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# Prospects for the Production of Biodiesel in Pakistan

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Additional information is available at the end of the chapter

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## 1. Introduction

The use of renewable energy resources (biodiesel) to generate power is receiving attention around the world, and for Pakistan, it can address the current and upcoming energy stresses of the country. Pakistan is facing a severe economic crisis owed to an unceasingly rising gap between energy demand and energy supply. The scarcity in power and gas supply has already frozen a number of industrial sectors such as textile, small and medium enterprises, and local transport. It is common anxiety in today's world that fossil fuels will be exhausted soon. The price of energy is rising unceasingly and is predicted to be at its peak by 2050. The fossil fuel sources are decreasing in Pakistan, the result of which is the import of about 8.1 million tons at approximately US\$ 9.4 billion per annum. Thus, renewable and sustainable energy resources, such as biodiesel needs to be maintained so that a sustainable energy mix could be achieved to confirm energy security. In the ambit of this justification, augmenting the scarce energy resources in Pakistan through intense coupling of the various biodiesel sources can effectively address the shortage and can confirm energy security. Towards this end, the advancement achieved in biodiesel-associated researches in Pakistan are assessed and presented, highlighting ways of attaining the objective set forth by the Government. To this effort, biodiesel as a renewable energy source has been deliberated, to overcome energy crisis, achieve pollution-free environment, economic growth and more importantly, significantly increase the income of our farmers. This study has also identified areas in Pakistan where there are substantial possibility to renovate bio-energy production distribution systems to deliver diverse energy carriers like electricity, industrial and domestic fuel, and gases. Fences are observed over the entire bio-energy range and policy issue and institutional roles and odd jobs are discoursed. Now the responsibility is upon the officialdoms such as of the Alternative Energy Develop-

ment Board (AEDB) and Pakistan State Oil (PSO) to connect the research results from several native universities and to develop a full-scale biodiesel economy in Pakistan.

In the past, mankind has investigated a number of energy resources from wood, coal, oil and fossil fuel to nuclear energy. Recently, the public and governmental sensitivities to pollution and energy security have led to the elevation of renewable energy assets. Biofuel is one such reserve that could play a significant role in a more diverse and sustainable energy mixture [1]. Biofuel is that source of fuel whose energy is derived from biological carbon fixation. Biofuels comprise fuels derived from biomass conversion, as well as solid biomass, liquid fuels, and various biogases [1]. The fabrication of liquid biofuels has augmented five-fold in the previous two decades due to policy interferences and changing relative energy prices [2]. The increasing production of biofuels is mainly for energy security by lessening reliance on import of fast-depleting fossil fuels and saving considerable amounts of foreign exchange; to mitigate the global warming emissions by reducing the use of fossil fuels; and to improve agricultural development by offering better prices and new jobs [1].

Energy plays a basal role in the socio-economic advancement of a country by providing for daily life needs. For thousands of years, biofuel has been used as an energy source by men. The statistical data documented by the International Energy Agency clarify that conventional energy resource, such as fossil fuel are still the main sources of energy trailed by coal and gas, contributing about 80% of Total Primary Energy Supply (TPES) [1]. Energy sources diversification is vital for energy security, climate change, and sustainable development issues. Additionally, too much dependence on non-renewable energy sources for power generation in the long-term is unfeasible. Consequently, extensive consumption of renewable energy sources such as biofuel, geothermal energy, solar energy and wind energy, is indispensable to overcome the energy crisis [2]. The biofuel potential is impressive and its capability to address the world's energy demand has been extensively recognized. Presently, renewable energy globally is still ruled by the "old" renewable such as hydropower and traditional biofuel that supplies 6% and 9%, respectively, of the world's key energy demand. While the "new" renewable sources such as mini- and micro-hydro, photovoltaic and wind energies afford only 2% of the world's primary energy. In South Asia, households are likely to follow the energy ladder including power sources like dung, crop residue, firewood, kerosene, gobar gas, LPG, and electricity for cooking purposes. Evidence suggests that while it is possible to observe such transition in urban and semi-urban areas, the change is very slow in rural areas. In developing countries, improving power services for poor households is one of the most tenacious challenges to them.

Pakistan is also located in the south Asian region with a total land area of 888,000 km<sup>2</sup>. The approximate population of Pakistan is about 173.51 million with an annual growth rate of 2.05%; it is estimated that Pakistan will become the fourth largest nation on earth in terms of population by 2050 (Economic Survey of Pakistan 2010). The draft population policy 2009–2010 foresees a reduction in fertility level from 3.56 (2009) to 3.1 births per woman by the year 2015. With a median age of around 20 years, Pakistan is also a "young" country. It is assessed that there are currently about 104 million Pakistanis under the age of 30 years [1]. Pakistan is basically an agriculture-dependent country. About 62% of the country's inhabitants live in

rural areas, and is directly or indirectly reliant on agriculture for their income. Pakistan has about 5.17% of land covered by forest out of which 5% is protected. To lessen dependence on natural forests, national forest policy calls for the promotion of alternate energy resources including energy plantations, micro-hydropower generation, bio-gas, solar and wind energies, liquid petroleum gas (LPG), and natural gas for use in critical mountain ecosystems [1].

The key objective for power sector reforms in Pakistan is rural electrification. However, there is no secure government policy for the growth of devolved power supply. Pakistan, for nearly two decades, has been one of the fastest growing power markets in the world though it has a young and growing population, low per capita electricity consumption, rapid urbanization, and strong economic growth. Its economic growth has been significantly hindered by acute energy dearth for five years (Economic Survey of Pakistan 2009). Among the power sectors, the electricity sector in Pakistan consumed 15 million tons of oil in 2008 equaling to 28% of petro-fuels consumed by the country. As our oil reserves were not enough, therefore 71% of the country's oil requirements were imported in 2008 [3]. The high consumption of oil in the energy sector not only tightens the economic pressure, but also increases CO<sub>2</sub> emission from the power generation sector. Moreover, high oil prices condensed the quantity of oil purchased, and therefore, electricity could not be supplied as per demand of the economy, which led to demand-supply gap of electricity. Because of this reason, the total supply of electricity altered from a surplus of 1230MW at the end of financial year 2005 to a shortfall of 5885MW at the end of financial year 2010 [4].

This inability of the electricity supply to address increasing demand is mainly attributed to the lower utilization of existing installed generation capacity which is mainly due to increasing oil prices in international markets [4]. The average annual rise of electricity need from 2005–2010 was 8%, and is predicted to continue till 2035. If the growth continues at the same rate, the total need of the country will be 474 GW up to 2050. The power generation plan till 2030 indicates that electricity supply will be growing at an average annual growth rate of 11% till 2030, and 65% of the increase in installed generation capacity will be thermal-based electricity (Pakistan Economic Survey, 2009).

Under such circumstances, much of our dependence on petro-fuel will not only cause an increment in environmental pollutants but will also result in high electricity prices due to the increasing prices of fossil fuels, and could make the power sector vulnerable to international price vacillations of fossil fuels. In these circumstances, the share of renewable energy in the power sector in Pakistan was less than 1% till 2010 [3]. Therefore, for this reason, it is imperative that Pakistan exploits domestically existing alternative energy sources for power generation. However, to tap renewable energy resources in Pakistan, details on the potential of these energy sources considering commercially available and most promising technologies need to be evaluated and quantified.

It is stated by a careful evaluation that the energy requirements of the country will increase to three times up to 2050 and the capacity to deliver this need is not very encouraging. Consequently, it becomes necessary to tap the substitute and renewable resources for energy [5]. Biofuel experts recognize the land of Pakistan as rich in natural species of plants that can be used for biodiesel feedstock like *Pongamia pinnata*, *Cannabus*, *Jatropha* and *Ricinus commu-*

*nis*. The seeds of such plants are rich in oil that can firmly produce biodiesel in Pakistan. The cultivation of these plants is likely to create at least one job for every acre of planted trees; the overall influence on agricultural employment alone could be huge. Besides, these plants have the gift to nurture marginal, waste or arid land. Pakistan has huge areas of such deprived quality land (more than 80 million acres) ideal for the farming of energy crops, so planting *Pongamia pinnata*, *Cannabus*, *Jutropha* and *Ricinus communis* would not prevent lands from cultivating vital food crops. To synthesize biodiesel, besides vegetable oil, alcohol (ethanol or methanol) is also required. This is lavishly accessible in Pakistan courtesy of sugar industry. Another source of ethanol synthesis is natural gas. The more we cultivate fuel crops for alternate fuel source, the better it is for the environment and for our economy.

Biodiesel is a renewable form of fuel used in automobiles and is generally extracted from plant seeds or from its other parts (e.g. flowers). Basically, Pakistan is an agricultural country and there are enough resources to be utilized for the production of biodiesel. Unfortunately, no systematic investigations have been done on biodiesel technology due to lack of education, confidence, and interaction between our industries and research institutions [6]. The Government of Pakistan has laid down various schemes to harness indigenous renewable sources of energy (biodiesel). In Quaid-i-Azam University Islamabad, a lot of work has also been done on the production of biodiesel from plants.

## 2. Energy and poverty

Meanwhile energy plays an important role in the daily lives of humans, and poverty deprives people of chances for a better existence; and it is not surprising that there are manifold links between energy and poverty. Poverty means starvation, absence of medical treatment, and deprived access to rudimentary facilities such as electricity and water supply. It means being unable to send children to school, and often needing them to work instead. Eradicating poverty, being the most unrelenting priority, is the realization of man's elementary desires, which include nutriment, housing, water supply and hygiene, and other amenities that will advance their standards of living, such as adequate health care, education, and better transport [7].

Even though energy is not in itself a rudimentary necessity, it is essential as a critical input for providing indispensable human desires. The availability of modern energy facilities can contribute to poverty mitigation by (1) improving living standards through better lighting, access to cleaner cooking fuels, and safe drinking water, and (2) improving effective transfer of services such as reliable space- and water-heating, lighting, refrigeration of vaccines and other medicines, and sterilization of equipment in health centers. The provision of economical and good-quality lighting also allows students to extend study hours and to improve their employment prospects [7].

### 2.1. Biodiesel synthesis technology

Synthesis involves three reactions, whereby triglyceride is converted successively to diglyceride, monoglyceride, and glycerol, consuming one mole of alcohol in each step and liberating

one mole of ester [8]. The final biodiesel composition depends on the initial feedstock, as well as on the reaction conversions and process separation efficiencies. The thermo-physical properties depend on factors such as chain length, branching, and degree of saturation [9]. The reaction of transesterification proceeds in the presence of a suitable catalyst. When raw materials (oils or fats) have a high percentage of free fatty acids or water, the alkali catalyst will react with the free fatty acids to form soaps. The water can hydrolyze the triglycerides into diglycerides and form more free fatty acids. Both of the above reactions are undesirable and reduce the yield of the biodiesel product. In this situation, the acidic materials should be pre-treated to inhibit the saponification reaction [10].

## 2.2. Biodiesel: A solution to energy crisis in Pakistan

In 2003, Jeffrey Dukes, a biologist, estimated that the fossil fuels we use in a calendar year were the result of decay of organic matter "containing  $44 \times 10^{18}$  grams of carbon, which is more than 400 times the net primary productivity of the planet's current biota". In simple English, this means that each, year we routinely use four centuries' worth of assets of natural biota (plants and animals) [11]. Currently, Pakistan is in the clutch of a serious energy crisis that is distressing all zones of the economy and the different parts of the society. The way circumstances are currently positioned, explanations or solutions for the problem are scarce. It is time to alter attitudes and life styles at the national level, which should be initiated by those in authority and then followed by all sectors of the society, all of whom have the right to electricity. At best, there could be some short, medium, and long-term solutions to the crisis but they want instant planning and implementation with a massive investment. Former leaders of the republic have not succeeded in resolving the energy crisis, and the problem continued to persist.

To grow the economy of the country, energy is the key source. Pakistan has to face a major energy crisis in *natural gas, power and oil and this is the main reason for the delay in the country's economic growth (which is already in intricacy)*. The high price of the import of oil, building of giant dams and indeterminate local sanctuary environment attached with non-existence of national covenant to physique dams are probably to adjournment swift resolution of energy crises. This energy discrepancy will lead to inflation. Likewise subventions of billions of rupees have to be dragged out of the "Water and Power Development Authority (WAPDA)" to bear loses. This would seriously disturb the national exchequer.

Unremitting and economy supply of energy is essential for sustainable economic progression. Currently, the role of renewable and sustainable sources of energy in Pakistan is inadequate, to say the least, and key actions are needed to make it a noteworthy player in the country's energy supply mix [5]. It is highlighted that the fabrication of biodiesel is a prerequisite to sustainable growth and will lessen reliance on imported fuel. The core deduction that was derived from the study was that if indigenous vegetation yielding inedible oil is cultivated on massive unproductive areas of the country, the feedstock cost could be reduced and biodiesel could become a solution to Pakistan's ailing energy crisis. About 70% of Pakistan's overall geographical area lay coarse, thus providing an opportunity to cultivate inedible oil-yielding vegetation that in turn is converted to biodiesel. Thus, it is necessary to develop plant-based

biodiesel productions in Pakistan, which will be valuable for the improving socio-economic settings of the country [12].

### **2.3. National biodiesel program**

To use biodiesel as substitute energy source in Pakistan, the AEDB has verbalized policy recommendations, the primary aims of which are to minimize the bill of imported fuel of the country, address the demand of raw material for biodiesel which will be the prime goods for biodiesel fabrication, and promote a pollution-free environment. Also on 14<sup>th</sup> Feb. 2008, the Economic Coordination Committee (ECC) of the National Cabinet has permitted the strategy for the use of biodiesel as an alternate energy source in its conference. Striking points of the dogma are as follows:

1. AEDB shall be the primary coordinating and facilitating body for the National Biodiesel Program.
2. Gradual introduction of biodiesel fuel blends with petroleum diesel so as to achieve a minimum share of 5% by volume of the total diesel consumption in the country by the year 2015 and 10% by 2025.
3. The Ministry of Petroleum & Natural Resources shall come up with the fuel quality standards for B-100 and blends up to B-20.
4. Oil Marketing Companies (OMCs) are to purchase biodiesel (B-100) from biodiesel manufactures; and sell this biodiesel blended with petroleum diesel (starting with B-5) at their points of sale [13].

### **2.4. Biodiesel feasibility for Pakistan**

In general, vegetable oil is treated with either methanol or ethanol to synthesize biodiesel. The main reason for the use of methanol worldwide is its low price. The main source of methanol is coal, and in Pakistan, the coal reserve value is about 180 billion tons and is the 5<sup>th</sup> largest in world. At present, ethanol production in Pakistan is also high (300,000 tons of cane per day) because currently, 76 sugar mills are operational [14]. The main source of ethanol is the molasses from sugar cane which is actually the by-product. There are 21 distillery units in Pakistan with a capacity to process 2 million tons of molasses to produce 400,000 tons of ethanol; therefore, it means that excess ethanol can be either for gasohol purpose or for biodiesel production [15]. The production capacity of these 21 units is about 400,000 tons and the country's need plus export is up to 80,200 tons and yet, there is still leftover ethanol, which is about 318,000 tons [15]. Thus, in terms of ethanol requirements for synthesis of biodiesel, the stock is sufficient to increase production.

Conventionally, NaOH is used as a catalyst during biodiesel synthesis which is produced in enough quantity to cover the country's requirements, and production can be easily augmented because of massive reserves of NaCl [14]. As it is well known, Pakistan is an agricultural country with 70% of its population working in the farm fields, and so the Soil Survey of Pakistan surveyed and classified its soil types into 79 major classes, the details of which are given in

Table 1 (Soil Survey of Pakistan). In the figure, land use for agriculture which is spread throughout the country is shown by yellow color (Soil Survey of Pakistan). In the country, 28 million hectares of land is unused and this is due to water scarcity, high temperature, and soil salinity (Fig. 1). Unfortunately, despite the rich land, Pakistan, which is known as an agriculture-based country, has to rely on imports for edible oil, wheat, and milk [14].

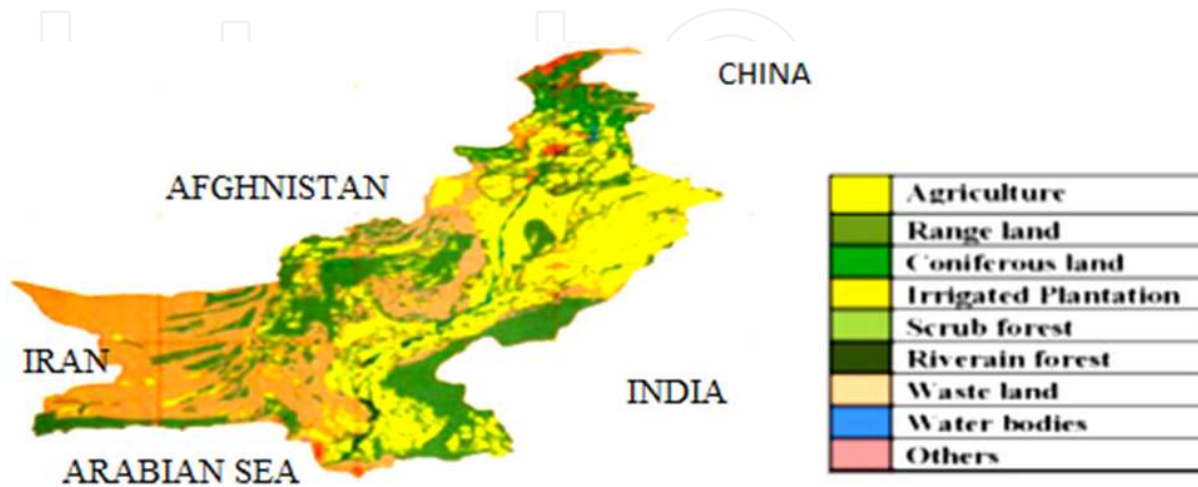


Figure 1. Land use for agriculture in Pakistan

From *Jatropha* seed, India successfully produces biodiesel. In Pakistan, *Jatropha* plants can also be cultured very easily and grow well, especially in saline soil with less quantity of water and can also withstand high temperature [14]. A one-hectare field of *Jatropha* can yield up to two tons of biodiesel fuel per year. If Pakistan makes use of all uncultured land for biodiesel manufacturing, then Pakistan will be able to yield 56 million tons of biodiesel in a calendar year, while the current necessity of fuel is about 8.5 million tons [14]. In short, land is available for cultivation of energy crops. Pakistan's energy requirement is rising and a 10% increase (including for power and transport sectors) is perceived per annum. Consequently, biodiesel assignment is feasible and has a very promising future in Pakistan; raw materials for biodiesel fabrication are accessible, and more importantly, the Government of Pakistan is very serious in energy-generation programs [14].

The organic material resulting from biological organisms (plants and animals) is called biomass. Bio-energy can be defined as energy obtained from biological and renewable sources (biodiesel); it may be processed or converted in the form of heat or transformed into electricity for distribution. Biomass is a portable feedstock that can be easily transmuted into biofuels for the production of bio-energy, manufactured straight or indirectly from biomass. Biofuels are either solid (fuel wood, charcoal, wood pellets, briquettes, etc.) or liquid (bioethanol, biodiesel). Now with the evolving advancement in bio-energy using more recent technology, biomass energy can be divided into traditional biomass and modern bio-energy. Traditional biomass is the chief font of energy used in evolving countries mainly for food preparation and warming at the home level, typically using three-stone stoves, or in some areas improved cooking stoves. The energy source of this type is present in the form of wood-fuel (including fuel wood and charcoal), crop residues, and animal dung and is often processed and used by women and



S/No.	Type of Land Use	Area in 1000ha
1	Agriculture	21,733
2	Range Land	25,475
3	Coniferous Forest	1,353
4	Irrigated Land	80
5	Scrub Forest	196
6	Riverains Forest	239
7	Waste Lands	28,501
8	water bodies	1,274
9	Others	159
	Total	79,610

**Table 1.** Different lands used by Pakistan

children on everyday basis. On the other hand, modern bio-energy is used generally for the generation of electrical energy or transport power. Liquescent biofuels for transport such as ethanol and biodiesel are examples of emerging energy substitutes [1].

About 62% of Pakistan's residents have restricted access to commercial energy; only the traditional methods of using wood, animal waste and crop waste for home fuel needs are available to them because they are located in the rural areas. Effectiveness of use is very squat and most of the latent is lost because of non-scientific conventional technologies. Therefore, it is essential to develop modern bio-energy technologies so that renewable capitals of energy may serve to supplement the long-term energy requirements of Pakistan to a momentous level [1].

## 2.5. National biodiesel program

To use biodiesel as substitute energy source in Pakistan, Alternative Energy Developed Board has verbalized Policy Recommendations, the primary aims of which are to minimize the bill of imported fuel of the country, the demand of raw factual of biodiesel which will be the prime goods for biodiesel fabrication and a pollution free environment. Also on 14<sup>th</sup> Feb 2008 the Economic Coordination Committee (ECC) of the National Cabinet has permitted the Strategy for usage of biodiesel as an alternate energy source in its conference. Striking points of the dogma are as follows:

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3. Ministry of Petroleum & Natural Resources shall come with the fuel quality standards for B-100 and blends up to B-20.
4. Oil Marketing Companies (OMCs) to purchase Biodiesel (B-100) from Biodiesel manufactures; and sell this Biodiesel blended with Petroleum diesel (starting with B-5) at their points of sale [16].

## **2.6. Research and development on biodiesel in various Pakistani institutions**

On biodiesel technology, numerous projects have been initiated at different universities and industries in Pakistan. Unfortunately, all efforts have been conducted individually, and apparently, there was minimal knowledge sharing between and among institutions. This work is an effort at assembling all the figures produced by numerous national organizations and to present it in an articulate form for the assistance of the future [7].

## **2.7. Impact of Jatropha and Pongame on Pakistan's biodiesel plans**

The efforts done by Pakistan in rearing and harnessing Jatropha and pongame plants for biodiesel production is nothing short of praiseworthy. Research and progress reporting are also ongoing and findings are continually studied and evaluated [7].

## **2.8. Status of Jatropha cultivation for biodiesel production**

In Sindh, the presence of Jatropha has long been reported [17]. It is locally identified as Karanga, RatanJothor or Jamal Ghoti and was used to treat several diseases in villages and towns [18]. Through imported seeds from a number of countries, Jatropha has been mostly cultured on small scale by private tycoons [17]. Their plantations have increased from about 2 acres in 2005 to more than 400 acres in 2008 as shown in Fig. 2. This increase in Jatropha farming was primarily due to an aggressive campaign started by the AEDB [17]. In the private sector, numerous organizations are interested in cultivating Jatropha nurseries at several locations in Sindh, Punjab, and Baluchistan. These nurseries have become the root for a quantity of Jatropha ranches in the same areas. In these ranches, the normal age of a plant may range from several weeks to about 18 months [17].

In 2005, roughly 2 acres were cultivated for Jatropha farming [17]. However, after that, the private sector started mounting nurseries for further cultivation. In 2006, more than 10,000 saplings were provided by nursery proprietors to several growers in Sindh and Punjab for transplantation into the farms. Similarly in 2007, these nurseries presented about 50,000 saplings for transplantation to various growers in Sindh and in Baluchistan [17]. However, because of glorified interest, cognizance, and conceivable economic gains in cultivating Jatropha, agrarians in Sindh presented more concentration, and because of the large-scale accessibility of saplings in the nurseries, during 2008, more than 200,000 saplings were provided by several nurseries in Sindh for transplantation [7].

Seeing this interest, in 2008, Pakistan State Oil (PSO) also brought seeds for developing nurseries and for cultivating about 20,000 Jatropha plants in their own farmhouse [17].

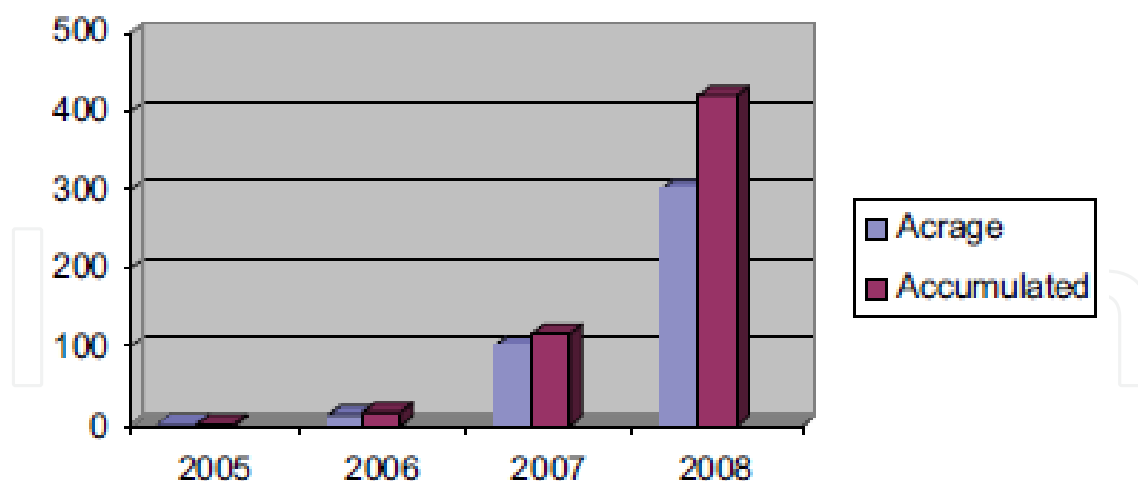


Figure 2. Growth of cultivation of Jatropha in Pakistan

Currently, the PSO has about 10,000–20,000 saplings for such transplantation [19]. Upon calculation, within the quarter of 2009, their nurseries located adjacent to Karachi already had more than 200,000 saplings and were prepared to offer additional saplings if requested. The growth projections of Jatropha cultivation, up to the last of calendar year 2014, are shown in Fig. 3 [17].

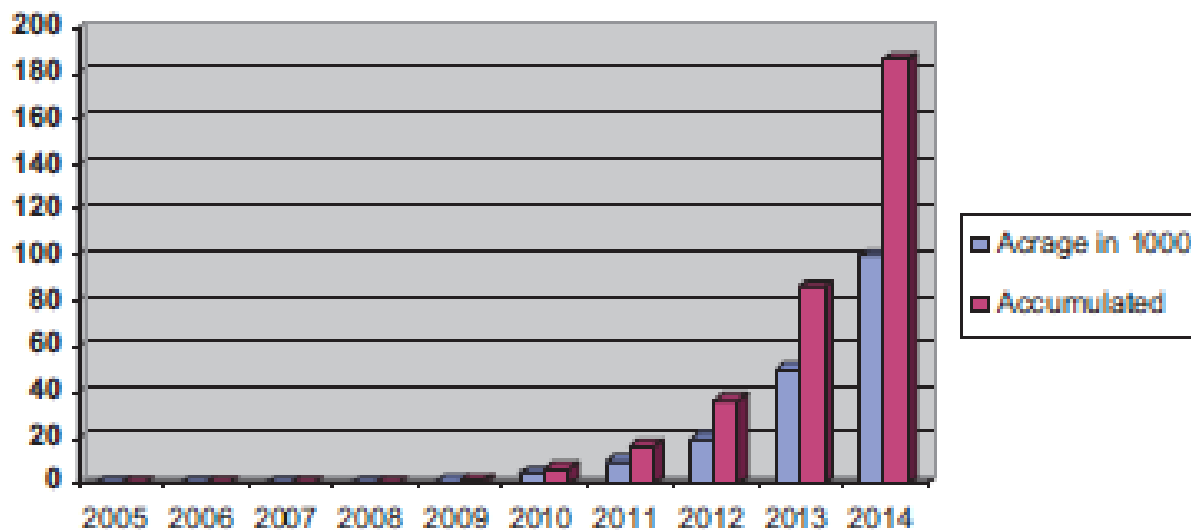


Figure 3. Projected growth of Jatropha cultivation by PSO

PSO spearheaded an experimental project centered on harnessing *Jatropha curcas* plants from its private farmhouses for the synthesis of biodiesel on commercial scale. The predicted outcomes for Pakistan are the following [20]:

- Six million plants will be cultivated for a greener environment.

- Five hundred planters will be rented to accomplish the cultivation of plants on a 5,000- acre land.
- Twenty-four million kilograms of seeds will be produced per year from this plantation.
- A total of 7.2 million liters of biodiesel (costing roughly PKR 345 million @ PKR 48/liter of fossil diesel) will be manufactured/year which is equal to 17 MT of biodiesel/day.

Similarly, other interested investors such as Karachi's Forest Department together with the Pakistan Army have efficaciously planted *Jatropha* plants in several areas of Sindh [16]. So far, the Forest Department succeeded to nurture 3000 samplings on a trial basis in Malir Cantonment in 2010 for the cultivation of the *Jatropha* seeds which were supplied by PS [17]. Likewise, the Pakistan Agricultural Research Council (PARC) and a Canadian company, KijaniEnergy, are also interested in developing large-scale cultivation of *Jatropha* for biodiesel production on marginal lands [21]. In 2009, Kijani Energy capitalized approximately US\$ 150 million, which has resulted in the use of 200,000 acres of land in Cholistan, Umerkot, Tharparker, Khairpur, and Sanghar for the purpose of *Jatropha* cultivation [22].

The advantages and benefits of such deeds can be multifarious. The culturing of *Jatropha* is likely to produce at least one vacancy for each acre of planted samples; thus, the overall influence on agricultural employment alone can be gigantic [17]. The charge of earning of seeds, cost of synthesis, tax policies made by government, consumption of by-products, oil cake, and other *Jatropha* surplus continue to influence the cost of biodiesel production. While considering the aspect of expenses, it is indispensable to recognize the rural occupation generation, energy sanctuary, carbon swapping issues, and savings of external exchange. Overall, job opportunities will be created from plantation, seed gathering, extraction of oil, biodiesel manufacturing, and local scattering. Job opportunities generated from plantation and seed collection alone are appraised to be 40 men days/ha/year [7].

## 2.9. Biodiesel research status by consuming indigenous *Jatropha* oil

The *Jatropha curcas* plant is a drought-resilient crop that grows profound taproot surface roots permitting it to counterattack and control soil erosion. It yields approximately 2–4 kg/seed/tree/year. The oil yields of *Jatropha curcas* is estimated to be 1590 kg/ha. The chief fatty acids in *Jatropha curcas* seed oil are the oleic, linoleic, palmitic, and stearic acids [23].

For biodiesel fabrication, expenses to be incurred may vary because of variation in location and labor duties, land procurement, and policies in place. However, Silitonga et al. [23] presented a solid case for biodiesel manufacturing from *Jatropha*. According to them, if 500 hands work on a farmland of 1,500,000 ha, an estimated amount of 2,250,000 liters of oil can be produced. Taking into account the labor charges related to the area of attention, the estimated proceeds can be calculated. For *Jatropha* cultivation, the cost is negligible because it does not require crop rotation or expensive fertilizers. This partly explains the growing number of organizations in Pakistan that have been involved in the manufacture and testing of biodiesel from *Jatropha curcas* oil. The aim of all this work is to produce/extract high-oil content from the seeds (ca 30% to 40%) as well as to eliminate the presence of anti-nutritional chemicals in the oil that tend to make it inedible [7].

## 2.10. Research work in universities

The universities that testified results for the synthesis of biodiesel through transesterification of *Jatropha curcas* oil were the University of Agriculture in Government College University, Faisalabad [16], Quaid-i-Azam University in Islamabad [6], and the NED University in Karachi [24]. On the other hand, PSO itself also has partnered with many other universities in Pakistan for the same purpose [20].

Biodiesel fuel properties for *Jatropha* oil assessed by PSO and unconnectedly at Faisalabad are shown in Table 2.

Parameters	High speed Diesel (PSO)	B10 (PSO)	B100 (PSO)	B100 (Faisalabad)	Test Method
Density at 20 C/cm <sup>3</sup> (lb/in <sup>3</sup> )	0.83(0.03)	0.8522	0.8816	0.88	ASTM D 1298
Kinematic viscosity mm <sup>2</sup> /s (in <sup>2</sup> /s)	2.73 (0.0042)	4.19	4.38	4.8	ASTM D 445
Cetane index	46	53	47	NE	ASTM D 976
Flash point C	37 (310)	90	140	188	ASTM D 93
Calorific value Btu/lb	19528	19233	17162	NE	ASTM D 420

**Table 2.** Please send caption

NED University succeeded in experimenting on PSO's biodiesel in a single cylinder four-stroke compression ignition engine (Rotronics) and established that its discharge profile was better than that of diesel, canola oil biodiesel, and castor oil biodiesel [24]. The researchers at NED University also determined that biodiesel from *Jatropha curcas* seeds was inexpensive to manufacture than indigenous castor and taramira oil biodiesels (Table 3) [7].

S/No.	Biodiesel	Cost/L (PKR)
1	Jatropha	94.549
2	Castor	162.708
3	Taramira	277.004

**Table 3.** Cost of biodiesel synthesis/L in PKR from different non-edible feedstock

## 2.11. Pakistan state oil research

By using the state-of-the-art trans-esterification unit, PSO has effectively transformed *Jatropha* oil obtained from its own farms into biodiesel [20]. Engine performance and discharge analysis of PSO's B10 were recently spearheaded by NED University [7]. These results plainly illustrate that *Jatropha* biodiesel has minimum influence on the environment in contrast to other indigenous biodiesel oils as well as fossil diesel, but its engine efficiency is slightly inferior to its mineral complements. This is because of its lesser greasy value than fossil diesel. This

concern can be solved if further investigation is led by Pakistani institutions to create an upsurge in the calorific value of *Jatropha* oil biodiesel [7].

### 2.12. Status of biodiesel research using indigenous Pongame oil

The Pongame plant grows well in humid and subtropical habitats and is planted in those zones with an annual rainfall of between 500 and 2500 mm. Pongame is a possible raw material for biodiesel manufacturing in Pakistan. The oil-yielding capacity of its seeds is about 35%. They can flourish in saline soil, in water logged area, and in slightly icy ground; it can also grow on diverse sorts of soil, thus, it is not a problem for highly uncultivated land in Pakistan to be finally used for biodiesel production [7].

In Quaid-e-Azam University (QAU), pongame oil has been effectively transesterified into biodiesel through catalytic transesterification using NaOH as catalyst. As a result, a maximum 90% of crude oil was converted to biodiesel. A comparable, but much effective effort was also made by other researchers in the NED University in Karachi (unreported). The fuel properties of the biodiesel samples produced at both institutions are given in Table 4. The biodiesel synthesis at NED had improved properties compared with the one manufactured at QAU. In addition, its flash point was higher, signifying that it was safer to stock. However, its ignitibility was less than the biodiesel manufactured at QAU [7].

Properties	ASTM Test Method	ASTM Limits	HSD	Pongame B100 (NED)	Pongame B100 (QAU)
Density	ASTM D 1298	0.875-0.900	0.85	0.88	0.92
Viscosity	A ASTM D 445	1.9-6.0	2.8	3.9	7.53
Flash point	ASTM D 93	93 C Min	68	152	90
Sulphur contents %	ASTM D 5453	0.0015 Max	2.4	0.001	0.0084
Cetane index	ASTM D 613	47 Min	46.2	58	53
Total acid value	ASTM D 974	0.50 Max	NA	0.2	NA

**Table 4.** A comparison of the fuel properties of biodiesel from Pongame at QAU and at NED University

The efficiency experiment of biodiesel was taken at the test ground for internal combustion engines in the engines laboratory of QAU and a road test run of a Toyota car (2D) belonging to the AEDB, Islamabad was completed with positive results [25]. The advantage of Pongame biodiesel is that it has slighter discharge of pollutants than *Jatropha* and had comparable brake power and torque with *Jatropha* at the same engine speeds.

### 2.13. Harnessing indigenous resources for biodiesel production – AEDB’s pioneering work and contribution

The Government of Pakistan created the AEDB in 2003, with the purpose of endorsing and facilitating the harnessing of renewable energy capitals in the country [26]. The policy for the development of renewable energy was made and issued in 2006. Thus far, AEDB has been able

to stimulate different organizations and universities to initiate research work on biodiesel technology and other renewable energy resources. The government also took the task of promoting biodiesel technology through a National Awareness Program via AEDB. The organization has also been successfully nurturing *Jatropha* in Karachi with the assistance of various stakeholders [27].

#### **2.14. Collaboration with local universities**

In 2009, the AEDB has effectively completed their first research work of biodiesel resources. The potential oil resources which were recognized for use in biodiesel synthesis were composed of *Pongamia pinnata*, rapeseed, and castor bean. The organization fruitfully validated B10 and B20 biodiesel fuels from these indigenous resources in vehicles running through petrodiesel. The AEDB also successfully established a research laboratory at Quaid-i-Azam University Islamabad and a fuel-testing laboratory at the University of Engineering and Technology, Taxila [28]. The electrification of a village in inner Sindh province (Goth Umar Din) followed suit. For this, a close policy was made, where the manufacturer of the alternative energy was also the consumer. The villagers were growing the required seeds for the vegetable oil and producing biodiesel through transesterification, and also operated the installed generator set to generate electricity for their village [7].

#### **2.15. Commercial projects**

The commercial level fabrication of biodiesel was started by Clean Power (Pvt.) Ltd. along with AEDB by setting up a 400 liters/day refinery. This project has diverse goals that include plantation of crops in waste areas, cultivation of *Pongamia* and *Jatropha* plants, and the use of waste vegetable oil. The company also worked with Pakistan Railways to cultivate Pongame seeds in several areas of the country [7].

#### **2.16. Formulation of biodiesel policy recommendation**

In 2008, the AEDB also verbalized a policy for biodiesel which encompassed the succeeding major proposals [29]:

- a. Introduction of 5% biodiesel blended fuel by 2015 and 10% by 2025 in Pakistan.
- b. Oil marketing companies were to buy B (100) biodiesel from biodiesel fabrications and market the biodiesel blended fuel (B-5) at their points of sale.
- c. Oil gas regulatory authority was to regulate the pricing mechanism of various blends of biodiesel.
- d. All imprinted plants machinery, equipment, and specific items used in the production of biodiesel were to be exempted from customs duty, income tax, and sales tax.

After the endorsement of Policy Recommendations for the use of biodiesel as a substitute fuel, SRO474(I)/2008, for the exemption of taxes and duties on biodiesel-associated paraphernalia, machines, and other specific items was issued by the Federal Board of Revenue (FBR),

Government of Pakistan. In answer to that, the AEDB received endorsement for setting up a 10,000 t/annum biodiesel fabrication capability as part of the Government's viability study for starting a B5-use countrywide program by 2015. The additional advantage of the above-mentioned policy was the inauguration of Pakistan's principal commercial biodiesel fabrication ability (amounting to 18,000 t/annum of fuel) under the sponsorships of M/s Eco-Friendly Fuels Private Ltd. and AEDB [27].

### **2.17. The possibility of harnessing indigenous algae for biodiesel production**

The production of biodiesel from algal cell lipase is not a new concept or technology. It has been carefully studied by numerous investigative groups that have deliberated its potential for the energy market worldwide [7]. A number of officialdoms in Pakistan have used this idea to do primary research biodiesel synthesis from algae based upon preliminary screening studies of numerous indigenous species. Two of them are in Karachi, one being the Pakistan Council for Scientific and Industrial Research and the other being the Department of Biochemistry, University of Karachi [7]. Unfortunately, the oil yield of the algae grown in the laboratories of both institutes was not sufficient to meet the standard defined by Chisti [30].

A Pakistani researcher at Mie University of Japan has recently claimed that the nation could benefit by harnessing its 27–28 million acre saline lands for algal farming [31]. This has also been confirmed by researchers in Malaysia [32]. Considering that about 40% of algal biomass consists of lipids from which oil can be extracted for producing biodiesel, the researcher mentioned that Pakistan should follow the example of other countries that are running similar projects of reclaiming saline lands and producing sustainable biofuels. He also remarked that the Pakistan Technology Board, an organization of Ministry of Science and Technology responsible for identifying and promoting key technologies in Pakistan, had already taken some initiatives to promote innovative research approaches towards biofuel production [31]. Other researchers have identified four strains of algae suitable for cultivation in Pakistan's deserts [33]:

- a. *Haematococcus pluvialis*.
- b. *Microcoleus vaginatus*.
- c. *Chlamydomonas perigranulata*.
- d. *Synechocystis*.

So far, there has been quite a clamor on commencing a large-scale algal biodiesel project in Pakistan, but very little has been done to date. No commercial reports are available in the scanty literature either. One of the main reasons may be due to the high costs associated with farming algae on a large scale as reported in a recent article in Dawn [34]. If a cost-effective method of producing algae on both saline lands and sewage networks is developed, algal biodiesel could become a major success in Pakistan [7].



## 2.18. Comparison between fossil-diesel and biodiesel

Biodiesel as fuel can compete with the existing fossil-diesel fuel. Biodiesel is compared with fossil-diesel in a number of categories such as energy content, hazardous material rating, health and social impacts, and engine performance rating.

## 2.19. Environmental drawbacks of petro-fuel

The main users of diesel and petrol are vehicles and are the main cause of environmental degradation. Old models of diesel engine are main contributors to air pollution. In Pakistan, many cities have high air pollution as compared with World Health Organization (WHO) standards, and in the past 20 years, the amount of  $\text{SO}_2$  increased to approximately 23 folds. The losses due to air pollution in terms of health care are approximately about 500 million dollars per year while the diseases due to air pollution are increasing (Khwaja and Khan 2004). Asthma and lung diseases are caused by  $\text{SO}_2$  and it also causes acid rain. Pollutants like CO,  $\text{CO}_2$ , Ozone,  $\text{NO}_x$  and many volatile organic matters are upsetting air quality to dangerous levels in major cities of Pakistan.

## 2.20. Environmental benefits of biodiesel

Diesel engines are the high pollutant-emission sources (79%) (AEDB, Government of Pakistan). Its pollutants consist of many of organic and inorganic compounds. These particles have hundreds of poisonous chemicals on their surfaces, such as mutagens and carcinogens. Using biodiesel can greatly reduce the emission of pollutants such as  $\text{SO}_x$ , PM, but not  $\text{NO}_x$ .

Biodiesel as fuel can also be helpful in decreasing the rate of global warming by reducing the discharge of greenhouse gases. A significant decline has been observed in smog-forming pollutants. It emits much less noxious pollutants compared with petro-diesel as shown in Table 5. The data of B20 and B100 are provided for overall view.

Smog-Producing Pollutants	B100	B20
Unburned hydrocarbons (HC)	67% Reduction	14% Reduction
Carbon monoxide (CO)	48% Reduction	10% Reduction
Particle matter (PM)	47% Reduction	10% Reduction
Sulphur ( $\text{SO}_x$ )	100% Reduction	20% Reduction
Nitrogen oxide ( $\text{NO}_x$ )	10% Reduction	2% Reduction

**Table 5.** Reduction rate of smog-forming pollutants

Other noxious pollutants, polycyclic aromatic hydrocarbons (PAH) and NPAH (nitrated PAH), also show a great reduction (Table 6).

Smog-Producing Pollutants	B100	B20
Polycyclic aromatic hydrocarbons (PAH)	80% Reduction W/B100	13% Reduction w/B20
NPAH (nitrated PAH)	90% Reduction w/B100	50% Reduction w/B20

(Feasibility paper 4)

**Table 6.** Other toxic-emission reduction

### 2.21. Hazardous rating comparison

Biodiesel in nature is non-hazardous when compared with fossil-diesel. Its flash point is high, therefore, it is safe to use. Biodiesel is biodegradable and 95% of it can be degraded in 28 days. Biodiesel in blended form, for example, as B20 can degrade faster than normal petro-diesel. Hazardous rating comparison between petro-diesel and biodiesel is shown in Table 7 [14].

Properties	Biodiesel	Fossil-Fuel (Diesel)
Biodegradability	Readily biodegradable, about 3 times faster than fossil fuel	Slow biodegradability
Flash point	150 C	51.7 C
Toxicity	Essentially non-toxic	Highly toxic
Spill hazard	Biodiesel is safe with no dangerous chemicals	Dangerous and toxic

**Table 7.** Hazardous rating comparison of biodiesel vs. fossil fuel (diesel)

### 2.22. Social benefits

Pakistan is an agriculture country with 70% of its population relying on agriculture for their livelihood. They can uplift their standards of living by producing oil seed generating crops in their field. Small-scale biodiesel production facility can be designed with a small investment and will be helpful in providing biodiesel fuel for their agriculture machinery. Those areas of land which are not being used due to water shortage or soil salinity can now be used for oil crops. The Government pays a huge bill for its crude oil import, thus, giving no benefit to its local economy. If farmers are able to generate energy crops then this will be beneficial not only to themselves but also to the country's overall economy. In Europe, biodiesel plants are being developed by large conglomerate entities. The produced fuel is then transported back to widely dispersed distribution depots. Germany is a successful example and is increasing its production capacities [14].

### 2.23. Engine performance

The diesel-engine industry has the right to decide whether biodiesel is good or not. After going through a number of experimental tests, scientists agreed upon the better or comparable performance of biodiesel fuel [14].

### 3. Recommendations

Based on the above analyses, the government of Pakistan may wish to:

- Create a national mission or a central government organization that is dedicated to biodiesel development: It would encourage entrepreneurs to adopt this new technology by working with the small enterprise development authority, to create business models and pre-feasibility studies for biodiesel production facilities and feedstock farms. This organization would also develop an industrial standard for biodiesel specifications.
- Create and empower environmental groups to solicit support in favor of widespread adoption of alternative fuels.
- Work in conjunction with other states to create a more uniform distribution of biodiesel feedstock production.
- To grow plants producing biodiesel in long roadsides to yield raw material for biodiesel and also to benefit the environment.
- Extend the project of biodiesel: There is need to establish pilot projects to commercialize biodiesel and set up its supply chain. The project may be extended step wise like conversion vehicle fleets of designated departments to run on biodiesel.

### 4. Conclusion

From the reviewed articles and publications, it is clear that the energy need of Pakistan can be attained and that the present energy crisis can be stopped. To achieve this, the practice of indigenous renewable energy sources of Pakistan is highly significant. However, further research and development on renewable energies are needed to create an upturn in their effective consumption. With effective usage of biodiesel in manufacturing energy, Pakistan can encounter a variability of energy requirements, counting producing electricity, providing energy for kitchen proposes to homes, fueling vehicles and providing energy to industries, but there is still a necessity for more thoughtful and broad research to encourage the renewable energy technologies coherent biodiesel policies by the Government essential to been involuntary with more emphasis devoted to supporting the initial local research efforts. In addition, the AEDB and PSO's initiatives to involve various universities all over the country should be harnessed so that effective solutions can be found in meeting the requirement of blending 10% of biodiesel with mineral diesel by 2025.

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## References

- [1] Bhutto, A. W., A. A. Bazmib and G. Zahedib. 2011. "Greener energy: Issues and challenges for Pakistan—Biomass energy prospective." *Renewable and Sustainable Energy Reviews*.15: 3207– 3219.
- [2] Pode, R. 2010. "Addressing India's energy security and options for decreasing energy dependency." *Renewable and Sustainable Energy Reviews*. 14.
- [3] HDIP, Pakistan Energy Yearbook, 2009. Hydrocarbon Development Institute of Pakistan (HDIP), Islamabad.
- [4] NEPRA, State of Industry Report 2011.National Electric Power Regulatory Authority (NEPRA), Ministry of Water and Power Development, Government of Pakistan, Islamabad.
- [5] Amjid, S. S., M. Q. Bilal. M. S. Nazir and A. Hussain. 2011. "Biogas, renewable energy resource for Pakistan." *Renewable and Sustainable Energy Reviews*. 15: 2833–2837.
- [6] Ahmad, M., M. A. Khan. M. Zafar. S. Sultana and S. Gulzar. 2007. "Indigenous plants based biodiesel resources in Pakistan." *Ethnobotanical Leaflet*. 11: 224–230.
- [7] Chakrabarti, M. H. M. Ali. J. N. Usmani. N. A. Khan. D. B. Hasan. Md. S. Islam. A. A. A. Raman. R. Yusoff and M. F. Irfan. 2012. "Status of biodiesel research and development in Pakistan." *Renewable and Sustainable Energy Reviews*. 16: 4396–4405.
- [8] Stephenson, A. L., J. S. Dennis and S. A. Scott. 2008. "Improving the sustainability of the production of biodiesel from oilseed rape in the UK." *Process Safety and Environmental Protection* 86: 427–440.
- [9] Saraf, S. and B. Thomas. 2007. "Influence of feedstock and process chemistry on biodiesel quality." *Process Safety and Environmental Protection*.360–385.
- [10] Leung, D. Y., C. X. Wu and M. K. H. Leung. 2010. "A review on biodiesel production using catalyzed transesterification." *Applied Energy*. 87: 1083–1095.

- [11] Monbiot, G. 2005. The most destructive crop on earth is no solution to the energy crisis. By promoting biodiesel as a substitute, we have missed the fact that it is worse than the fossil-fuel burning it replaces. *The Guardian*, Tuesday 6 December 2005.
- [12] Ahmad, M., M. A. Khan. M. Zafar and S. Sultana. 2007. "Systematic studies of Oil yielding Plants and their applications as a Bio-diesel resource in Pakistan." CSF-HEC workshop on promoting industry academia linkages for developing the knowledge-based enterprise sector in Pakistan.
- [13] Ali, S. I. 2009. "CDGK to grow jatropha plants." /<http://www.nation.com.pk/pakistan-news-newspaper-daily-english-online/Regional/Karachi/14-Jul-2009/CDGK-to-grow-Jatropha-plants>
- [14] Khan, N. A., and H. el Dessouky. 2009. "Prospect of biodiesel in Pakistan." *Renewable and Sustainable Energy Reviews*. 13: 1576–1583.
- [15] Ministry of Industries, Production and Special Initiatives, Pakistan.
- [16] Ali, S. I. 2009. <http://biodieselpk.blogspot.com/2010/03/cdgk-to-grow-jatropha-plants.htm>.
- [17] Khan. N. A., and J. N. Usmani. 2011. "Status of jatropha cultivation for biodiesel production in Pakistan." *Personal communication*.
- [18] Soomro, R., and R. A. Memon. 2007. "Establishment of callus and suspension culture in *Jatropha curcas*." *Pakistan Journal of Botany*. 39: 2431–2441.
- [19] CEO AEDB Visits PSO's Biodiesel Pilot Nursery. 2009. /[http://www.psopk.com/media/vol10\\_no5\\_jan\\_mar09/ceo.php](http://www.psopk.com/media/vol10_no5_jan_mar09/ceo.php)
- [20] Progress Report on PSOs' Biodiesel Initiative for the promotion of Biodiesel in Pakistan. 2011. /[http://www.psopk.com/products\\_services/pdf/bio\\_diesel.pdf](http://www.psopk.com/products_services/pdf/bio_diesel.pdf)
- [21] Plan for mass jatropha cultivation. 2009. /<http://www.thebioenergysite.com/news/3596/plan-for-mass-jatropha-cultivation>
- [22] Canadian firm to produce bio-diesel. 2009. /<http://archives.dawn.com/archives/172385>
- [23] Silitonga, A. S., A. E. Atabania. T. M. I. Mahlia. H. H. Masjuki. I. A. Badruddin. and S. A. Mekhilefe. 2011. "Review on prospect of *Jatropha curcas* for biodiesel in Indonesia." *Renewable and Sustainable Energy Reviews*. 15: 3733–3756. Soil Survey of Pakistan, [www.pakistan.gov.pk/divisions/food-division](http://www.pakistan.gov.pk/divisions/food-division).
- [24] Chakrabarti, M. H., J. N. Usmani and M. A. Ali. 2010. "Techno-economic evaluation of two non-edible vegetable oil based biodiesel in Pakistan." *NED University Journal of Research*. 7(1): 43–54.

- [25] Ahmad, M., and M. Zafar. 2005. "Pongamiapinnata (Sukh Chain) as a biodiesel resource in Pakistan." Two day seminar on Indigenous development of innovative technologies in the field of renewable energy. Best Western Hotel Islamabad.
- [26] Alternative Energy Development Board. 2011. /[www.aedb.org](http://www.aedb.org)
- [27] National Biodiesel Program. Alternative energy development board, ministry of water and power, government of Pakistan. 2011. /<http://www.aedb.org/bioprogram.htm>
- [28] National Biodiesel Program. 2009. /<http://www.research.org.pk/Databank/NATIONAL%20BIODIESEL/20PROGRAMME.pdf>
- [29] Siddiqui, M. A. 2007. "Biodiesel as alternative and indigenous source of energy for every village." /[http://www.powerasia.com.pk/icaep2007/presentations/1st\\_Session/Bio\\_Diesel\\_as\\_Alternative\\_&\\_Indigenous.pdf](http://www.powerasia.com.pk/icaep2007/presentations/1st_Session/Bio_Diesel_as_Alternative_&_Indigenous.pdf)
- [30] Chisti, Y. 2007. "Biodiesel from microalgae." *Biotechnology Advances*. 25(3): 294–306.
- [31] Pakistan's 27 mac resa line land fit for biofuel production. 2011. /<http://etcgreen.com/industry-news/biofuel/pakistan-s-27m-acre-saline-land-fit-for-bio-fuel-production>
- [32] Liaquat. A. M., M. A. Kalam. H. H. Masjuki and M. H. Jayed. 2010. "Potential emissions reduction in road transport sector using biofuel in developing countries." *Atmospheric Environment*. 44: 3869–3877.
- [33] Production of biodiesel from algae. 2011. /<http://www.scribd.com/doc/29870128/Production-of-Bio-Diesel-From-Algae>
- [34] High costs seen hampering use of algae as biofuel. 2011. /<http://www.dawn.com/2011/06/17/high-costs-seen-hampering-use-of-algae-as-biofuel.html>

