.8 Gt from sustainably sourced biomass

http://e360.yale.edu/feature/refilling_the_carbon_sink_biochars_potential_and_pitfalls/2349/
Biochar - Challenges

- Optimize for soil or energy, or combination of both?
- Distribution of feedstock
- Need to study effect in different soils under different conditions
- Economic, social, logistics issues

Palm Oil

http://www.flickr.com/photos/greenpeace_switzerland/4523210042/
https://en.wikipedia.org/wiki/File:Elaeis_guineensis_-_K%C3%B6hler%E2%80%93s_Medizinal-Pflanzen-056.jpg
“Carbon Payback” Time

Figure 2.12 | The ecosystem carbon payback time for potential biofuel crop expansion pathways across the tropics comparing the year 2000 agricultural system shown in (a) with a future higher yield scenario (b) which was set to equal the top 10% of area-weighted yields. The asterisk represents oil palm crops grown in peatlands with payback times greater than 900 years in the year 2000 compared to 600 years for a 10% increase in crop productivity. Based on Gibbs et al. (2008) and reproduced with permission from IOP Publishing Ltd.

http://srren.ipcc-wg3.de/report
Pathways for Carbon Fixation in Photosynthesis

$C_4$

$C_3$

CAM
$C_3$ versus $C_4$ photosynthesis - Energy Capture

<table>
<thead>
<tr>
<th></th>
<th>Upper Limit</th>
<th>Full Season</th>
</tr>
</thead>
<tbody>
<tr>
<td>$C_3$</td>
<td>4.6%</td>
<td>2.4%</td>
</tr>
<tr>
<td>$C_4$</td>
<td>6.0%</td>
<td>3.4%</td>
</tr>
</tbody>
</table>

Current Opinion in Biotechnology 2013, 24:369–375
C₃ versus C₄ photosynthesis

Current Opinion in Biotechnology 2013, 24:369–375
Power Density of Energy Crops

Best Energy Crops, NW Europe

- wood (commercial forestry)
- rape
- rape to biodiesel
- maize
- sugar beet
- short rotation coppice calorific value
- energy crops calorific value
- miscanthus to electricity
- switchgrass
- corn to ethanol
- wheat to ethanol
- jatropha

sugarcane (Brazil, Zambia)

tropical plantations (eucalyptus)

tropical plantations*

Everything you ever wanted to know and more...

http://srren.ipcc-wg3.de/report
Primary Energy Sources

Figure SPM.2 | Shares of energy sources in total global primary energy supply in 2008 (492 EJ). Modern biomass contributes 38% of the total biomass share. [Figure 1.10, 1.1.5]

http://srren.ipcc-wg3.de/report
Renewable Energy Potential

Electricity

- Geothermal Energy
- Hydropower
- Ocean Energy
- Wind Energy

Heat

- Geothermal Energy
- Biomass
- Direct Solar Energy

Primary Energy

- Global Heat Demand, 2008: 164 EJ
- Global Primary Energy Supply, 2008: 492 EJ

Range of Estimates of Global Technical Potentials

<table>
<thead>
<tr>
<th>Source</th>
<th>Max (in EJ/yr)</th>
<th>Min (in EJ/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geothermal</td>
<td>1109</td>
<td>118</td>
</tr>
<tr>
<td>Hydropower</td>
<td>52</td>
<td>50</td>
</tr>
<tr>
<td>Ocean Energy</td>
<td>331</td>
<td>7</td>
</tr>
<tr>
<td>Wind Energy</td>
<td>580</td>
<td>85</td>
</tr>
<tr>
<td>Geothermal</td>
<td>312</td>
<td>10</td>
</tr>
<tr>
<td>Biomass</td>
<td>500</td>
<td>50</td>
</tr>
<tr>
<td>Direct Solar Energy</td>
<td>49837</td>
<td>1575</td>
</tr>
</tbody>
</table>

Figure SPM.4 | Ranges of global technical potentials of RE sources derived from studies presented in Chapters 2 through 7. Biomass and solar are shown as primary energy due to their multiple uses; note that the figure is presented in logarithmic scale due to the wide range of assessed data. [Figure 1.17, 1.2.3]
Notes: Medium values are shown for the following subcategories, sorted in the order as they appear in the respective ranges (from left to right):

<table>
<thead>
<tr>
<th>Electricity</th>
<th>Heat</th>
<th>Transport Fuels</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Biomass:</strong></td>
<td><strong>Biomass Heat:</strong></td>
<td><strong>Biofuels:</strong></td>
</tr>
<tr>
<td>2. Small scale combined heat and power, CHP</td>
<td>2. Anaerobic digestion based CHP</td>
<td>2. Soy biodiesel</td>
</tr>
<tr>
<td>(Gasification internal combustion engine)</td>
<td>3. Steam turbine CHP</td>
<td>3. Wheat ethanol</td>
</tr>
<tr>
<td>3. Direct dedicated stoker &amp; CHP</td>
<td>4. Domestic pellet heating system</td>
<td>4. Sugarcane ethanol</td>
</tr>
<tr>
<td>4. Small scale CHP (steam turbine)</td>
<td></td>
<td>5. Palm oil biodiesel</td>
</tr>
<tr>
<td>5. Small scale CHP (organic Rankine cycle)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Solar Electricity:**

1. Concentrating solar power
2. Utility-scale PV (1-axis and fixed tilt)
3. Commercial rooftop PV
4. Residential rooftop PV

**Geothermal Electricity:**

1. Condensing flash plant
2. Binary cycle plant

**Hydropower:**

1. All types

**Ocean Electricity:**

1. Tidal barrage

**Wind Electricity:**

1. Onshore
2. Offshore

**Solar Thermal Heat:**

1. Domestic hot water systems in China
2. Water and space heating

**Geothermal Heat:**

1. Greenhouses
2. Uncovered aquaculture ponds
3. District heating
4. Geothermal heat pumps
5. Geothermal building heating

The lower range of the levelized cost of energy for each RE technology is based on a combination of the most favourable input-values, whereas the upper range is based on a combination of the least favourable input values. Reference ranges in the figure background for non-renewable electricity options are indicative of the levelized cost of centralized non-renewable electricity generation. Reference ranges for heat are indicative of recent costs for oil and gas based heat supply options. Reference ranges for transport fuels are based on recent crude oil spot prices of USD 40 to 130/barrel and corresponding diesel and gasoline costs, excluding taxes.

http://srren.ipcc-wg3.de/report
Production Costs - Liquid Biofuels

![Bar chart showing production costs for various regions and feedstocks.](image)

**Figure 2.7** | Snapshots of regional ranges of current (2008-2009) estimated production costs for ethanol and biodiesel from various biomass feedstocks and wastes based on Millbrandt and Overend (2008) and Table 2.7.

http://srren.ipcc-wg3.de/report
Lifecycle GHG Emissions

Electricity Generation Technologies Powered by Renewable Resources

Electricity Generation Technologies Powered by Non-Renewable Resources

* Avoided Emissions, no Removal of GHGs from the Atmosphere

Count of Estimates

<table>
<thead>
<tr>
<th>Technology</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biopower</td>
<td>222(+4)</td>
</tr>
<tr>
<td>Photovoltaics</td>
<td>124</td>
</tr>
<tr>
<td>Concentrating Solar Power</td>
<td>42</td>
</tr>
<tr>
<td>Geothermal Energy</td>
<td>8</td>
</tr>
<tr>
<td>Hydropower</td>
<td>28</td>
</tr>
<tr>
<td>Ocean Energy</td>
<td>10</td>
</tr>
<tr>
<td>Wind Energy</td>
<td>126</td>
</tr>
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</table>

Count of References

<table>
<thead>
<tr>
<th>Technology</th>
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</tr>
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<tr>
<td>Biopower</td>
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<tr>
<td>Concentrating Solar Power</td>
<td>13</td>
</tr>
<tr>
<td>Geothermal Energy</td>
<td>6</td>
</tr>
<tr>
<td>Hydropower</td>
<td>11</td>
</tr>
<tr>
<td>Ocean Energy</td>
<td>5</td>
</tr>
<tr>
<td>Wind Energy</td>
<td>49</td>
</tr>
</tbody>
</table>

* Avoided Emissions, no Removal of GHGs from the Atmosphere

Figure 5PM.8 | Estimates of lifecycle GHG emissions (g CO₂eq/kWh) for broad categories of electricity generation technologies, plus some technologies integrated with CCS. Land use-related net changes in carbon stocks (mainly applicable to biopower and hydropower from reservoirs) and land management impacts are excluded; negative estimates for biopower are based on assumptions about avoided emissions from residues and wastes in landfill disposals and co-products. References and methods for the review are reported in Annex II. The number of estimates is greater than the number of references because many studies considered multiple scenarios. Numbers reported in parentheses pertain to additional references and estimates that evaluated technologies with CCS. Distributional information relates to estimates currently available in LCA literature, not necessarily to underlying theoretical or practical extrema, or the true central tendency when considering all deployment conditions. [Figure 9.8, 9.3.4.1]
Figure T5.2.5 | Ranges of GHG emissions per unit energy output (MJ) from major modern bioenergy chains compared to current and selected advanced fossil fuel energy systems (land use-related net changes in carbon stocks and land management impacts are excluded). Commercial and developing (e.g., algae biofuels, Fischer-Tropsch) systems for biomass and fossil technologies are illustrated. When CCS technologies are developed, capture and sequestration of biomass carbon emissions can compensate fossil fuel-based energy production emissions. [Figure 2.10]
Planting Biofuels next to Highways?

- 100 km/hr
- 7L / 100km
- 1200 L biofuel / (hectare * year)
- 100 m spacing

http://www.youtube.com/watch?v=-5bVbfWuq-Q
How many cars per year?

\[ \text{car speed} = \frac{100 \ m}{hr} \cdot \frac{1 \ hr}{3600 \ sec} \cdot \frac{1000 \ m}{1 \ km} = 27.77778 \frac{m}{s} \]

\[ \text{time between cars} = 100 \ m \cdot \frac{1}{27.77778 \frac{m}{s}} = 3.6 \ sec \]

\[ \text{cars per year} = 1 \ \text{year} \cdot \frac{365 \ days}{1 \ \text{year}} \cdot \frac{24 \ hours}{1 \ \text{day}} \cdot \frac{60 \ min}{1 \ \text{hour}} \cdot \frac{60 \ sec}{1 \ \text{min}} \cdot \frac{1}{3.6 \ sec} = 8,760,000 \]
Fuel use per meter

\[
\text{car fuel consumption} = \frac{7 \, L}{100 \, km} \cdot \frac{1 \, km}{1000 \, m} = 0.00007 \frac{L}{m}
\]

\[
\text{total fuel consumption} = \frac{0.00007 \, L}{m} \cdot 8,760,000 \text{ cars} = 613.2 \frac{L}{m}
\]
How big a strip of land?

\[ \text{total fuel consumption} = 613.2 \frac{L}{m} \]

\[ \text{total fuel consumption} = \frac{1}{613.2 \frac{L}{m}} = 0.001630789 \frac{m}{L} \text{ (for 8,760,000 cars)} \]

\[ \text{biofuel production} = \frac{1200 L}{\text{hectare}} \cdot \frac{1 \text{ hectare}}{10,000 \text{ m}^2} = 0.12 \frac{L}{m^2} \]

\[ \text{biofuel production} = \frac{1}{0.12 \frac{L}{m^2}} = 8.333333 \frac{m^2}{L} \]

\[ 613.2 \frac{L}{m} \cdot 8.333333 \frac{m^2}{L} = 5110 \text{ m} \]
About Fuel Efficiency

\[
\frac{\text{Liters}}{100 \text{ km}} \quad \text{or} \quad \frac{\text{Miles}}{\text{Gallon}}
\]
About Fuel Efficiency

\[
\frac{5 \text{ Liters}}{100 \text{ km}} = \frac{0.005 \text{ m}^3}{100000 \text{ m}}
\]
About Fuel Efficiency

\[
\frac{5 \text{ Liters}}{100 \text{ km}} = \frac{0.005 \text{ m}^3}{100000 \text{ m}} = 5 \cdot 10^{-8} \text{ m}^2 = 50 \text{ mm}^2
\]
About Fuel Efficiency

http://what-if.xkcd.com/11/
Now with 8,760,000 cars

\[
\frac{613.2 \ L}{m} \cdot \frac{0.001 \ m^3}{1 \ L} = 0.6132 \ m^2
\]

\[
0.6132 \ m^2 = \pi r^2
\]

\[
\frac{0.6132 \ m^2}{\pi} = r^2
\]

\[
r = \sqrt{\frac{0.6132 \ m^2}{\pi}} = 0.4418 \ m
\]
A greenhouse gas indicator for bioenergy: some theoretical issues with practical implications

Jeroen B. Guinée · Reinout Heijungs · Ester van der Voet

Received: 26 June 2008 / Accepted: 29 March 2009 / Published online: 7 May 2009
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Abstract

Background, aim, and scope The expectations with respect to biomass as a resource for sustainable energy are sky-high. Many industrialized countries have adopted ambitious policy targets and have introduced financial measures to stimulate the production or use of bioenergy. Meanwhile, the side-effects and associated risks have been pointed out as well. To be able to make a well-informed decision, the Dutch government has expressed the intention to include sustainability criteria into relevant policy instruments.
Main features Among other criteria, it has been proposed to calculate a so-called life-cycle-based greenhouse gas (GHG) indicator, which expresses the reduction of GHG emissions of a bio-based fuel chain in comparison with a fossil-based fuel chain. Life-cycle-based biofuel studies persistently have problems with the handling of biogenic carbon balances and with the treatment of coproducts and inventory analysis. In this step, system boundaries are set, processes are described, and process flows are quantified. Multifunctionality problems can be identified and the model of the product system is drafted. The second step concerns solving the remaining multifunctionality problems. For this step, various ways of solving the multifunctionality problem have been proposed and applied, on the basis of mass, energy, economic value, avoided burdens, etc. As the GHG indicator may constitute the basis for granting subsidies to stimulate the use of bioenergy, for example, and as the method for the GHG indicator provides no guidelines on the handling of biogenic CO₂ and guidelines for solving multifunctionality problems such as with coproducts and recycling that leave room for various choices, this study analyzed whether the current GHG indicator provides results that are a robust basis for granting such subsidies.
It's not just about the energy

- Plants don't really “want” this
Solar Fuels / Artificial Photosynthesis

versus


Solar Fuels / Artificial Photosynthesis

- **Pros**
  - Energy storage
  - Decoupling from NPK, water usage, ecosystem services

- **Cons**
  - Material scarcity of catalysts?
  - Economics?
  - Land use?
Biomass – Areas of Concern

- Potential of bioenergy is large (but << solar – 1-2% eff.)
- Issues of energy density, processing, distribution
- Land use concerns, ecosystem services, dead zones
- Coupling of energy to water usage
- Coupling to NPK cycles
- EROEI
Food/Fibre versus Fuel

- Dependence on oil/natural gas for pesticides, herbicides, fertilizers, transportation, processing, etc.
- Cows – machine for turning corn into meat
  - 40% of world grain goes to livestock
Opportunities/Future Research

- C4 more efficient use of water, does better in high temperatures, limited N, etc.
- Convert C3 plants to C4
- Improving photosynthetic processes
- Increasing sensitivity to spectrum
- GMO
- Perennialize annual variants of energy crops
Questions?
Motivations for Energy Storage

- Electricity generation initially demand driven, now driven by supply & demand
- Current storage extremely small
- Some within-day storage currently possible
- Storage across seasons (???)
Jatropha

- Good land – 0.18 W/m²
- Bad land – 0.065 W/m²
Figure 1. Biorefinery Classification Scheme [IEA Bioenergy Task42]

http://www.iea-bioenergy.task42-biorefineries.com/nl/publications/reports/?eID=dam_frontend_push&docID=2051
Options

• (Co)combustion, specially grown plants
  • Could also use by-products, but of lower quality than dedicated plants
• Biodiesel, ethanol
• Bacteria/Algae (GMO possibly)
Photosynthesis

- 40 – 140 TW of energy (half is plankton)
- Human power consumption 13 TW
  - (check against BP Statistics)
- 100 W human x 7 billion = 700 GW

• Sunlight is about 100 W/m² in Western Europe
• Best plants 2% efficient turning sunlight into carbohydrates (depends on light levels, could be too high)
• In Europe, best is 0.5 W/m²
• Typical house 1.5 kW, then need 3000 m²
• NL 0.06 ha per person

http://www.indexmundi.com/facts/netherlands/arable-land
Syngas

- Flexible feedstocks – Fossil fuels or biomass
Pyrolysis Products at the Grocery

https://en.wikipedia.org/wiki/Liquid_smoke
• Look at other Smil book in Calibre library
• Dominant form of energy conversion is combustion (rapid oxidation)
• First steam engine – 1% efficiency
• Biomass usage still dominant in some areas – IEA sankey diagrams – Africa, Bangladesh, India (transition), etc.
• Not just changing fuels, but how we use them (conversion techniques)
• Transitions – biomass → coal → gas – transitions happen with different speeds (Arab countries, etc.)
• Role of local wood shortages (UK) in transition to coal (Nef, 1932)
• BP Statistical Review – Biomass – look for interesting stories in different countries
- Energy densities of bio-fuels
- Smil – biomass 95% of fuel total by 1840
- 1860 – 85%
- 1880 – 70%
- 1890's – fossil fuels used for ½ of all fuel needs
- 1800 – 1900, biomass provided no less than 85% of total fuel energy
- Coal 5% around 1840, 10% 1850, 25% 1870's
- Fisher-Pry plot? - show biomass trends around the world using BP data
- Big picture – how much can biomass provide? - Smil gives an answer, compare to BP data to get demand
- Total photosynthesis – 60 TW, current fossil fuel use is ~360 EJ
• Energy density – is an issue, you can convert it to other stuff, but should really do an analysis of the overall energy balance (are we better off)
• Fisher-Pry plots – start with one country – then move to wider facet grid analysis
  • Logarithmic important – can see exponential growth, doubling every year (show hypothetical data from a variety of different perspectives)
• Explain base load, load duration curve, merit order
• Distributed conversion? Centralized conversion? At what scale do the economics work? - similar issue with manure in the netherlands
• [http://www.nasa.gov/topics/earth/features/carbon-capacity.html](http://www.nasa.gov/topics/earth/features/carbon-capacity.html) How much are humans using currently
• Should be optimistically cautious within certain contexts
• Ecosystem services
• A cow is mobile stored solar energy – higher energy density than crops (density plot – insert cow here) – solar panels are doing something quite similar
• How much energy is in a cow:
  • https://answers.yahoo.com/question/index?qid=20081220234733AAfe5zj
  • http://www.lifebygeek.com/2012/11/03/how-much-energy-is-in-a-cow/
• Also look at energy density of plants
• Conversion efficiencies for different technologies?
• Artificial Leaf – MIT Guy – Daniel N...
• Netherlands - 33,893 sq km, 25% arable land = ????? sq km
• 0.88% permanent crops
• Rapeseed 0.13 W/m2
• Sugar Beets 0.4 W/m2
Fischer-Tropsch

https://commons.wikimedia.org/wiki/File:GTL_process.GIF