PROBLEMY EKOROZWOJU – PROBLEMS OF SUSTAINABLE DEVELOPMENT
2012, vol. 7, no 2, 15-22

Energy Production from Maize

Produkcja energii z kukurydzy

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Abstract

All biofuels produced in the world utilize food resources. This contributes to the world starvation problem that is reported to be more than 66% of the world population being malnourished. Starvation is the number one cause of death in the world. Approximately 40% of U.S. corn is being converted into ethanol and 1.6 liters of fossil oil equivalents are required to produce 1 liter of ethanol. Thus, the U.S. is importing oil to produce ethanol at an enormous economic and fuel cost to the people of the nation, and reduces food resource availability to the people.

Key words: biofuels, maize, carbon print

Streszczenie

Produkcja biopaliw oznacza zużywanie zasobów żywności – to prowadzi do narastania problemu głodu. Szacuje się, że więcej niż 66% ludzi na świecie cierpi z powodu niedożywienia. Głód jest także najważniejszą przyczyną śmierci. Tymczasem ok. 40% amerykańskiej kukurydzy przeznacza się na produkcję etanolu. Co więcej, na wytworzenie 1 litra etanolu zużywa się 1,6 litra ekwiwalentu ropy. W tej sytuacji Ameryka musi importować ropę w celu produkcji etanolu, ponosząc przy tym ogromne koszty, zmniejszając zarazem dostępność żywności dla obywateli.

Słowa kluczowe: biopaliwa, kukurydza, ślad węglowy

***Note from the editorial board:**
In the European Union, through low carbon economy, wide use of ethanol as an alternative fuel for cars is being promoted. The article, that is printed here, shows that this solution is a dead end. Through the analysis of production cycle the Author proves, that carbon print of ethanol is bigger than carbon print of fuels extracted from oil. What's more, the production of ethanol as a fuel is connected with major pollution of the environment and significant increase of water used for irrigation of crops.
Professor D. Pimentel is also pointing out at a moral aspect: production of liquid biofuels from biomass is leading to increase of food prices, and the food is becoming more difficult to get for people living in poor parts of the world.
The arguments, formulated by professor D. Pimentel, undermine the thesis, that liquid fuels produced from biomass are the alternative for the fuels extracted from the oil. The analysis showed, that introducing liquid fuels from biomass is also in contradiction to the idea of sustainable development.

*** Nota od redakcji:**
W Unii Europejskiej w ramach ekonomii niskowęglowej promuje się min. szerokie stosowanie etanolu jako alternatywnego paliwa dla samochodów. Z artykułu, który publikujemy, wynika, że jest to ślepa uliczka. Analizując cały cykl produkcyjny Autor wykazuje, że ślad węglowy etanolu jest większy od śladu węglowego paliw uzyskiwanych z ropy naftowej. Ponadto, produkcja etanolu jako paliwa jest związana ze znaczącym zanieczyszczeniem środowiska i ze znaczącym zwiększeniem zużycia wody do nawadniania upraw.
Profesor D. Pimentel zwraca uwagę jeszcze na aspekt moralny: produkcja biopaliw ciekłych z biomasy wpływa już na wzrost cen żywności, która staje się coraz trudniej dostępna dla mieszkańców ubogich części świata.

Argumenty przedstawione przez profesora D. Pimentela podważają tezę głoszącą, że paliwa ciekłe produkowane z biomasy stanowią alternatywę dla paliw uzyskiwanych z ropy naftowej. Co więcej, przeprowadzona analiza wykazuje, że wprowadzanie ciekłych paliw produkowanych z biomasy jest sprzeczne z ideą zrównoważonego rozwoju.

Introduction

Each year, the U.S. and other nations import more than 60% of their oil at a tremendous cost to themselves (USCB, 2009). In the U.S. alone, oil represents nearly 40% of the U.S.'s energy consumption, leading the International Energy Administration (2008) and other organizations to estimate that cheap world oil supplies will be depleted by 2040 (Murray, 2004; Green et al., 2006; Hodge, 2008; W. Youngquist, Personal communication, December 8, 2009). Such a forecast has created an urgent need for an alternate liquid fuel and has stimulated many nations to seek diverse ways to produce liquid fuels. As a consequence, maize ethanol production has become a popular feedstock for ethanol production. Unfortunately the production of ethanol from maize grain has proven to be energetically and environmentally costly in terms of the subsidies which now total $12 billion per year (Koplow and Steenblik, 2008). In addition, converting corn into ethanol has increased U.S. food prices (Pimentel et al.,2009). Clearly, using food as a source of ethanol presents important ethical problems.

Increasing food costs and reduced food supplies worldwide has both the Director General of the United Nations and President of the World Bank warning that using grains and other human foods to produce fuel is leading to increasing malnutrition and starvation worldwide (Spillius, A. 2008). A total of 2.3 billion tons of grains are produced annually in the world and about 20% of this total is used for ethanol production. Another important food product, vegetable oils, are being used for biofuel, these oils include soybean, canola, and palm oil. Currently in Europe 60% of the rapeseed oil is being used for biodiesel or about 1.5 billion gallons (6 billion liters) (FAO, 2009).

Using food products in the production of biofuels is particularly troublesome because of the limited supply of biofuel energy that can be produced from foods. For example, the U.S. currently produces 34 billion liters of ethanol, consuming 33% of all U.S. maize production now, but only provides 1.7% of total oil consumption in the U.S. assuming no fossil energy inputs (USCB, 2009). In fact, if 100% of U.S. maize were converted into ethanol it would provide the U.S. with only 5% of its needed oil fuel, assuming again zero fossil energy inputs.

Other countries like Brazil, are producing about 27 million liters of ethanol but their source of ethanol is from sugarcane (Ministry of Brazilian Agriculture 2009). However, even the 27 million liters of ethanol are not enough to meet their consumption needs as Brazil's oil consumption during the past 10 years has increased 42% (Ministry of Brazilian Agriculture 2009). Additional costs to consumers in Brazil include the subsidies that total several billion dollars per year just for ethanol (Murray, 2004; Coelho, 2005; Green et al., 2006; Hodge, 2008;Berg, 2004; FEE, 2009; Schmitz et al., 2009). Others report that there are no subsidies for Brazilian ethanol (Union of Sugarcane Industry Association, 2009; Walter, 2009). However, the subsidies for ethanol are contributing to deforestation and other environmental problems in Brazil (Pacific Ecologist, 2009).

In addition to the subsidies in the U.S. and Brazil, there is the question whether green plants, such as maize, switchgrass, willow, and all other kinds of biomass can provide suitable sources of liquid fuels. Unfortunately, these green plants in the U.S. convert only about 0.1% solar energy into plant material (Table 1; Pimentel et al., 2009). The use of grain and other biomass for liquid fuels, also contribute CO_2 emission to the atmosphere (Pimentel et al., 2009). In contrast, photovoltaic cells collect more than 150 times the solar energy that green plants collect and add relatively little CO_2 to the atmosphere (Pimentel, 2008; Pimentel and Patzek, 2008).

In this article, we examine the potential for improving the efficiency of converting corn grain and cellulosic biomass into ethanol. Also we examine the production of biodiesel using algae. In summary, we attempt to define the impact of biofuel production on greenhouse gas emissions and the prevention of malnutrition and hunger.

Energy Inputs in Corn Ethanol Production

In this analysis, the most recent scientific data for maize fermentation/distillation were used. All current fossil energy inputs were also used in maize production and for the fermentation and distillation and were included to determine the entire energy cost of ethanol production. Additional costs to consumers include federal and state subsidies (Koplow and Steenblik, 2008), plus costs associated with environmental pollution and/or degradation that occur during the entire production process.

In a large ethanol conversion plant, the ethanol yield from 2.69 kg of maize grain produces 1 liter of ethanol (approximately 9.5 liters pure ethanol per bushel of corn). The production of maize in the United States requires a significant energy and monetary investment for an average of 14 inputs, including labor, farm machinery, fertilizers, irrigation, pesticides, and electricity (Table 2). As listed in table 2, the production of an average maize yield of 9,500 kg/ha (151 bu/ac) of maize using up-to-date production technologies requires the expenditure of about 7.4 million kcal of energy inputs (mostly natural gas and oil). This is the equivalent of about ~743 liters of oil equivalents expended per hectare of maize. The production costs total $835/ha for the 9,500 kg/ha or approximately 11¢/kg (**$**2.34/ bushel) of maize produced (Table 1).

Table 1. Total amount of biomass and solar energy captured each year in the United States.
An estimated 27.8 x 10^{18} BTU of sunlight reaching the U.S. per year suggests that the green plants (crops, grasses, and forests) in the U.S. are collecting 0.1% of the solar energy reaching these plants (Pimentel et al., 2009).

	Million ha	tons/ha	x 10^6 tons	Total Energy Collected x 10^{15} BTU
Crop	160	5.5	901	14.4
Pasture	300	1.1	333	9.6
Forests	264	2.0	527	8.4
TOTAL	724		1,758	27.8

Full irrigation (when there is insufficient or no rainfall) requires about 100 cm/ha of water per growing season. Because from 15% to 19% of U.S. maize production is irrigated (USDA, 1997a; Supalla, 2007), only 8.1 cm per ha of irrigation was included for the growing season. On average, irrigation water is pumped from a depth of 100 m (USDA, 1997a). On this basis, the average energy input associated with irrigation is 320,000 kcal per hectare (Table 2).

Energy Inputs in Maize Fermentation/ Distillation

The average costs in terms of energy and dollars for a large, modern dry-grind ethanol plant are significant and are listed in Table 3. In the fermentation/distillation process, the maize is finely ground and approximately 8 liters of water are added per 2.69 kg of ground maize. Some of this water maybe recycled. After fermentation, the mixture is distilled to obtain a liter of 95% pure ethanol from the 8-12% ethanol beer and 92-88% ethanol concentration. The 1 liter of ethanol must be extracted from approximately 11 liters of the ethanol/water mixture. Although ethanol boils at 78°C, and water boils at 100°C, the ethanol is not extracted from the water in the first distillation, which obtains 95% ethanol (Maiorella, 1985; Wereko-Brobby and Hagan, 1996; S. Lamberson, personal communication, Cornell University, 2000). To be mixed with gasoline, the 95% ethanol must be further processed and more water removed, requiring additional fossil energy inputs to achieve 99.5% pure ethanol (Table 3). Thus, a total of 8 liters of wastewater is required

Table 2. Energy inputs and costs of corn production per hectare in the United States.

Inputs	Quantity	kcal x 1000	Costs $
Labor	11.4 hrs[a]	520[b]	148.20
Machinery	55 kg[d]	1,018[e]	110.00[f]
Diesel	62 L[g]	620[h]	46.42
Gasoline	9 L[i]	90[j]	7.14
Nitrogen	150 kg[k]	2,475[l]	85.25[m]
Phosphorus	55 kg[n]	228[o]	48.98[p]
Potassium	62 kg[q]	202[r]	26.04[s]
Lime	1,120 kg[t]	315[u]	28.64
Seeds	21 kg[v]	520[w]	74.81[x]
Irrigation	8.1 cm[y]	320[z]	123.00[aa]
Herbicides	2.3 kg[bb]	230[ee]	35.29
Insecticides	0.7 kg[cc]	70[ee]	32.55
Electricity	103.2 kWh[g]	34[ff]	7.22
Transport	107 kg[gg]	122[hh]	61.20
TOTAL		7,438	834.74
Corn yield 9,500 kg/ha[ii]		kcal input: 1;4.60	

a) NASS, 2005.
b) It is assumed that a person works 2,000 hrs per year and utilizes an average of 9,000 liters of oil equivalents per year.
c) It is assumed that labor is paid $20 an hour.
d) Pimentel and Pimentel, 2008.
e) Prorated per hectare and 10 year life of the machinery. Tractors weigh from 6 to 7 tons and harvesters 8 to 10 tons, plus plows, sprayers, and other equipment.
f) Estimated.
g) William McBride, Personal Communication, USDA, 2010.
h) Input 11, 400 kcal per liter.
i) Estimated
j) Input 10,125 kcal per liter.
k) NASS, 2003
l) Cost $.55 per kg.
m) Patzek, 2004
n) NASS, 2003.
o) Input 4,154 kcal per kg.
p) Cost $.62 per kg.
q) NASS, 2003.
r) Input 3,260 kcal per kg.
s) Cost $.31 per kg.
t) Estimated.
u) Input 281 kcal per kg.
v) Pimentel and Pimentel, 2008.
w) Pimentel and Pimentel, 2008.
x) Estimated.
y) USDA, 1997a.
z) Batty and Keller, 1980.
aa) Irrigation for 100 cm of water per hectare costs $1,000 (Larsen et al., 2002).
bb) NASS, 2005.
cc) USDA, 2002.
dd) USDA, 1991.
ee) Input 100,000 kcal per kg of herbicide and insecticide.
ff) Input 860 kcal per kWh and requires 3 kWh thermal energy to produce 1 kWh electricity.
gg) Goods transported include machinery, fuels, and seeds that were shipped an estimated 1,000 km.
hh) Input 0.34 kcal per kg per km transported.
ii) Average. USDA, 2007; USCB, 2008.

Table 3. Inputs per 1000 liters of 99.5% ethanol produced from corn.[a]

Inputs	Quantity	Kcal x 1000	Dollars $
Corn grain	2,690 kg[a]	2,106[b]	634.14
Corn transport	2,690kg[b]	264[c]	27.63[d]
Water	7,721 L[e]	46[f]	3.86[g]
Stainless steel	3 kg[i]	42[r]	8.52[u]
Steel	4 kg[i]	40[s]	2.39[u]
Cement	8 kg[i]	11[s]	1.86[v]
Steam	2,564,764 kcal[t]	2,362[t]	59.94[k]
Electricity	395 kWh[t]	2,863[t]	26.38
95% ethanol to 99.5%	9 kcal/L[m]	9[m]	40.00
Sewage effluent	20 kg BOD[n]	69[h]	6.00
Distribution	331 kcal/L[q]	331	375.00
TOTAL		8,143	$ 1185.72

a) Output: 1 liter of ethanol = 5,130 kcal (Low heating value). The mean yield of 9.5 L pure EtOH per bushel has been obtained from the industry-reported ethanol sales minus ethanol imports from Brazil, both multiplied by 0.95 to account for 5% by volume of the #14 gasoline denaturant, and the result was divided by the industry-reported bushels of corn inputs to ethanol plants (See: http://petroleum.berkeley.edu/patzek/BiofuelQA/Materials/TrueCostofEtOH.pdf (Patzek, 2006).
c) Calculated for 144 km roundtrip.
d) Pimentel et al., 2009.
e) 7.7 liters of water mixed with each kg of grain.
f) Pimentel et al., 2009.
g) Pimentel et al., 2009.
h) 4 kWh of energy required to process 1 kg of BOD (Blais et al., 1995; Illinois Corn, 2004).
i) Estimated from the industry reported costs of $85 million per 65 million gallons/yr dry grain plant amortized over 30 years. The total amortized cost is $43.6/1000L EtOH, of which an estimated $32 go to steel and cement.
j) Patzek, 2008.
k) Calculated based on coal fuel. Below the 1.95 kWh/gal of denatured EtOH in South Dakota, see j).
l) $0.07 per kWh (USCB, 2004-2005).
m) 95% ethanol converted to 99.5% ethanol for addition to gasoline (T. Patzek, personal communication, University of California, Berkeley, 2004).
n) 20 kg of BOD per 1000 liters of ethanol produced (Martinelli, 2009).
p) Newton, 2001.
q) DOE, 2002.
r) Johnson et al., 2007
s) Venkatarama and Jagadish, 2003.
t) Lin and Echkhoff, 2009.
u) Steel Mill, 2010.
v) Concrete Products, (2010).

for the production of 1 liter of ethanol, and the disposal of this relatively large amount of sewage effluent comes at an energetic, economic, and environmental cost.

The production of a liter of 99.5% ethanol, including the energy to produce the corn, requires 158% more fossil energy than the energy present in 1 liter of ethanol and costs $1.19 per liter ($4.48 per gallon) (Table 3). The corn feedstock requires more than 26% of the total energy input. In this analysis, the total cost, including the energy inputs for the fermentation/distillation process and the apportioned energy costs of steam, electricity, and stainless steel tanks and other industrial materials is significant (Table 3).

Net Energy Yield

The largest energy inputs in cmaize-ethanol production are corn feedstock production energy, steam energy, and electricity used in the fermentation and distillation process. The total energy input to produce a liter of ethanol is 8,143 kcal (Table 3). However, a liter of ethanol has an energy value of only 5,130 kcal. Based on a net energy loss of 3,013 kcal of ethanol produced, 58% more fossil energy is expended than is produced as ethanol.

Economic Costs

Current maize ethanol production technology uses more fossil fuel and costs substantially more to produce in dollars than its energy value is worth on the market. Without the more than $12 billion annual federal and state government subsidies, U.S. ethanol production would be reduced or cease, confirming the basic fact that ethanol production is uneconomical and does not provide the U.S. with any net energy benefit (Koplow and Steenblik, 2008).

Federal and state subsidies for ethanol production that total more than $12 billion/year for ethanol are mainly paid to large corporations (Koplow and Steenblik, 2008), while maize farmers are receiving a minimum profit per bushel for their maize (Pimentel and Patzek, 2008). Senator McCain reports that direct subsidies for ethanol, plus the subsidies for maize grain, amount to 79¢ per liter (McCain, 2003).

About 80% of the ethanol in Brazil is also heavily subsidized (Berg, 2004). Even with heavy subsidies, about half of the fuel burned in autos in Brazil is gasoline, only about 50% is ethanol (Berg, 2004). Sugar subsidies have a major impact on ethanol production from sugarcane.

If the production cost of a liter of ethanol were added to the tax subsidy cost, then the total cost for a liter of ethanol would be $1.54. The mean wholesale price of ethanol was almost $1.00 per liter without subsidies. Because of the relatively low energy content of ethanol, 1.6 liters of ethanol have the energy equivalent of 1 liter of gasoline. Thus, the cost of producing an amount of ethanol equal a liter of gasoline is about $2.33 ($8.82 per gallon of gasoline). This is more than the 53¢ per liter, the current cost of producing a liter of gasoline. The subsidy per liter of ethanol is 60 times greater than the subsidy per liter of gasoline! This is the reason why ethanol is so attractive to large corporations.

Maizeland Use

In 2008, about 34 billion liters of ethanol (9 billion gallons) are being produced in the United States each year (EIA, 2008). The total amount of petroleum fuels used in the U.S. is about 1,270 billion liters (USCB, 2009). Therefore, 34 billion liters of ethanol (energy equivalent to 22 billion liters of petroleum fuel) provided only 1.7% of the petroleum utilized. To produce this 34 billion liters of ethanol, about 9.6 million ha or 34% of U.S. maize land was used. Expanding maize-ethanol production to 100% of U.S. maize production would provide just 4% of the petroleum needs of the U.S., while diminishing cropland needed for food production.

However, U.S. maize cultivation may continue to increase because of the ethanol targets (36 billion gallons) set by the most recent Energy Bill (Donner and Kucharik, 2008) of which 15 billion gallons which are to be produced from maize grain.

Corn production is the prime cause of the *dead zone* in the Gulf of Mexico (NAS, 2003). Increased maize ethanol production will increase the nitrogen fertilizer pollution in the Gulf of Mexico (Donner and Kucharik, 2008).

By Products

The energy and dollar costs of producing ethanol can be offset partially through by-products, like the dry distillers grains (DDG) made from dry-milling of maize. From about 10 kg of maize feedstock, about 3.3 kg of DDG with 27% protein content can be harvested (Stanton, 1999). The DDG is suitable for feeding cattle that are ruminants, but has only limited value for feeding hogs and chickens. In practice, this DDG is generally used as a substitute for soybean feed that contains 49% protein (Stanton, 1999). However, soybean production for livestock feed is more energy efficient than maize production because little or no nitrogen fertilizer is needed for the production of this legume feed (Pimentel et al., 2002). In practice, only 2.1 kg of soybean protein provides the equivalent nutrient value of 3.3 kg of DDG (or nearly 60% more DDG is required to equal the soybean meal protein). Thus, the credit fossil energy per liter of ethanol produced is about 445 kcal. Factoring this credit for a non-fuel source in the production of ethanol reduces the negative energy balance for ethanol production from 158% to 151% (Table 3). The high energy credits for DDG given by some are unrealistic because the production of livestock feed from ethanol is uneconomical given the high costs of fossil energy, plus the costs of soil depletion to the farmer (Patzek, 2004).

The resulting overall energy output/input comparison remains negative even with the large credits for the DDG by-product.

Environmental Impacts

Some of the economic and energy contributions of the by-products are negated by the widespread environmental pollution problems associated with ethanol production. First, U.S. maize production causes more soil erosion than any other U.S. crop (Pimentel et al., 1995; NAS, 2003). In addition, maize production uses more herbicides and insecticides and nitrogen fertilizer than any other crop produced in the U.S. Consequently, maize causes more water pollution than any other crop since there is a large quantity of these chemicals invading ground and surface waters, thereby causing more water pollution than any other crop (NAS, 2003).

Another environmental impact of biomass crop production is the land use change that they demand. Nabuurs et al. (2007) reports that the limit for biomass crops is the availability of arable land, and that the massive scale necessary will require deforestation. However, an important consideration when evaluating the environmental effects of biofuels is whether the emissions avoided are higher and in favor of biofuel production or in favor of forest preservation and expansion (Righelato, 2007). According to the International Energy Authority, forests converted to cropland has a negative environmental impact because of the land change that destroys the carbon sink that the forest represented (IEA, 2004). Renton Righelato (2007) of the World Land Trust investigated the impacts of land use changes from forest to biofuel cropland, and found that the amount of carbon sequestered, emissions avoided, by tropical forests is 3 to 4 times more than the emissions avoided by bioethanol production. Only after the forest area reaches maturity, 50 to 100 years, would the emissions avoided from cropland conversion be able to surpass the amount of carbon stock that is accumulated and calculated according to models for the power of age in a forest structure (Righelato, 2007; Alexandrov 2007; Sylvesster-Bradley, 2008).

As mentioned, the production of 1 liter of ethanol requires 1,700 liters of freshwater both for corn production and for the fermentation/distillation processing of ethanol (Pimentel and Patzek, 2008). In some Western irrigated corn acreages, like some regions of Arizona, ground water is being pumped 10-times faster than the natural recharge of the aquifers (Pimentel et al., 2004). Ethanol production using sugarcane requires slightly more water per ethanol liter than corn ethanol or about 2,000 liters of water.

In addition, because 1.59 liters more fossil fuel is required to produce 1 liter of ethanol than the ethanol produced, this confirms that ethanol production is significantly contributing to the global warming problems (Pimentel and Pimentel, 2008). All these factors confirm that the environmental and agricultural system in which U.S. maize is being produced is experiencing major degradation. Further, it substantiates the conclusion that the U.S. maize production system, and indeed the entire ethanol production system, is not environmentally sustainable now or for the future, unless major changes are made in the cultivation of this major food/feed crop. Because maize is raw material for ethanol production, it cannot be considered a renewable energy source.

Pollution problems associated with the production of ethanol at the chemical plant sites are also emerging. The EPA (2002) already has issued warnings to ethanol plants to reduce their air pollution emissions or be shut down. Another pollution problem concerns the large amounts of wastewater produced by each ethanol plant. As noted, the production of 1 liter of maize ethanol produces 6-12 liters of wastewater. This polluting wastewater has a biological oxygen demand (BOD) of 18,000 to 37,000 mg/liter depending on the type of plant (Kuby, et al., 1984; Patzek, 2004). The cost of processing this sewage in terms of energy (4 kWh/kg of BOD) was included in the cost of producing ethanol (Table 3) maize and all other biomass crops is that they collect on average only 0.1% of the solar energy per year (Pimentel et al, 2009). At a fairly typical gross yield of 3,000 liters of ethanol per hectare per year, the power density achieved is only 2.1 kW/ha. That is compared with the gross power density achieved via oil, after delivery for use, on the order of 2,000 kW/ha. (Ferguson, 2007).

World Malnutrition and Use of Food for Biofuel

The Food and Agriculture Organization (FAO) of the United Nations estimated that there were 1.02 billion undernourished people worldwide in 2009, representing approximately a sixth of the entire population. In its 2009 report, *The State of Food Insecurity in the World*, the FAO defined undernourishment as being *when caloric intake is below the minimum dietary energy requirement (MDER)*, where MDER *is the amount of energy needed for light activity and a minimum acceptable weight for attained height.* Caloric intake is certainly not the only measurement of malnourishment; micronutrient deficiencies can also have severe health impacts. In 2000, the World Health Organization (WHO) estimated that the number of people who have iron deficiency anemia is around two billion. Anemia can result in extreme fatigue, impairment of physical and mental development in children, and higher maternal deaths. The WHO also estimated that 740 million people have iodine deficiency disorder, which can have severe impacts on children's brain development. Both WHO and FAO combined are reporting more than 66% of the world population are currently malnourished results in the number one cause of death in the world.

As more land and crops are devoted to the production of biofuels, rather than to human consumption, concerns have been raised that malnutrition will worsen (Pimentel et al, 2009). Jacques Diouf, head of the FAO, stated in 2007 that he feared that a number of factors, including the production of crops for biofuels, create *a very serious risk that fewer people will be able to get food* and the poor will suffer (Rosenthal 2007). The president of the World Bank, Robert Zoellick, shared a similar apprehension, asserting that demand for biofuels has been a *significant contributor* to ballooning food prices. According to Zoellick, *It is clearly the case that programs in Europe and the United States that have increased biofuel production have contributed to the added demand for food* (2008) and increased food prices (Congressional Budget Office, 2009). Jean Ziegler, the UN Special Rapporteur on the Right to Food, has taken a more extreme stance. In 2007, he claimed biofuels to be a *crime against humanity* and called for a five-year moratorium on their production (Ferrett 2007).

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