COMPREHENSIVE LIFE CYCLE ANALYSIS OF FUTURE, LIQUID FUELS FOR LIGHT VEHICLES

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This presentation…

- Is created by independent experts not hired by any energy or transportation company
- Is based on peer-reviewed public information sources such as journals and gov't studies
- Is devoid of opinions
- Is based on science and the scientific method embodying the international principles of <u>cradle to grave analysis known as life cycle analysis</u>
- We welcome your attempts to disprove any points made herein using the scientific method, no politics or unjustified assertions please

Motivation behind research

- In the past few years many have realized that the traditional sources of energy – oil and gas – are in limited supply and that we need to prepare for the approaching production maxima.
  - It is in the interest of national economic security to investigate alternative sources of transportation energy before the extraction of existing supplies becomes prohibitively expensive.

Scope of research

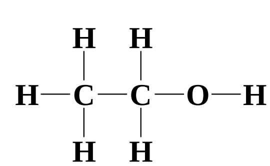
- This study investigates a number of potential fuels and their sources, including
  - agricultural solutions
    - corn ethanol
    - cellulosic ethanol
    - biodiesel
  - unconventional fossil fuels
    - coal-to-liquid
    - oil shale retorting
    - tar sand processing
- The final slide will compare the LCA results for all liquid fuels

What it is and what it isn’t

- This is a summary of different solutions
  - We recognize that there is a wide variety of opinions, convictions, likes, and dislikes but do not include anything non-scientific in what follows
- Values in this presentation result from independent calculations and research.
- This research is not meant to disparage or promote a specific technology but to level the playing field and provide information in a uniform format with a uniform set of transparent assumptions (see 2007 ASME & 2009 SAE papers).

Ethanol

- Ethanol weighs about 6.60 pounds per gallon
  - volumetric density of ethanol is about 7% greater than that of conventional gasoline



- A gallon of ethanol has a heating value of 76,000 BTU
  - This is about 2/3 the heating value of gasoline

Corn-based ethanol

Yields of ethanol depend on feedstock and fermentation process

Component	Reported ethanol yield	Equivalent yield (gal per ton)
Corn grain	2.5 gallons per bushel (wet milling)[a]	89
	2.6 gallons per bushel (dry milling)[a]	93
	124 gallons per dry ton of feedstock[b]	124
	52 liters per 100 kg with fiber conversion[c]	125
	46 liters per 100 kg without fiber conversion[c]	110
Corn cobs	120 grams per kg - hydrolyzation w/o enzymatic enhancement[d]	36
	300 grams per kg - hydrolyzation with enzymatic enhancement[d]	91
Corn stover	113 gallons per dry ton of feedstock[b]	113
	70 gallons per dry ton of feedstock[e]	70

[a] www.newfarm.org/features/0804/biofuels/index.shtml
[b] www1.eere.energy.gov/biomass/ethanol_yield_calculator.html
[c] www.nrel.gov/docs/gen/old/5639.pdf
[d] ift.confex.com/ift/2002/techprogram/paper_10450.htm
[e] www.biomass.govtools.us/pdfs/bcota/abstracts/31/z263.pdf

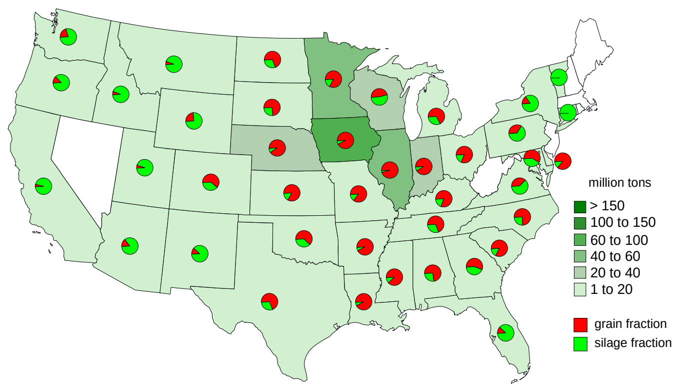
Note: the US uses 390,000,000 gallons of gasoline per day.

Corn-based ethanol experience

- We have a few years of experience now
  - Water consumption is high; environmental impacts vary and are significant
  - Economics are uncertain – e.g., refineries; even with subsidies – top 10% of Iowa subsidized corn industries received 55% of the $ through 2006
  - Unforeseen consequences already manifested
  - Accelerated attention to cellulosic ethanol based on difficult corn results

Corn-based ethanol land use

Corn is now grown on about a quarter of all cropland in the U.S.



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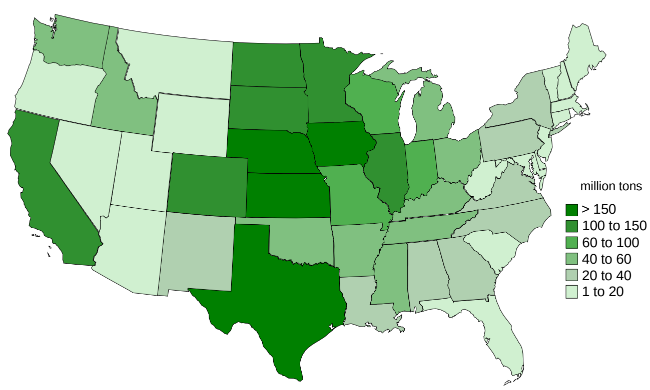
Corn-based ethanol land use

If **all** cropland was used to grow corn…



…enough ethanol would be produced to satisfy **half** the near-term U.S. automotive energy needs

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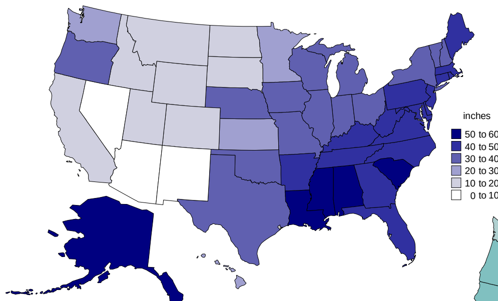
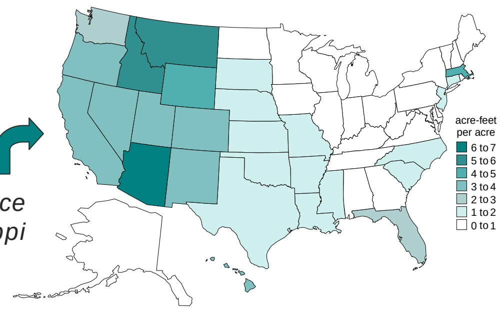
Irrigation water use

Most precipitation falls east of the Mississippi

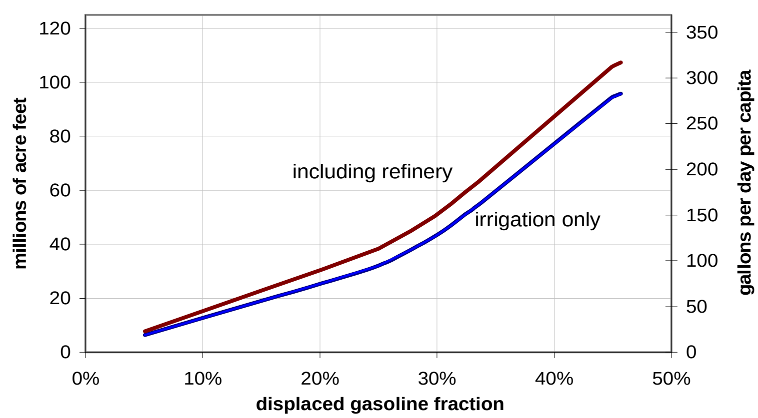


Most irrigation takes place west of the Mississippi



Corn-based ethanol water use

Extra annual water requirements to irrigate corn for ethanol production



Cellulosic Ethanol - from switchgrass for example

Switchgrass is a perennial grass native to North America that grows 5 to 10 feet tall in a single season and has been used as animal feed and for ornamental purposes.

The USDA reports that switchgrass can provide 70 gallons of ethanol per dry ton (through hydrolyzation during the brewing process). Other cellulosic: 100 gal/ton (1 gal ~ 4 liters; 1 ton ~ 0.9 tonne)

A typical yield for switchgrass is about 7.5 tons per acre, equivalent to about 520 gallons (1970 l) of ethanol per acre.

Switchgrass water use

Nonetheless, crop establishment of switchgrass still poses problems such as long dormancy of the seeds and the need for high temperatures and good water supply for good germination, usually <u>requiring irrigation after sowing</u>.

- European Energy Crops InterNetwork, Dec 1998

http://www.eeci.net/archive/biobase/B10432.html

The Mountain region (AZ, CO, ID, MT, NM, NV, UT, WY) is not presented, as switchgrass, willow, or hybrid poplar <u>production on any large scale is not possible in this region without irrigation</u>. California is also not represented for the same reason.

- Oak Ridge National Laboratory, Apr 1999

http://bioenergy.ornl.gov/reports/graham/regional.html

Bioethanol energy input

- While the yields per acre for switchgrass are greater than for corn, it takes more energy to convert it into ethanol because the sugars are more complex.

	Corn			Switchgrass		
	Fraction of gasoline displaced			*Fraction of gasoline displaced*		
	10%	**25%**	**50%**	**10%**	**25%**	**50%**
Agricultural diesel fuel use	0.084	0.21	0.43	0.060	0.15	0.30
Irrigation pumping energy	0.028	0.069	0.18	0.013	0.033	0.065
Other farming energy	0.26	0.65	1.3	0.26	0.64	1.3
Refining energy	1.2	3.1	6.1	1.4	3.5	7.0
Transportation energy	0.024	0.059	0.12	0.024	0.059	0.12
Total	**1.6**	**4.1**	**8.1**	**1.8**	**4.4**	**8.8**

Data shown in quadrillion BTU per year

Logistical Problems are Enormous - examples

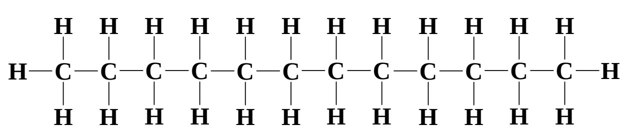
- Raw material – shipment by rail and truck – 70 billion additional ton-miles/yr or 10,000 miles (16000 km) for 50% gasoline replacement;
- Processing material – enormous reactor tank requirement: thousands of reactors – building a few per day will take 30-40 years – who makes, who pays, who can wait around for this?
- Long fermentation periods make contamination inevitable; yields drop in real, full scale plants. Lignocellulose is a tough nut to crack.
- Distribution of final product – truck and/or tank rail car; no pipeline possibility; for 50% trucks would line up to the moon, back from the moon and halfway back to the moon a second time.

Logistical Problems are Enormous – Cont'd

- To say nothing of the fact that there is not one, single cellulosic ethanol plant in operation in the world; only a few pilot plants with mixed results and claims – no public data for scientific review.
- Typical hype – one company claims to be able to produce ethanol for $1/gal <u>anywhere</u> in the world; in fact there is <u>nowhere</u> in the world where this can be done without a large, negative cost for the biomass needed or by using voodoo economics. BTW, plant construction financing from where?
  - Please see http://i-r-squared.blogspot.com/2008/08/coskata-due-diligence.html

Diesel fuel and biodiesel fuel

- The great majority is traditional diesel fuel, created by cracking and refining crude oil
  - Traditional diesel fuel is simpler to refine than gasoline and is 15 to 18 percent more dense than traditional gasoline. It is made of long hydrocarbon chains from cetane up to $C_{12}H_{26}$



- Biodiesel fuel is derived from pure or recycled vegetable oil
  - creates low- or no-sulfur fuel

Biodiesel fuel crops

Potential biodiesel fuel crops and yields based on USDA numbers – Yields smaller than ethanol

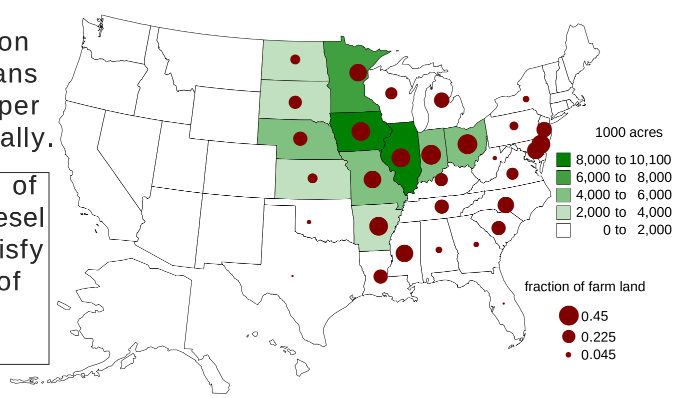
Crop	Yield [a]	Approximate equivalent yield (*gallons per acre*) [b]
Soybeans	30 gallons per ton	39 (using 43.3 bushel per acre)
Soybeans	1.4 gallons per bushel	61 (using 43.3 bushel per acre)
Corn	7.7 pounds of corn oil per gallon	-
Canola	5 gallons per hundredweight	71 (using 1419 pounds per acre)
Rapeseed	5.3 gallons per hundredweight	80 (using 1500 pounds per acre)
Sunflower	5.3 gallons per hundredweight	83 (using 1564 pounds per acre)
Mustard seed	5.3 gallons per hundredweight	42 (using 787 pounds per acre)
Animal fats and oils	7.7 pounds of yellow grease per gallon	-

[a] Yield for first soybeans entry is from www.msnbc.msn.com/id/10723254; all others are from www.fsa.usda.gov/daco/bioenergy/2002/2002FactorsNFormulas.pdf
[b] Yield per acre from U.S. average values for 2005, found at www.nass.usda.gov

Soybean production in the U.S.

About 93 million tons of soybeans are produced per year domestically.

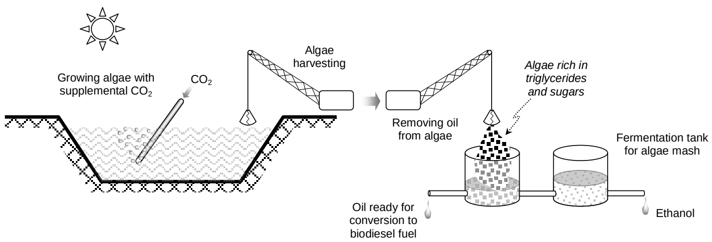
Converting **all** of this into biodiesel fuel would satisfy less than 1% of automotive energy needs.



Devoting **all** of the cropland in the U.S. to soybeans for biodiesel production would satisfy about 1/8 of the total domestic transportation energy needs

Algae

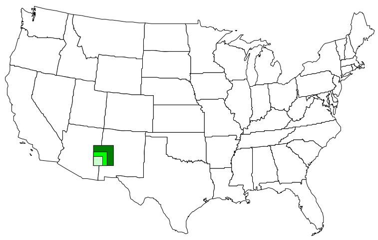
- Algae are grown in an open or closed bioreactor



Algae

- Algae are grown in an open or closed bioreactor; CO_2 absorption is new twist
- Water and land use are small compared to other biofuels; yields per hectare are high
- Six companies are operating pilot plants in the US; Arizona Public Service pilot plant had greater than expected production
- APS will now install full scale plant at Four Corners Power Plant according to recent press releases
- Key product is biodiesel

Algae – Land needs with closed bioreactor



Courtesy of MSNBC.com

Pervasive Biofuel Concerns

- Logistical requirements are huge
- US economy will have major difficulty funding what is needed for a significant biofuels industry – transport, plants; investment large, returns uncertain (in 2007 ethanol oversupply while corn price increased), tight credit market
- Water requirements are significant – the US is out of discretionary water, there is no more; southwest entering more arid climate era (NOAA, Princeton, NCAR)
- Land requirements are daunting – there is far from sufficient land to mount a real biofuels industry using crops
- Too much hype, too little attention to engineering and economic basics – more dreamland than reality just now
- Except for corn ethanol there are no large scale, proven processes in operation nor scheduled

Pervasive Biofuel Concerns, Cont'd

- "Food or fuel" moral problem with corn; falls unevenly on developing countries. The Fed and World bank blame corn ethanol explicitly for food price increases.
- Environmental impacts (GHG, water, air) are significant, there is no demonstrable benefit to biofuels from an environmental viewpoint, only a greater environment burden.

The Fossil Fuel Players Coal-to-liquid

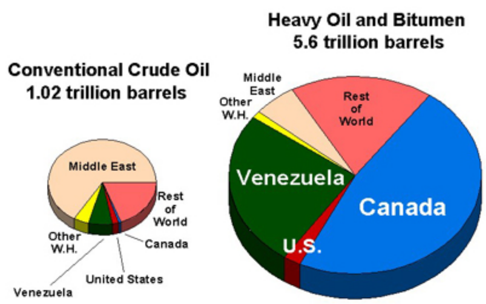
- Another possible source of automotive liquids is the conversion of coal to liquid.
  - One coal-to-liquid process involves the initial gasification of the coal
    - the subsequent process producing liquids can also be applied to the conversion of natural gas or any other hydrocarbon-rich gas.
  - The process uses about 1 ton of water per ton of coal.
  - Most of the energy that drives the process comes from the coal feedstock.

Coal-to-liquid

- Indirect liquefaction allows for 99% of sulfur and 95% percent of mercury to be removed from the stream.
  - Additionally, the CO_2 concentration in the flue gas is large and is likely to require carbon sequestration.
- The 500 billion ton U.S. coal reserve will last about 150 years
  - Even significant CTL production - 50 percent of domestic transportation fuel demand from 2025 onward – does not reduce the reserve to less than 100 years.
- Providing 50 percent of our gasoline needs using CTL by 2025 results in 1000 million tons CO_2 emissions and requires a billion tons of water annually.

Reserves of heavy oil & bitumen

Recent estimates have put the equivalent oil reserves of non-traditional sources at over five times that of conventional crude



Graphic from "Heavy Oil as the Key to U.S. Energy Security" by E. H. Herron and S. D. King, accessible at www.petroleumequities.com/cgi-bin/site.cgi?p=energysecurity.html&t=5

Other Unconventional Resources

- ***Oil shale*** is a dark marlstone rich in kerogen
  - The kerogen can be converted to oil through pyrolysis and then separated from the surrounding rock through retorting.
- Large reserves in Colorado, Wyoming, and Utah
  - Oil shale deposits in the Rocky Mountains have been estimated at anywhere from 750 billion up to 1.2 trillion barrels.
- Inherent problem is unlocking usable energy from the billions of tons of rock that contains it.
  - The rock is either mined and passed through a retorting process or it is heated in place for many years to simulate the oil window and create subsurface oil reservoirs.

Oil shale

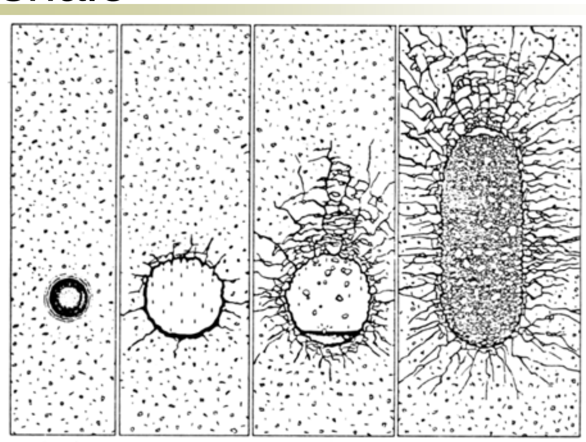
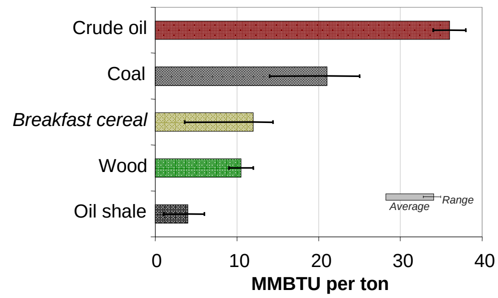


Figure 57. Typical Sequence of Events When a Nuclear Explosion is Detonated Underground

From Hendrickson, Thomas (1975) Synthetic Fuels Data Handbook, Cameron Engineers, Denver, p. 109.

Oil shale

- Oil shale has a low energy density compared to other fuels.
  - High quality oil shale would deliver about 30 gallons of oil per ton of rock mined or retorted. This is equivalent to slightly less than four million BTU per ton of rock.



Oil shale *in situ* retorting

- In-ground heating takes significant amounts of steam and/or electricity.

Randy Udall, of the Community Office for Resource Efficiency that promotes energy conservation in Carbondale, Colo., pointed out another drawback: the huge demand for electricity to cook the shale. "To do 100,000 barrels a day…we would need to build the largest power plant in Colorado history."

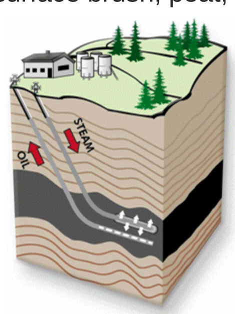
From USA Today, "Oil shale enthusiasm resurfaces in the West", June 2, 2006, p. 4A.

Other Unconventional Resources – Cont'd

- ***Tar sands*** (also called *natural bitumen* and *oil sands*) are any bitumen-rich sandy deposits
  - Oil retrieval method is similar to oil shale.
  - Athabasca tar sands in Alberta and Orinoco tar sands in Venezuela are two of the most promising deposits and combined maybe contain as much as 2/3 of the total world-wide oil deposits.
- In the United States, reserves of heavy hydrocarbons in the form of tar sands are primarily in Alaska and Utah.
  - The Kuparuk River deposits in Alaska contain an estimate 19 billion barrels (about 5x the estimated reserves in ANWR)
  - The total estimated reserves in Utah are about 32 billion barrels, with about two thirds concentrated in the Tar Sand Triangle deposits.

Tar sand extraction

- About twenty percent of the Canadian tar sands is in surface recoverable areas.
  - For the near-surface deposits it is estimated that about 1.2 million cubic feet of overburden (i.e., surface brush, peat, and topsoil) must be removed for every 50,000 barrels of recovered bitumen along with 100,000 tons of sand.
  - The rest are too deep and would have to be recovered with in-situ processing



Heavy oil extraction

- The heavy crude and bitumen reserves are estimated in the hundreds of thousands of barrels per acre.

Canada, which exports more oil to the United States than any other country, already is having trouble meeting its pledge to cut carbon dioxide emissions largely because of its mushrooming heavy-oil production. By 2015, ***Canada's Fort McMurray region, population 61,000, is expected to emit more greenhouse gases than Denmark, a country of 5.4 million people.***

From "As Prices Surge, Oil Giants Turn Sludge Into Gold," Wall Street Journal, Mar 27, 2006

Summary of Life Cycle results

		Land use				Water use (gallons)		Energy ratio	CO_2 emissions[a]
Fuel source	**Transportation energy displacement**	**Acres[b]**	**Fraction of U.S. cropland**	**gallons of fuel per acre**	**MMBTU of fuel per acre**	**per gallon of fuel**	**per MMBTU of fuel**	**BTU input per BTU of fuel**	**lb per MMBTU of fuel**
Conventional gasoline	**0-100%**	tens of thousands	very low	-	-	5	45	0.05	220
Conventional diesel	**0-100%**	tens of thousands	very low	-	-	10	80	0.09	220
Corn-based ethanol	**10%**	65 M	20%	370	28	170	2200	0.98	350
	25%	160 M	51%	370	28	180	2300	0.98	350
	50%	337 M	103%	360	28	220	2900	0.98	350
Cellulosic ethanol	**10%**	46 M	15%	515	39	146	1900	0.92	350
	25%	112 M	35%	515	39	146	1900	0.92	350
	50%	228 M	72%	510	39	149	1900	0.92	350
Soybean biodiesel fuel	**10%**	253 M	80%	57	7	900	6900	0.76	185-220
	25%	380 M	120%	57	7	900	6900	0.76	185-220
	50%	1.2 B	390%	57	7	900	6900	0.76	185-220
Coal-to-liquid	**10%**	4,100	very low	~4.4 M	~500,000	3	24	~0.5	~385
	25%	10,300							
	50%	20,600							
Algaculture[d]	**10%**	2.5 M	< 1%	6000	800	50	400	0.2	absorbs waste power plant CO_2
	25%	6.5 M	2%	6000	800	50	400	0.2	
	50%	13 M	4 %	6000	800	50	400	0.2	
Heavy crude - Canada	**0-100%**	a few thousand	very low	-	-	~10	~80	~0.25	~200
***In situ* oil shale**	**10%**	7,500[c]	very low	~20 M	~65,000	~6	~45	~0.15	~240
	25%	19,000[c]							
	50%	37,000[c]							
Tar sands - Canada	**10%**	48,000[c]	very low	~3 M	~350,000	~5	~38	~0.25	~200
	25%	120,000[c]							
	50%	240,000[c]							

[a]not including one time clearing of new land

For more information…

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Additional readings: www.fuelsandenergy.com