



Biofuels production: A sustainable solution to combat climate change

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ABSTRACT

This paper reviews the situation of biofuels production with regard to climate change and sustainability. The biomass energy or biofuels combustion is carbon neutral or even carbon negative as the carbon, which is stored during its growth, is released and does not add new carbon to the active carbon cycle, whereas fossil fuels such as coal, oil and natural gas remove carbon from geologic storage and contribute to climate change by emission of GHGs. Biofuel also controls the carbon emissions from biomass facilities which would have been released back into the atmosphere through natural decay or disposal through open-burning. In spite of these GHG benefits, the progress in biofuels expansion is at crossroads as it is influenced by various factors like land use changes and food security related issues. However biofuels from degraded land and from non-food crops are promising and will help in climate change mitigation. Proper planning in land use and identifying most appropriate policies for promoting this will help in tackling the global issue and in achieving the goal. The technology utilizing carbon sequestered in various sources, for ethanol, biodiesel and other biofuels production is a sustainable solution to climate change rather than biofuels from food crops.

Key words: Biofuel, Biomass, Climate change

Climate change has been recognized as a global issue with regional implications and one of the most serious challenges of the twenty first century. It is looming large with immense impact on various aspects. The United Nations Framework Convention on Climate Change (UNFCCC), define climate change as “a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods”. The new definition introduced by IPCC in Special Report (2011) for climate change- a change in the state of the climate that can be identified (e.g. by using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcing, or to persistent anthropogenic changes in the composition of the atmosphere or in land use.

According to the United Nations Intergovernmental Panel on Climate Change (IPCC 2007), the global climate is undergoing dramatic changes as the direct result of greenhouse gas (GHGs) emissions from human activity. The primary GHGs are carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O) and ozone (O₃) (Steinfeld *et al.*

2006). Global atmospheric CO₂ concentration has increased from a pre-industrial value of about 280 ppm in 1850 to current 396 ppm (December 2013; <http://www.noaa.gov/>) and there has been significant increases in methane and nitrous oxide as well (Table 1). Thus human activity has caused an imbalance in the natural cycle of the greenhouse effect and related processes. These GHGs are trapping heat over the Earth’s surface, resulting in changes in climatic processes as evidenced by higher temperatures, rising sea levels, increased ocean acidity and ice melting. Global surface temperature has increased by roughly 0.74 °C (1.33 °F) at the end of the 20th century. IPCC’s latest findings state the global average temperature will probably raise a further 1.1 to 6.4 °C (2.0 to 11.5 °F) this century, depending on the extent of greenhouse gas emissions (IPCC 2007). Carbon dioxide (CO₂) is the most significant greenhouse gas released to atmosphere and the share of anthropogenic activities to total emissions in CO₂-

Table 1 Global GHGs concentration over pre-industrial and current period (IPCC 2007)

Green house gas	Pre-industrial level	Current level	Increase since 1750	Radiative forcing (W/m ²)
CO ₂	280 ppm	394 ppm	114 ppm	1.46
CH ₄	700 ppb	1745 ppb	1045 ppb	0.48
N ₂ O	270 ppb	314 ppb	44 ppb	0.15
CFC	0	533 ppt	533 ppt	0.17

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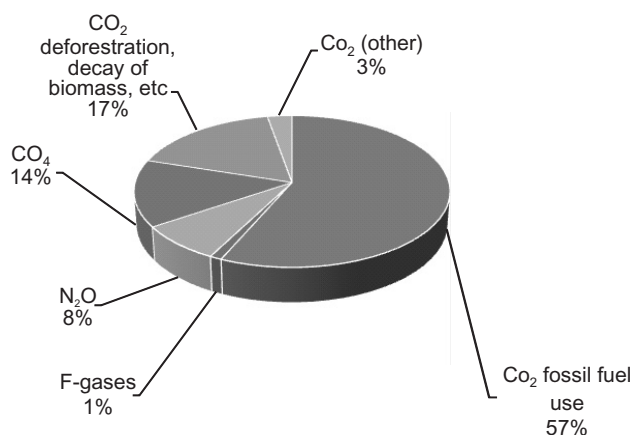


Fig 1 Contributions of GHGs by various anthropogenic activities to total emissions in CO₂-eq. (Source: IPCC, AR4 2007)

eq. (Fig 1) shows the major source is the burning of fossil fuels (IPCC 2007).

Since the industrial revolution the anthropogenic emissions of CO₂ has increased and its concentration today is more than 390 ppm (Table 1). The estimates of CO₂ concentrations at the end of the 21st century range from 490 to 1260 ppm, or a 75% to 350% increase above preindustrial concentrations (Greenhouse gas bulletin 2006). If the burning of fossil fuels like coal and oil is not decreased, the Earth will very likely heat up even faster, completely changing the world we live in. It is predicted to lead to adverse impacts on human systems like agricultural, health and leave irreversible impacts on the earth and the ecosystem as a whole. Climate change in particular appears to be altering the function, structure and stability of the Earth's ecosystems (Lovelock 2009). We can either adapt to the corresponding changes or try to reduce their impact by significantly reducing fossil fuel burning. Biofuels-based economy using energy from biomass, solar, wind and other renewable sources and nuclear energy seems to be a viable alternative. Globally, biofuels have attracted much attention since they have become a leading alternative to fossil fuel and are produced domestically by many countries; require only minimal changes to retail distribution and end-use technologies. Moreover they have the potential to spur rural development (Rajagopal *et al.* 2007).

The IPCC (IPCC 2007) proposed a 10% substitution of fossil fuels with biofuels within two decades. In order to achieve the estimated goal of substituting 10% of the projected diesel and gasoline consumption by 2030, 270 Mt of biodiesel and 435 Mt of ethanol are required globally and in India it is about 13 and 20 Mt, respectively. According to estimations the land requirement to meet this demand for India ranges from 14 to 20 Mha (OECD/FAO 2006, for total oil consumption for 2030). Sustainable transition to a biofuel-intensive future requires considerable technical innovation, such as agricultural productivity growth, development and commercialization of cellulosic biofuel/ethanol production, and a reduction in the resource intensity of biofuels (Rajagopal *et al.* 2007). But it is imperative

from the future perspective to have a smooth transition from a fossil fuel based economy to alternative clean biofuels.

CONTRIBUTION OF VARIOUS CONVENTIONAL ENERGY SOURCES TO CLIMATE CHANGE

Fossil fuel consumption

Fossil fuel consumption is the largest contributor to greenhouse gas emissions. The burning of fossil fuels like coal, petroleum and natural gas, etc. produces around 21.3 billion tonnes (21.3 gigatonnes) of carbon dioxide (CO₂) per year and the natural processes can only absorb or sequester about half of that amount, so there is a net increase of 10.65 billion tonnes of atmospheric carbon dioxide (USDoE 2007). Transportation sector is the primary consumer of petroleum products and significant contributor to overall GHG emissions, currently accounting for approximately 21% of global CO₂ emissions. The CO₂ emission from various fuel sources are given in Table 2.

It is predicted that the CO₂ emissions from transportation sector will increase by 23% of the total CO₂, by 2030 inspite of projected improvements in efficiency (IEA WEO 2009). The future emission estimates for transportation sector account for an even larger fraction, owing to exponential increase in number of vehicles all over the world, while greater reduction in emissions expected to come from other sector as a result of continuing development. Apart from carbon dioxide, methane and nitrous oxide would also have higher shares in the future emission from transportation sector unless strong action is taken. This indicates the essentiality of strong energy linked policies to combat climate change related issues in future. Furthermore, the IEA signifies the importance of transportation sector by stating that if energy-related CO₂ emissions need to be reduced by 2050 to half the level of 2005, the transport sector must make a significant contribution. However, it is difficult to achieve the rapid changes in this sector as it has central economic role and deeply influence the daily life (IEA 2008). So it is crucial to find a long-term, cost-effective strategy for reducing

Table 2 Mass of carbon dioxide emitted per quantity of energy for different fuels

Fuel	CO ₂ emission (lbs/10 ⁶ Btu)
Natural gas	117
Liquefied Petroleum Gas	139
Gasoline	156
Kerosene	159
Wood and wood waste	195
Coal (bituminous)	205
Petroleum coke	225

Source: Energy Information Administration Voluntary Reporting of Greenhouse Gases Program. <http://www.eia.doe.gov/oiaf/1605/coefficients.html>.

CO₂ emissions from the transport sector. The fossil fuel combustion leads not only to GHG emissions but also in release of some toxic compounds to atmosphere. It is proposed that, policies should also be more integrative across sectors, so that changes in energy efficiency, the automotive sector and global consumption patterns converge towards drastic reduction of the pressure on resources (Bessou *et al.* 2011).

Biomass burning and deforestation

Biomass burning is also recognized as a significant global source of emissions contributing as much as 40% of gross carbon dioxide and 38% of tropospheric ozone (Levine 1991). Besides, 1.4 million tonnes of methane (CH₄) emissions are also reported from burning traditional biomass fuels. Dung-cake is a common cooking fuel for many South Asian countries including Nepal, India, Bangladesh and Pakistan. The burning of cow dung for cooking energy resulting in the release of both toxic fumes and greenhouse gases far worse than a modern coal-burning plant could ever produce (Borders 2008). It is reported that deforestation is responsible for 17- 25% of all anthropogenic greenhouse gas (GHG) emissions worldwide (Strassburg *et al.* 2009). A large part of the deforestation in the developing countries is an effect of over consumption of firewood as a source of energy, accounting for 54% of the world's deforestation. Since the demand for firewood exceeds the supply, it leads to severe deforestation. Methane emissions from biomass burning increased by 9% in the world because of increases in tropical deforestation and the use of fuel wood (Hao and Ward 1993).

Biomass decay and climate change

Decay of biomass including manure contributes to the emission of GHGs, especially methane. Methane is a potent GHG contributing 17 per cent of total greenhouse gas emissions with global warming potential of 21 over carbon dioxide. Its concentration has increased by 150% since 1750s and accounts for 20% of total radiative forcing and currently its concentration is 1800 ppb (IPCC 2001, 2007). Livestock contributes about 18 per cent of the global GHG emissions and 37 per cent of anthropogenic methane. There are several factors governing methane emission from livestock manure including the amount of manure produced (*i.e.* average amount of manure produced per animal and the number of animals) and the portion of the manure that decomposes anaerobically (which depends on manure management system used and the climate, primarily temperature). More than 230 million metric tonnes of carbon dioxide equivalents (MMTCO₂e) of methane emissions, roughly 4 per cent of total anthropogenic methane emissions were contributed by the livestock manures in 2005. Swine (40 per cent), non-dairy cattle (20 per cent), and dairy cattle (20 per cent) - these three animal groups accounted more than 80 per cent of total emissions. Poultry is also a significant source of methane emission in some countries (EPA Report 430-R-06-003).

Enteric fermentation constitutes a major part of the total methane emissions, accounting for approximately 91 per cent, or 10.65 Tg of the total, while manure management of livestock accounts for only 9 per cent, or 1.09 Tg. Cattle and buffalo are the major source of methane emissions (10.9 Tg) compared to emissions from other livestock (0.86 Tg) (Chhabra *et al.* 2009). The production of methane is also reported from manure deposited on fields and pastures however the amount was very less. The agro-industrial wastes generated is another potential source of methane emissions, as its organic fraction is more readily biodegradable than that of manure. The nitrification and denitrification processes add to the production of N₂O during storage and treatment of animal wastes. The amount of N₂O released depends on the system and duration of waste management. The nitrogen present in manure is in ammonical (NH₃) form and converted into nitrate by nitrification aerobically and, denitrification occurs anaerobically converting the nitrate to N₂O.

Apart from these emissions, there are a number of other environmental problems associated with conventional energy use and the energy system which is turning out to be 'unsustainable' in the 21st century. In recent years, researchers have recognized the importance of holistic thinking and results include current Kyoto-based approaches to reduce the earth's greenhouse gases by seeking ways to reduce emissions and thereby solutions to the climate change.

ADAPTATION AND MITIGATION OPTIONS FOR CLIMATE CHANGE

The IPCC states that only a combination of adaptation and mitigation measures can significantly reduce the risks of expected climate change (IPCC 2007). At the 2012 Doha climate change talks, amendments to the Kyoto Protocol were made and the signed countries agreed to a second commitment period of emissions reductions from 1 January, 2013 to 31 December, 2020. Several industrialized countries committed according to second installment of Kyoto protocol to reduce greenhouse gas emissions differently to the extent of 5 to 15% either to 1990, 2000 or 2005 level until 2020. This target can only be met with significant transition from fossil fuels to other cleaner energy sources. European Union, for example, announced plans for further reduction of greenhouse gas emissions. These reductions will decrease greenhouse gas emissions by 2020 to a level 20% less than in 1990, by 2050 to 50% of those in 1990, and a minimum target of 10% biofuels by 2020 is also proposed (European Directive 2009/28/EC).

In 2008, India accounted for 17.7% of the world population but was the fifth-largest consumer of energy, accounting for 3.8% of global consumption. India's total commercial energy supply is dominated by coal and largely-imported oil, with renewable energy resources contributing less than 1% (this does not include hydro > 25 MW). Energy planning in India is taking place in the context of climate change negotiations. India participates in the international climate negotiation process, has pledged to

reduce its economy's greenhouse gas (GHG) intensity, and its per capita emissions does not exceed those of developed nations. India has implemented a National Action Plan on Climate Change (NAPCC), which suggested that 15% of energy could come from renewable sources by 2020. The NAPCC has eight National Missions, one of which is focused specifically on renewable energy. India is also an active participant of the Clean Development Mechanism (CDM) with the second largest number of projects registered among all participating countries, with the major number of renewable energy projects in its hand. Different methods of reducing the climate change problem could be increasing the use of carbon capture and storage (CCS) techniques, increasing energy efficiency and promoting the use of renewable energy and carbon free fuels. To overcome the problems associated with the use of petroleum derived fuels, it is urgently needed to develop a renewable energy source of energy which must be environmentally clean. The various ways for combating the climate change are increasing the use of carbon capture and storage (CCS) techniques, increasing energy efficiency by modifying the engine design, emission reduction by treating the exhaust gas and by fuel modification and promoting the use of renewable energy and carbon free fuels.

Role of biofuels in climate change

Biomass can act as a reservoir of carbon or as a direct substitute for fossil fuels with no net contribution to atmospheric CO₂ if produced and used sustainably. Biomass a substitute for fossil fuels is being promoted as a cleaner source of energy, and it is expected to play an important part in achieving the government's long-term goals for energy policy in cutting and stabilizing CO₂ emissions and contribute to the maintenance of energy supplies. The IPCC has considered a range of options for mitigating climate change and increased use of biomass for energy features in all of its scenarios. The biofuels expected to have an increasing share of total energy over the next century, rising to 25 to 46% in 2100 would help in achieving the target of stabilizing CO₂ in the atmosphere at present-day levels. Annual CO₂ emissions would fall from 6.2 Gt C in 1990 to 5.9 Gt C in 2025 and to 1.8 Gt C in 2100: this will result in cumulative emissions of 448 Gt C between 1990 and 2100, compared to 1300 Gt C in their business-as-usual case (IPCC 1996).

Biomass is the only renewable resource for producing carbon-bearing biofuels. There is substantial potential for renewable feedstocks on about 700 million hectares of currently unprotected grassland and woodlands, out of which only 125 million hectares would be sufficient to meet current biofuels targets to 2030 (Shah and Bencrif OFID 2009). Unused, discarded biomass residues from forestry, agriculture, and municipal sources are potential energy resources, which at present are not well managed and thus pose significant environmental problems especially greenhouse gas (GHG) emissions. A more effective use of this resource for bio-energy and related by-products could

contribute to displacement of fossil fuel emissions, stabilizing CO₂ again in terrestrial biomass and also achieve direct mitigation of GHG emissions implicated in climate change (IEA 2001).

Most of the biofuels are clean and environment friendly for transportation. The use of biofuels as an alternate to fossil fuels help in reduction of atmospheric CO₂ in three ways: (1) avoiding the emissions associated with fossil fuels; (2) allowing the CO₂ content of the fossil fuels to remain in storage; and (3) providing a mechanism for CO₂ absorption by growing new biomass for fuels. Due to the compatibility with the natural carbon cycle, biofuels offer the most beneficial alternative for reducing greenhouse gases from the transportation sector.

Bioethanol and biodiesel for climate change mitigation: Liquid biofuels for transport have been widely acclaimed to enable net greenhouse gas savings, improve fuel energy security and promote rural development. Biofuels development policies have become the thrust of publicly announced and time-bound mandates and targets in a number of countries including the United States, European Union, Brazil, China and India. Many countries initiated the effort to make bio-ethanol. For instance, Brazil and the United States together produce about 90% of the 36 billion litres of ethanol produced globally, while Germany accounts for over 50% of the 3.5 billion litres of global biodiesel production (Martinot 2005). The IEA estimated the total mitigation potential of biofuels in the transport sector in 2050 to range from 1800 to 2300 Mt CO₂ at 25 US\$/tCO₂-eq. based on scenarios with a respective replacement of 13 and 25% of transport energy demand by biofuels (IEA 2006).

Studies show that intensive cultivation and expansion of biofuel crop cultivation leads to direct and indirect land-use change (LUC) and GHG emissions from the induced LUC can substantially influence the climate benefit of biofuels production and use (Leemans *et al.* 1996, Schlamadinger *et al.* 2001, Fargione *et al.* 2008, Searchinger *et al.* 2008 and Gibbs *et al.* 2008). Further Farrell *et al.* (2006) evaluated many studies and concludes that on average the reductions are probably about 13% from corn ethanol compared to gasoline from conventional oil. The corn-ethanol benefits are minimal because corn farming and processing are energy intensive. Second-generation biofuels may represent a lower-carbon source of biomass energy, though carbon release from land use changes and soils must be accounted for in full field-to-tank analysis.

Producing lignocellulosic biofuels offers potentially greater greenhouse gas emission savings than those obtained by first generation biofuels. Lignocellulosic biofuels are predicted by oil industry body CONCAWE to reduce greenhouse gas emissions by around 90% when compared with fossil petroleum, in contrast first generation biofuels were found to offer savings of 20-70%. The ethanol from sugarcane appears to be unsustainable based on the impact its production has on water alone (de Oliveira *et al.* 2005) while palm biodiesel production for its consequences on

tropical rainforests as reported from Indonesia (Curran *et al.* 2004). Moreover reports indicates that the emissions due to fertilizers contribute significantly to total agricultural GHG emissions and affect the final GHG balance of palm oil (Arvidsson *et al.* 2010 and Choo *et al.* 2011).

Life cycle analysis showed lower impacts of sugar beet ethanol for abiotic depletion, global warming, ozone layer depletion and photochemical oxidation categories, less greenhouse gases than gasoline. While, it had higher impacts for acidification and eutrophication due to losses of reactive nitrogen in the arable field (Bessou *et al.* 2012). Robust lifecycle assessment (LCA) and/or ambitious minimum GHG reduction threshold values (e.g. 30% to 50% better GHG performance than fossil fuels) will go far to ensure that biofuels truly lead to verifiable GHG emission reductions. The LCA study (Fig 2) estimated range in reductions of GHG emissions per vehicle kilometer (v-km) for rape methyl ester (RME) compared to conventional diesel fuel (for which RME can substitute) is 16 per cent to 63 per cent, a range of a factor of four. The range in reduction indicated for SME (soy methyl ester) is 45 per cent to 75 per cent (CONCAWE 2004). The range for ethanol from sugar beets is somewhat smaller but complicated by three alternative sets of assumptions about how GHG emission credits are assigned to the residual pulp co-product of ethanol production. Ethanol from wheat showed anywhere from a 38 per cent GHG emissions benefit to a 10 per cent penalty relative to gasoline. Conditioning current biofuel support measures to such criteria would ensure that government policies do not inadvertently lead to increases in GHG emissions in this area.

The use of cellulosic biomass for energy production is expected to result in significantly higher energy return on investment (EROI) and carbon sequestration compared to starch and sugar based biofuel (Sheehan *et al.* 2003, Farrell *et al.* 2006 and Tilman *et al.* 2006). Analysis shows reductions in global warming emissions of 20% from corn ethanol and 85% from cellulosic ethanol (Argonne National

Laboratory 2007). Thus, greenhouse gas emissions in an E85 blend using corn ethanol would be 17% lower than gasoline, and using cellulosic ethanol would be 64% lower (Wu *et al.* 2006).

Biodiesel has emerged as one of the most strategically important alternative fuel substitutes to the fossil fuel and are considered as an important way of progress for limiting greenhouse gas emissions. According to Britain's National Non-Food Crops Centre, total net savings from using first-generation biodiesel as a transport fuel range from 25-82% (depending on the feedstock used), as compared to diesel derived from crude oil. In comparison to conventional diesel fuel, the use of biodiesel results in an overall reduction of smog-forming emissions from particulate matter, unburned hydrocarbons, and carbon monoxide. Sulfur oxides and sulfates, which are major components of acid rain, are not present in biodiesel.

One of the advantages of a life cycle approach is that it allows a fair comparison between two products and is thus useful for evaluating the benefits of the likes of *Jatropha* biodiesel regarding environmental impact as compared to petro-diesel. Over 90% of GHG emissions from the life cycle of both diesel and biodiesel are from the use phase. Rate of total global warming potential from biodiesel production and use is just 23% of diesel (Prueksakorn and Gheewala 2006). This is because the CO₂ emissions from combustion of biodiesel in the engine during the use phase are considered GHG-neutral as they are of biomass origin and thus absorbed from the atmosphere by the *Jatropha* plants during growth.

The main contributors of both energy consumption and GHG emissions which should be considered are from the transesterification, irrigation, and fertilization. Energy efficiency of biodiesel conversion should be given the first priority for the process improvement as it is the main contributor to both energy use as well as GHG emissions. Almost 60% of energy consumption in the transesterification step is from steam. Alteration and maintenance of engine, more and efficient biodiesel conversion technologies can also help in reducing the energy consumption. As the next priority, the range of watering and fertilizing amount should be tested to find out the optimum input values. The high amount of water and chemical requirement in this method of plantation (cutting the plants every year to get co-products) may be resulting in an energy gain at the expense of resource depletion (such as water and land use), nutrient enrichment problem from fertilizer, and ecological toxicity from chemical use of weedicides and insecticides. However, this needs to be further investigated. Fig 3 shows the comparative Life cycle of GHGs emissions of biodiesel and diesel (Kritana and Shabbir 2006).

Classic LCA studies on emissions from biofuel production and processing show that biofuel crops have net GHG savings between 20% and 90% (Thow and Warhurst 2007). It is reported that replacing gasoline with corn ethanol reduces GHGs by 20% in the 2015 scenario excluding land-use change (GREET 2007). But by using a worldwide

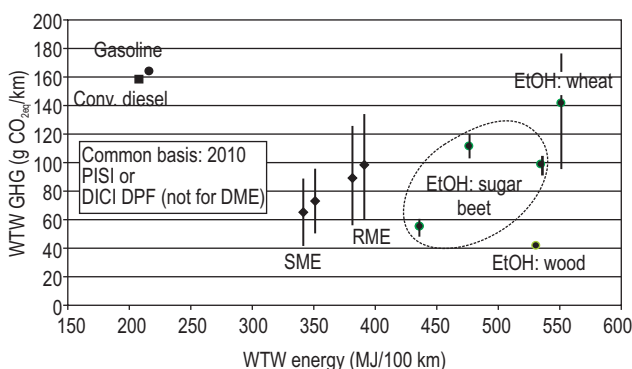


Fig 2 Well-to-wheels energy requirements and greenhouse gas emissions for conventional biofuel pathways compared with gasoline and diesel pathways, assuming 2010 vehicle technology (CONCAWE, 2004). Notes: EtOH-ethyl alcohol (ethanol); SME-soy methyl ester; RME-rape methyl ester; PISI-port injection spark ignition; DICI DPF-direct injection compression ignition with diesel particulate filter.

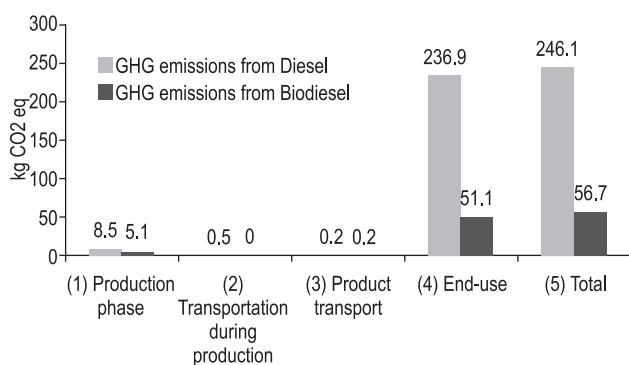


Fig 3 Life cycle of GHGs emissions of Biodiesel and Diesel (Source: Kritana and Shabbir 2006).

agricultural model to estimate emissions from land-use change, corn-based ethanol, instead of producing a 20% savings, nearly doubles greenhouse emissions over 30 years and increases greenhouse gas emissions for 167 years (Searchinger *et al.* 2008).

Thus land-use conversion from native land-uses leads consistently to significant GHG for instance conversion of crop land to biofuel crops will have a negative carbon balance (Fargione *et al.* 2008). Apart from this, studies have also highlighted that land-use conversion and cultivation of biofuel crops could have both positive and negative effects on food-security and natural resources like water (IEA 2006, IPCC 2007 and Thow and Warhurst 2007). In this regard biofuels could have globally significant impacts on rate of land use change depending on where they are located and their indirect effects. For instance, biofuel could be produced on existing tropical forest: 745.7 million ha of tropical forest are suitable for soy, sugarcane, or palm production (Stickler *et al.* 2007). However, Gibbs *et al.* (2008) conclude that conversion of degraded land to grow biofuel crops will provide immediate carbon savings.

Thus biofuels are a potential low-carbon energy source, but whether biofuels offer carbon savings depends on how they are produced (Fargione *et al.* 2008). Policies and frameworks should be made to convert much of degraded and abandoned agricultural lands for biofuel production and to protect native ecosystems (Tilman *et al.* 2006). Food security is another concern as expansion of biofuel crops take place. Thus extensive research for breeding high yielding varieties of grain crops should be made. This will ease the pressure on biofuels. Growing perennial grasses and woody species can offer GHG advantages over food based crops, especially if they are sufficiently productive on degraded soils (Parrish *et al.* 2005 and Graham *et al.* 2007). The Energy Independence and Security Act of 2007 outline standards for greenhouse gas reduction that must be met for a fuel to be considered renewable. In December 2010, the EPA finalized a set of Renewable Fuel Standard regulations (RFS2) establishing the necessary level of greenhouse gas reduction as compared to the emissions of the 2005 baseline average gasoline or diesel fuel that it replaces (EPA 2010). These reductions are calculated based

on a lifecycle analysis and include indirect emissions from land use changes associated with each fuel (Table 3).

Biogas as biofuel in methane management and climate change mitigation: Methane (CH₄) is one of the major greenhouse gases accounting for 15% of the total enhanced greenhouse effect. It is a significantly more powerful greenhouse gas than carbon dioxide. Burning one molecule of methane generates one molecule of carbon dioxide. Accordingly, burning methane which would otherwise be released into the atmosphere (such as at oil wells, landfills, coal mines, waste treatment plants, etc.) provides a net greenhouse gas emissions benefit. However, reducing the amount of waste methane produced in the first place has an even greater beneficial impact, as might other approaches to productive use of otherwise-wasted methane.

The life cycle analysis (LCA) shows that biogas when used as biofuel may considerably contribute to GHG emission reductions (Tilche and Galatola 2008). In India, over 4.0 million family size biogas plants have been installed so far. India is second only to China in biogas plants. In addition, enriched organic manure is produced from biogas plants to supplement and complement environmentally degrading chemical fertilizers. Methane is the main component of biogas, and provides a versatile carrier of renewable energy, as methane can be used for replacement of fossil fuels in both heat and power generation and as a vehicle fuel, especially in remote areas with no electric power transport infra-structure.

The anaerobic fermentation reduces emissions of methane (CH₄) by about 90%, substantially reduces emissions of nitrous oxide (N₂O), and also permits reductions in emissions of ammonia (NH₃) (FAL 2004). The possibility of using grass silage through biogas technology also offers great advantages in terms of preventing greenhouse gases, since it avoids ploughing up pasture, which would result in additional greenhouse gas emissions due to this change of land use. Another R&D initiative taken was converting biogas into natural gas, removing CO₂ from it and bottling for easy transportation and use in a decentralized manner.

Emission reduction by carbon-free biofuels: Another way to reduce carbon dioxide emissions is to use carbon-free or reduced-carbon sources of energy. Carbon-free biofuels generate energy without producing and emitting carbon dioxide to the atmosphere. Hydrogen is a carbon free fuel. Biofuels in general and bio-hydrogen from organic

Table 3 Reduction thresholds by various fuels

Fuel class	Lifecycle GHG Reduction Thresholds (%)	Examples
Renewable fuel	20	Corn-based ethanol
Advanced biofuel	50	Sugarcane ethanol
Biomass-based diesel	50	Soy-based biodiesel
Cellulosic biofuel	60	(none in production yet)

Source: <http://www.aaas.org/spp/cstc/briefs/biofuels/>

waste in particular seem to be well-positioned to play an important role in the near future, providing that they are economically viable and environment friendly (Sridhar and Ambarish 2013). Fuel cells offer the transportation sector the promise of decreased dependence on fossil fuels, low or zero tailpipe emissions, and high efficiency. Fuel cells produce much less waste heat and consequently offer a much higher theoretical efficiency. Unlike batteries, fuel cells can run continuously with sufficient input of reactants (fuel and oxidant). Fuel cells run best on pure or reformed hydrogen but some can operate directly on alternative fuels such as methanol or hydrocarbons. The only emission from fuel cells is water when hydrogen is fed to the fuel cell. Fuel cells can generate electricity with very low amounts of pollutants, such as GHG, NO_x, and SO_x (Zabihian and Fung 2010).

Carbon mitigation by Clean Development Mechanism (CDM): The Kyoto protocol (1997) proposed three market-based mechanisms aimed at achieving cost-effective reductions in GHGs including the International Emissions Trading (IET), Joint Implementation (JI), and the Clean Development Mechanism (CDM). Biomass will have an increasing role to play as a result of carbon trading activities. It may receive carbon offset credits from displacing fossil fuels; earn carbon sink credits from biological carbon sequestration; or enable physical sequestration of atmospheric carbon to occur by capturing carbon dioxide after biomass combustion and transporting it to permanent geological stores (UNHSP 2011). The technical transfer of modern biofuel technologies to developing countries are encouraged by the Clean Development Mechanism, but it will remain a challenge to implement them successfully. Where this has occurred, it has led to better and more efficient utilization of biomass that, in many instances, complements the use of traditional fuels. For example liquid fuels produced from corn husks in China by a small scale Fischer-Tropsch process is used for traditional cooking but the electricity co-product can also be generated by passing unconverted syngas through a combined cycle gas turbine (Dry 2004).

Biomass projects have been included in the Clean Development Mechanism (CDM) of the Kyoto Protocol. Special fast track procedures for small projects (<15 MW) to keep the transaction costs low will help to encourage their uptake. In developing countries where traditional biomass (firewood and dung) continues to be the major energy source, cultural acceptance and understanding of modern biomass production and conversion technologies may be easier to achieve than for other renewable energy sources (IPCC 2007). Developed countries must first increase their successful use of biomass domestically in order to demonstrate to governments of developing countries its reliability, environmental acceptance, social benefits and economic feasibility. The development of Joint Implementation bioenergy projects would certainly give them increased credibility when negotiating to build similar bioenergy plants in non-Annex 1 countries under the CDM.

All forms of biofuels, when substituted for fossil fuels, will directly reduce CO₂ emissions. Therefore, a combination of energy crop production with carbon sink and offset credits can result in maximum benefits from carbon mitigation strategies.

Although there has been some criticism of the CDM process (e.g. the additional financial and technical criteria necessary or the long and costly project certification process), India has been at the forefront of receiving CDM benefits. As of January 2010, 1 551 Indian projects have been granted host country approvals (REN 21). The projects are in the fields of energy efficiency, fuel switching, industrial processes, municipal solid waste (MSW), and renewable energy. At a price of INR 500 (USD 10) per CER, they would be worth INR 313.5 billion (USD 6.27 billion). In 2009, 478 of the world total 2,011 registered projects were generated by India next to China. As of September 2010, India had 532 registered CDM projects, 426 of which were in the energy sector, with the overwhelming majority comprised of renewable energy projects (REN 21).

Ways to sequester carbon

A best option for reducing carbon dioxide in the atmosphere is carbon sequestration. The famous quotation by physicist and futurist Freeman Dyson (2008) reads "If we can control what the plants do with carbon, the fate of the carbon in the atmosphere is in our hands." This shows the significance of C-sequestration in mitigating global change in climate. Carbon sequestration involves the capture and storage of carbon dioxide that would otherwise be present in the atmosphere, contributing to the greenhouse effect. Carbon dioxide can be removed from the atmosphere and retained (stored) within plants and soil supporting the plants. The soil C pool, which is 3.3 times the size of the atmospheric C pool of 760 GT, includes about 1550 GT of soil organic carbon (SOC) and 950 GT of soil inorganic carbon (SIC) (Lal 2004, 2008). Alternatively, carbon dioxide can be captured (either before or after fossil fuel is burned) and then be stored (sequestered) within the earth.

Sequestering carbon in terrestrial biomass: A terrestrial carbon sink such as a biomass plantation effectively captures and disposes of atmospheric carbon dioxide (CO₂) by converting it, through photosynthesis, into carbon. For instance, forests in the Northern Hemisphere have been estimated to sequester up to 0.7 GT of C annually, which accounts for almost 10% of current global fossil-fuel C emissions (Goodale_ *et al.* 2002). The carbon is stored as biomass in four carbon pools: above-ground biomass; dead organic matter; below-ground biomass; and soil organic carbon. Above-ground biomass consists of tree stems, branches, and foliage. Below-ground biomass refers to root biomass; dead organic matter is mostly leaf litter and woody debris; and soil organic carbon consists of micro biotic organisms in the soil.

The success of biomass plantation measures to sequester carbon must examine their effects on each of these carbon

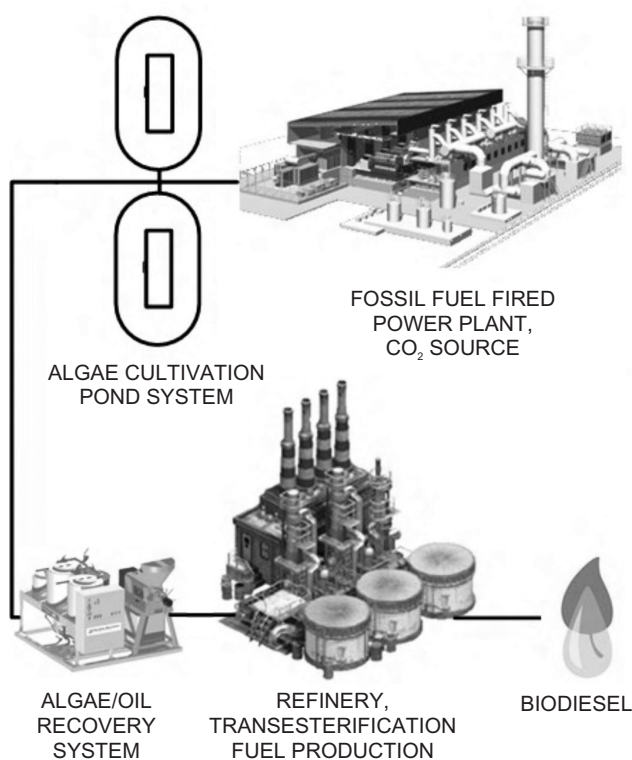


Fig 4 Simplified schematic of the algae biodiesel production with introduction of CO₂ from fossil fuel fired power plant.

pools. Afforestation is defined by the United Nations Framework Convention on Climate Change as the direct human-induced conversion of land that has not been forested for a period of at least 50 years to forested land through planting, seeding, and/or the human-induced promotion of natural seed sources (Article 3.3 of the Kyoto Protocol). So, through planting fast-growing trees on marginal farmland, for example, afforestation can increase the size of the terrestrial carbon sink, which in turn reduces atmospheric GHG levels. As there is a finite amount of land available, this benefit is relatively short lived if the trees are just left standing. However, the opportunity for long-term reductions lies in the use of the afforested biomass for energy conversion. By using carbon-sequestering tree plantations as feedstock for ethanol production, emissions from the production and combustion of fossil fuels can be offset within the transportation and energy sectors.

Sequestering carbon in algal biomass: Promising results are coming up in the efficiency of algae for biofuel production in recent time and this will go long way as the solution to global energy crisis (Chisti 2008). It is known from long that algae have the ability to produce a great variety of lipids, hydrocarbons and other complex oils (Chisti 2007 and Hu *et al.* 2008). Carbon dioxide could be captured and sequestered into the aquifers or depleted oil and gas wells which are expensive options. Commercial interests into large scale algal-cultivation systems could be obtained by placing algae plants near coal power plants, sewage treatment facilities or any industry that emit large quantities

of carbon-dioxide into the atmosphere (Fig 4). This approach not only provides the raw materials for the system, such as CO₂ and nutrients, making in that way greater yield of biodiesel, but it changes those wastes into resources. Much work has been done on the effect of different fuel gas constituents on microalgae growth rates and carbon dioxide fixation. Typical coal power plant flue gases have carbon dioxide levels ranging from 10–15% (4% for natural gas fired ones). At the typical carbon dioxide percentages in the atmosphere of 0.038%, microalgae show no signs of significant growth inhibition. Furthermore, various studies have shown that microalgae respond better to increased carbon dioxide concentrations, outgrowing (on a biomass basis) microalgae exposed only to ambient air.

CONCLUSION

Biofuel production has been advocated by many experts as a solution to meeting the energy needs of the countries while reducing greenhouse gas (GHG) emissions. The biofuel production and utilization strategies could also help to reduce CO₂ emissions from the transportation sector. Others argue that biofuel production will compete with land needed for food production. However it appears biofuel production especially from biomass residues may be an option for creating economic diversification and provide affordable energy without competition with land needed for food production and environmental degradation. Climate change mitigation and adaptation approaches including the biomass-to-biofuels, renewable energy policy, clean development mechanism and emissions trading, and ways to sequester carbon could contribute to a net reduction of total greenhouse gas emissions and not exacerbate global climate change.

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