Energy Crops

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Account of the Agricultural and Forestry Products Produced and Traded

![Bar chart showing the distribution of agricultural and forestry products by use and crop type.](image)

- **Food use**
  - Cereals
  - Roots & Tubers
  - Sugar crops
  - Oil crops
  - Fruits
  - Stimulants
  - Industrial crops
  - Fodder crops

- **Feed use**
  - Cereals
  - Fodder crops

- **Seed/waste**
  - Cereals
  - Other crops
Terminology in biomass analysis, also applicable for other solid fuels

- The “as received” composition (ar)
- The “dry basis” composition (db)
- The “dry, ash free” basis (commonly abbreviated as “daf”)
- The elemental or ultimate analysis

http://bisyplan.bioenarea.eu/fuel_appendix.html
A biofuel is a mixture of organic compounds derived from biological carbon fixation and whose energy content can be recovered by combustion (fuel). Biofuels include liquid fuels derived from biomass conversion, as well as solid biomass, and various biogases. Biofuels are gaining increased public and scientific attention, driven by factors such as oil price hikes, the need for increased energy security, and concern over greenhouse gas emissions from fossil fuels.

- **Bioethanol**
  - from sucrose or oligosaccharides
  - from starch
  - from lignocellulose materials

- **Biodiesel**
  - from oil crops
  - from algae

\[ \text{Biofuel of first generation} \]
\[ \text{Biofuel of second generation} \]
Plants used for processing into Biofuels can be classified based on the main components involved in the chemical transformation:

- Plants producing sugars or starches
- Plants producing oils
- Plants whose whole biomass can be used
- Plant residuals (wastes) whose biomass can be used
Plants Based on Starch: Wheat (genus *Triticum*)

**Wheat** - more than 10-20 species through East Mediterranean to Iran. Temperate crop. Complex ancestry and were first domesticated in the Near East some time before 7000 BC.

Evolution through polyploidy
- Diploid – *T. monococcum* (einkorn)
- Tetraploid – *T. dicoccon* (emmer)
- Hexaploid – *T. aestivum* (common bread wheat - *T. durum* (durum, flint, hard or macaroni)

Emmer and einkorn – high amylose and not suitable for leavened bread
Two main proteins - glutenin and gliadin which makes the dough elastic when mixed with water.
Rice (*Oryza Sativa*)

While cooking gelatinizes and cell wall ruptures.
Two to three races
- indica type – long-grain; dry and separate
- Japonica or sativa – short grain soft and slightly gluey
- Javanica – Indochina; equatorial plane, gluey

Gelatinous temperature and amylose content.
- High amylose – dry and flaky
- Low amylose – sticky and moist

Mainly contains starch, 12% proteins
- Glutelins, albumins, prolines

Lack lysine and threonine.
Removing bran and germ removes thiamine – beriberi disease.
Maize (Zea mays)

Corn

- Domesticated in Central America; the only cereal used as vegetable; The more diffused cereal
- Ancestors – Mexican teosinte
- Flowers unisexual
- 70% endosperm and 11% embryo
  - 11% proteins of aleuronic layer
    - The germ provides glutelin whereas aleuron layer have zein
    - Zein – rich in leucine but lack of lysine and tryptophan
    - Excess of leucine prevent conversion of tryptophan to niacin - pellagra
Barley (*Hordeum vulgare*)

*Barley:*

- A temperate plant; domesticated plant, a member of the grass family and is a major cereal grain
- A major animal feed and brewing
- Has low gluten and cannot be leavened
- Has beta glucan – lower blood cholesterol
- Reduces colon cancer
- Barley beer was probably one of the first alcoholic drinks developed by Neolithic humans.
Oat: Oat (Avena sativa)

- Has elongated caryopsis
  - Two aleurone layers
  - 12-13% proteins; 4-5% oils; 66-77% CHO and 12-15% crude fiber (reduce blood sugar by reducing absorption)

- Used more for medicinal value
- Has all essential amino acids
- Is heat processed to denature enzymes
Rye (Secale cereale)

Rye:

- Feed cereal
- Alcoholic drinks
- Infections – ergot
- Has pentosans not starch – does not disintegrates and gelatinization – soft crumbs
- Usually mixed with wheat flour
Soybeans (*Glycine max*)

A summer annual member of the legume family native to East Asia. The most important oil seed crop and protein crop in most countries. The beans contain significant amounts of phytic acid, $\alpha$–linolenic acid, and isoflavones. Composition: 40% proteins, 20% oil, 35% sacc. and 5% ash.
Based on Sugars:
Sugarcane (*Saccharum officinarum* L. (*Poaceae*))

**Sugarcane:**
- 12-15% sucrose, glucose and fructose
- 12-20% fiber
- 0.3-0.4% nitrogenous compounds
- Fats, waxes, acids and pectins

- Sugarcane juice: acotinic acid, citric and malic acids; vit B, D and enzymes like invertase and oxidases
Sugar Beet (Beta vulgaris var. rapa)

Sugar Beet:

- Roots have up to 20% sugar
- Betaine (red pigment) is commercially extracted
- Waste has galacturonic acid – used to synthesize vitamin C

\[
\text{Betaine} \quad \begin{array}{c}
\text{N} \\
\text{O} \\
\text{O} \\
\text{H}
\end{array}
\]

sugar

\[
\text{sugar} \quad \begin{array}{c}
\text{O} \\
\text{H} \\
\text{N} \\
\text{O}
\end{array}
\]

Betaine

\[
\text{Betaine} \quad \begin{array}{c}
\text{O} \\
\text{N} \\
\text{O} \\
\text{H}
\end{array}
\]
Based on Oils: Oil Producing Trees
Production, Oil-Content and Fat Yield of Oil Crops

<table>
<thead>
<tr>
<th>Kind of Oil Crops</th>
<th>Production Rate (kg/ha)</th>
<th>Oil Content (%)</th>
<th>Oil Yield Rate (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jatropha</td>
<td>5,000</td>
<td>30</td>
<td>1,500</td>
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<tr>
<td>Palm</td>
<td>20,501</td>
<td>20</td>
<td>4,100</td>
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<tr>
<td>Rapeseed</td>
<td>3,440</td>
<td>40</td>
<td>1,376</td>
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<tr>
<td>Sunflower</td>
<td>1,434</td>
<td>42</td>
<td>602</td>
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<tr>
<td>Soybean</td>
<td>2,314</td>
<td>18</td>
<td>416</td>
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</table>

Oil Content of Different Oil Crops

Oil Yield Rate of Different Oil Crops
<table>
<thead>
<tr>
<th>Plant</th>
<th>Latin Name</th>
<th>Gal Oil /acre</th>
<th>Plant</th>
<th>Latin Name</th>
<th>Gal Oil /acre</th>
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</thead>
<tbody>
<tr>
<td>Oil palm</td>
<td><em>Elaeis guineensis</em></td>
<td>610</td>
<td>Rice</td>
<td><em>Ozisa sativa L.</em></td>
<td>85</td>
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<tr>
<td>Macauba palm</td>
<td><em>Acrocomia aculeata</em></td>
<td>461</td>
<td>Buffalo Gourd</td>
<td><em>Cucurbita foetidissima</em></td>
<td>81</td>
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<tr>
<td>Pequi</td>
<td><em>Caryocar brasiliense</em></td>
<td>383</td>
<td>Safflower</td>
<td><em>Carthamus tinctorius</em></td>
<td>80</td>
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<tr>
<td>Buriti Palm</td>
<td><em>MAuritia flexuosa</em></td>
<td>335</td>
<td>Crambe</td>
<td><em>Crambe abyssinica</em></td>
<td>72</td>
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<tr>
<td>Oiticia</td>
<td><em>Licania rigida</em></td>
<td>307</td>
<td>Sesame</td>
<td><em>Sesamum indicum</em></td>
<td>71</td>
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<tr>
<td>Coconut</td>
<td><em>Cocos nucifera</em></td>
<td>276</td>
<td>Camelina</td>
<td><em>Camelina sativa</em></td>
<td>60</td>
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<tr>
<td>Avocado</td>
<td><em>Persea americana</em></td>
<td>270</td>
<td>Mustard</td>
<td><em>Brassica alba</em></td>
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<tr>
<td>Brazil Nut</td>
<td><em>Bertholletia excelsa</em></td>
<td>245</td>
<td>Coriander</td>
<td><em>Coriandrum sativum</em></td>
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<tr>
<td>Macadamia Nut</td>
<td><em>Macadamia temiflora</em></td>
<td>230</td>
<td>Pumpkin Seed</td>
<td><em>Cucurbita pepo</em></td>
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<tr>
<td>Jatropha</td>
<td><em>Jatropha curcas</em></td>
<td>194</td>
<td>Euphorbia</td>
<td><em>Euphorbia lagascoe</em></td>
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<tr>
<td>Babassu Palm</td>
<td><em>Orbignya martiana</em></td>
<td>188</td>
<td>Hazelnut</td>
<td><em>Caylus avellana</em></td>
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<tr>
<td>Jojoba</td>
<td><em>Simmondsia chinensis</em></td>
<td>186</td>
<td>Linseed</td>
<td><em>Linus usitatissimum</em></td>
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<tr>
<td>Pecan</td>
<td><em>Carya illinoensis</em></td>
<td>183</td>
<td>Coffee</td>
<td><em>Coffea arabica</em></td>
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<tr>
<td>Bacuri</td>
<td><em>Platonia insignis</em></td>
<td>146</td>
<td>Soybeen</td>
<td><em>Glycine max</em></td>
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<tr>
<td>Castor bean</td>
<td><em>Ricinus communis</em></td>
<td>145</td>
<td>Hemp</td>
<td><em>Cannabis sativa</em></td>
<td>37</td>
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<tr>
<td>Gopher plant</td>
<td><em>Euphorbia lathyris</em></td>
<td>137</td>
<td>Cotton</td>
<td><em>Gassypium hirsutum</em></td>
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<tr>
<td>Piassava</td>
<td><em>Attalea funifera</em></td>
<td>136</td>
<td>Calendula</td>
<td><em>Calendula officinalis</em></td>
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<tr>
<td>Olive tree</td>
<td><em>Olea europea</em></td>
<td>124</td>
<td>Kenaf</td>
<td><em>Hibiscus cannabinus L.</em></td>
<td>28</td>
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<tr>
<td>Rapeseed</td>
<td><em>Brassica napus</em></td>
<td>122</td>
<td>Rubber seed</td>
<td><em>Hevea brasiliensis</em></td>
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<tr>
<td>Opium Poppy</td>
<td><em>Papaver somniferum</em></td>
<td>119</td>
<td>Lupine</td>
<td><em>Lupinus albus</em></td>
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<tr>
<td>Peanut</td>
<td><em>Aiachis hypogea</em></td>
<td>109</td>
<td>Palm</td>
<td><em>Erythea salvadorensis</em></td>
<td>23</td>
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<tr>
<td>Cocoa</td>
<td><em>Theobroma cacao</em></td>
<td>105</td>
<td>Oat</td>
<td><em>Avena sativa</em></td>
<td>22</td>
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<tr>
<td>Sunflower</td>
<td><em>Helianthus annuus</em></td>
<td>98</td>
<td>Cashew Nut</td>
<td><em>Anacardium occidentale</em></td>
<td>18</td>
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<tr>
<td>Tung oil tree</td>
<td><em>Aleurites fordii</em></td>
<td>96</td>
<td>Corn</td>
<td><em>Zea mays</em></td>
<td>18</td>
</tr>
</tbody>
</table>
By-Products in Oil Crops

By products per ha and year

(Metric Ton/ha - year)
Oil Palm Tree (*Elaeis guineensis jacq.*)

- The **palm oil** tree originates from West Africa where it grows in the wild, later it was developed into an agricultural crop.
- Oil palm is a monoecious crop as it bears both male and female flowers on the same tree. Each tree produces compact bunches weighing between 10 and 25 kg with 1000 to 3000 fruitlets per bunch. Each fruitlet is almost spherical or elongated in shape. Generally, the fruitlet is dark purple, almost black and the color turns to orange red when ripe. Each fruitlet consists of a hard kernel (seed) enclosed in a shell (endocarp) which is surrounded by a fleshy mesocarp.
That is one of the reasons why palm oil makes up more or less a third of the 151 million tonnes of vegetable oil produced worldwide.\textsuperscript{1} Its wide availability and low price combined with certain unique characteristics means that it is used in many packaged food and personal care products that line supermarket shelves. Ice cream, margarine, biscuits, cakes, breakfast cereals, soup stock cubes, snacks, ready meals, instant noodles, shampoos, soaps, lipsticks, candles and washing-up liquids—all of these items often contain palm oil that was produced in tropical countries such as Indonesia and Malaysia.

Demand is around 77 million tonnes to help feed the world’s growing population and the increased affluence of emerging economies and its use may grow even more if demand increases for palm oil as a biofuel.

\textsuperscript{1}USDA. Table 03: Major Vegetable Oils: World Supply and Distribution (Commodity View). Accessed October 22, 2011 \url{http://www.fas.usda.gov/oilseeds/Current/}

\textsuperscript{2}FAO, 2006, World agriculture: towards 2030/2050. Prospects for food, nutrition, agriculture and major commodity groups. Interim report
Mass Balance in Palm Oil Processing

Fresh Fruit Bunch 100%

Empty Fruit Bunch 21.0%

Fruitlets 64.5%

Condensate 13.5%

Nut 11.9%

Mesocarp 53.4%

Dilution water 15%

PKO = palm kernel oil
PKM = palm kernel meal
CPO = crude palm oil
POME = palm oil mill effluent
RBD = refined, bleached and deodorized
PFAD = palm fatty acid distillate

Kernel 4.9%

CPO 23.5%

Shell 6.4%

Fiber 14.4%

PKO 23%

Oil + Vit. E 18.18%

PKM 2.7%

RBDPL 22.82%

REDPO 18.18%

POME 58.3%

RBDPS 4.63%

Washing water 14.4%

CPO

Fiber

PKO

POME

PFAD

olein

PKM

RBDPL

REDPO

Oil + Vit. E

stearin

Attilio Citterio
Rapeseed and Canola (*Brassica spp.*)

Rapeseed is a member of the mustard family. Canola is a variety of rapeseed bred to have low levels of erucic acid and glucosinolates (both of which are undesirable for human consumption)

- Both spring and winter varieties grown
- Depends on geographical location
- Winter crop in NC

- Good oil yield
- Premium cold flow properties.
- 70% of feedstock for EU biodiesel production.
Camelina (Camelina sativa)

- Camelina is a member of mustard family
- Summer annual crop suited to grow in semi-arid climates and northern U.S.
- Research on variety development and economic feasibility are being conducted in U.S.A.
  - The cost of camelina-based biodiesel would likely be $0.526 per L compared to $0.789 per L for soy-based
- Variable and fixed costs are 1/3 - 1/4 the cost of canola
  - $45 to $68 per 4047 m²
Sunflower (*Helianthus annus*)

- Sunflower and safflower are summer annuals in the sunflower family. Sunflower and safflower seeds are excellent sources of oil. The meal can be used for animal feed.
- Safflower oil yields under irrigation range from 532 to 880 kg/ha. Without irrigation, safflower oil yields can drop to 112 kg/ha.
- Sunflower oil yields under irrigation range 840-930 kg/ha. Sunflower oil concentration in the seed ranges from 40-45%. $.036-.055 per kg market value.
- Second largest biodiesel feedstock in the EU.
Safflower (*Carthamus tinctorius*)

Old crop (known to Egyptian and Chinese 2000 BC) is used for food and for oil. This is particularly precious for its content in unsaturated fatty acids.

A source of yellow and red colors.
Peanuts (*Arachis hypogaea*)

**Advantages:**

High Oil Yield ~50-60% Soy is only ~18% oil.

Nearly 15% of peanuts are crushed for oil use in U.S.

Value range of $0.23-.30 per lb. of peanut depending on state, variety, production system (higher for organic) $.50 per gallon of oil obtained (on average)

**Obstacles:**

High Value Commodity

Shelling and sorting is costly process
Jatropha (Jatropha curcas)

**Jatropha** is a small shrub native of C. America and a member of Euphorbia family, it is a drought-resistant perennial, living up to 50 years and growing on marginal soils. Oil content: ~35%

Oil: normally Not Edible.

Other oil uses: insect repellent
**Castor Beans (Ricinus communis)**

*Castor bean* - drought-resistant, annual plant of tropical origin with immense spread-out. The plant can grow between 2 to 5 m.

Oil: soluble in alcohol (no heat) – fit for biodiesel.

Oil content: ~55%.

Oil: Not Edible (high level of Ricinoleic Acid – 85%).

Other oil uses: Over 700

![Ricinoleic Acid](image)
Flax (Linum usitatissimum)

- Flax is the source of linseed oil. Seed oil contents range from 30 to 34%.
- Both spring and winter forms are available. No specific breeding efforts are present in the Pacific Northwest.
- Used also to produce linen, also known as fiber flax.
- Flax oil contains polyunsaturated triglycerides which have a distinctive reaction toward oxygen in air.
Crambe is an ideal crop for production of specialised industrial oil qualities that must not be mixed with food quality oils. Crambe is already a non-food oil crop and it does not cross fertilise with Brassicas such as rapeseed. With regards to cultivation, Crambe is a low input oil crop compared to many others and it can be grown over large part of Europe. Oil content in the seed: 35% with 55% erucic acid. It is mainly used for lubricants, plastics or nylon.)
Limitations of (some) 1st generation biofuels

- Limited ability to meet fuel demands
- Compete with land for food crops
- Low net energy yield
- Limited greenhouse gas reductions
- Potentially lead to deforestation and negative impacts on biodiversity
Lignocellulosic feedstocks

- Most abundant form of biomass
- Can be grown on low-value land
- High greenhouse gas reductions
- High net energy yield
- Greater yield per hectare

Examples:
- woody biomass
- agricultural residues
- perennial grasses
Based on cellulose/hemicellulose
Crops for 2nd Generation Biofuels
Energy Crops: 
**Miscanthus (Miscanthus Giganteus)**

Miscanthus is a large perennial grass (it can grow up to 13 feet in height) characterized by:

- Lower fertilizer & water needs
- Strong photosynthesis, perennial
- Stores carbon & nutrients in soil
- Great field characteristics, longer canopy season
- Economics: +$3000 vs -$300 (10yr profit)
- 1 year growth without replanting!

20 tons/acre? ([www.bical.net](http://www.bical.net))
10-30 tons/acre ([www.aces.uiuc.edu/DSI/MASGC.pdf](http://www.aces.uiuc.edu/DSI/MASGC.pdf))
Energy Crops: Switch Grass (*Panicum virgatum*)

- Natural prairie grass in the US; enriches soil
- Less water; less fertilizer; less pesticide
- Reduced greenhouse gases
- More biodiversity in switchgrass fields (vs. corn)
- Dramatically less topsoil loss
- High potential for co-production of animal feed
Sorghum is a genus with many species and subspecies, including grain sorghums, grass sorghums (for pasture and hay), sweet sorghums (for syrups), and Broomcorn.

- Drought resistant biofuels crop
- *Sorghum bicolor* – tropical Africa.
- Major food in India, and Africa where leavened bread is not important (*Sorghum vulgare*)
- Very versatile crop
- Black and brown sorghum has polyphenol such as condensed
- Grain sorghum and maize (corn) are comparable in costs of production and in nutrition
Giant Cane, is a tall perennial cane growing in damp soils, either fresh or moderately saline.

is native to eastern and southern Asia, and probably also parts of Africa and southern Arabic Peninsula. It has been widely planted and naturalized in the mild temperate, subtropical and tropical regions of both hemispheres.

It forms dense stands on disturbed sites, sand dunes, in wetlands and riparian habitats.

In ideal conditions it can exceed 10 m, with hollow stems 2 to 3 cm diameter.

The maximum CO$_2$ uptake ranged between 19.8 and 37 $\mu$mol m$^{-2}$ s$^{-1}$, depending on irradiance,
Poplar (genus *Populus*)

Poplars are rapid-growing but relatively short-lived trees, widely distributed throughout the northern temperate regions, (North America, Eurasia, north Africa, with a few species extending even beyond the Arctic Circle). The leaves are alternate and ovate or heart-shaped in outline, with finely to coarsely toothed margins. Male and female flowers grow on separate trees and bloom in drooping catkins long before the leaves emerge. The fruits, which mature before the leaves are fully grown, are small, thick-walled capsules that contain many minute seeds clothed in cottoney tufts of silky hairs, which assist in wind dispersal. The wood is soft and mostly used to make paper, cardboard boxes, crates, and veneer.
Hemp (Cannabis sativa)

Hemp is a bast fiber plant similar to flax, kenaf, jute and ramie. Long slender primary fibers on the outer portion of the stalk characterize bast fiber plants. An annual fast growing plant can be grown on a range of soils, but grow best on land that produces high yields of corn. Hemp is dicotyledons, which means their stalks have an outer bast fiber and an inner core fiber. The hemp plant is harvested for its fibers, seed, seed meal and seed oil. The valued primary fibers are contained around the hollow, lignin rich woody core of the hemp stalk. Low THC content!