Renewable and Sustainable Energy Reviews 72 (2017) 445–464

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

A review on the prospects of sustainable biodiesel production: A global scenario with an emphasis on waste-oil biodiesel utilization

Masoumeh Hajjari[a,b], Meisam Tabatabaei[a,c,*], Mortaza Aghbashlo[d,**], Hossein Ghanavati[a,c]

[a] Biofuel Research Team (BRTeam), Karaj, Iran (www.brteam.ir)
[b] South Raadab Eng. Co., Tehran, Iran
[c] Microbial Biotechnology Department, Agricultural Biotechnology Research Institute of Iran (ABRII), Agricultural Research, Extension, and Education Organization (AREEO), Karaj, Iran
[d] Department of Mechanical Engineering of Agricultural machinery, Faculty of Agricultural Engineering and Technology, College of Agriculture and Natural Resources, University of Tehran, Karaj, Iran

ARTICLE INFO

Keywords:
Biodiesel
Energy demand
Feedstock sustainability
Iran
Waste cooking oil (WCO)
Biodiesel utilization scenario

ABSTRACT

Due to the large amount of diesel fuel demands worldwide and the negative environmental and health impacts of its direct combustion, biodiesel production and consumption have been globally increasing as the best short-term substitute for mineral diesel. However, using edible and non-edible oil feedstocks for biodiesel production has led to several controversial issues including feedstock availability and cost, greenhouse gas (GHG) emission, land use changes (LUC), and fuel vs. food/feed competition. Fortunately, these problems can be effectively overcome using non-crop feedstocks. In this context, waste-oriented oils/fats have been proposed as the excellent options to produce biodiesel by overlooking the trivial collection/recycling costs. In this review article, a comprehensive collection plan followed by an elaborated integrated utilization strategy called "waste oil biodiesel utilization scenario" (WO-BUS) is proposed for Iran in order to achieve cost-effective and eco-friendly production/consumption of biodiesel. WO-BUS is adoptable by the countries with similar situations and infrastructures.

1. Introduction

The world's total primary energy consumption (TPEC) is increasing day-by-day because of increasing population and modernization. In the year 2015, the world's TPEC stood over 150,000,000 GW h and it has been envisaged to rise by 57% by the year 2050 [1] (Fig. 1). This dramatic growth of energy consumption will eventually result in more GHG emissions and more environmental problems [2]. Today, over 80% of the total energy used in the world is provided by fossil fuels, leading to their severe contribution to environmental and health concerns [3,4].

Due to the above-mentioned concerns, tremendous efforts have been made to find the best alternative fuels for overcoming the economic and environmental impacts of fossil fuels consumption around the world [5–10]. In case of Iran, this issue becomes more serious because of the extreme dependency of the country's manufacturing and transportation sectors on low-price energy resources, making its economy very vulnerable to any changes in policies such as the fossil fuels subsidies removal state program implemented in 2010. Therefore, it is vital to scrutinize the country's current and future situations and potentials in order to find practical ways to manage its national energy scenarios more efficiently and in a less risky manner. According to Zarifi et al. [11], Iran's transportation sector is the second largest energy consumer of the country. Thus, replacement of a portion of national gasoline and diesel demands, which are the major transportation energy careers in Iran, with renewable and carbon-neutral fuels like bioethanol and biodiesel can effectively mitigate the high vulnerability of this sector in terms of fossil-derived fuels dependency.

Abbreviations: B2, 2% biodiesel/98% petro-diesel blend; B5, 5% biodiesel/95% petro-diesel blend; B20, 20% biodiesel/80% petro-diesel blend; B100, Neat biodiesel; BRTeam, Biofuel research team; BTE, Brake thermal efficiency; CNG, Compact natural gas; DI, Direct injection; FAME, Fatty acid methyl esters; FFA, Free fatty acid; GDP, Gross domestic product; GHG, Greenhouse gas; IBS, Iranian biofuel society; IKCO, Iran Khodro company; LDC, Least developed countries; LUC, Land use changes; ML, Million liters; NDP, National development plan; NER, Net energy-balance ratio; NIORDC, National Iranian oil refining and distribution company;; NRDDI, National renewable diesel demonstration initiative; PAHs, Polycyclic aromatic hydrocarbons; RIPI, Research Institute of Petroleum Industry; ROI, Return on investment; RTFO, Renewable transport fuel obligation; TPEC, Total primary energy consumption; UNDP, United nation development program; WCO, Waste cooking oil; WO-BUS, Waste oil biodiesel utilization scenario; WOF, Waste oil/fats

* Corresponding author at: Biofuel Research Team (BRTeam), Karaj, Iran.
** Corresponding author.
E-mail addresses: meisam_tab@yahoo.com, meisam_tabatabaei@abrii.ac.ir (M. Tabatabaei), maghbashlo@ut.ac.ir (M. Aghbashlo).

http://dx.doi.org/10.1016/j.rser.2017.01.034
Received 29 October 2015; Received in revised form 21 November 2016; Accepted 8 January 2017
1364-0321/

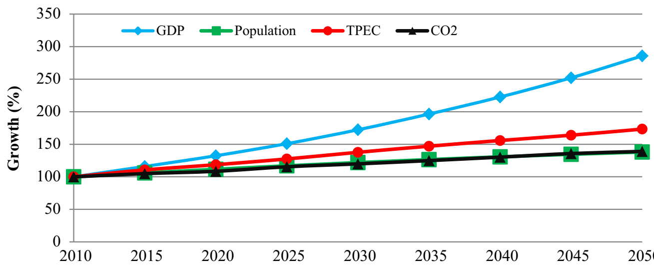

Fig. 1. Trends in global gross domestic product (GDP), population, TPEC, and Carbon Dioxide (CO_2) emissions vs. time [1].

Such a sustainable strategy not only can boost energy efficiency but also can balance economic and social development through environment protection.

The present manuscript was aimed at comprehensively discussing various aspects of energy resources and demands in Iran, particularly diesel fuel, with a focus on biodiesel production and consumption as a suitable and sustainable diesel alternative. In this regard, a detailed survey was conducted to achieve the most compatible feedstocks with Iran's current situation, needs, and transportation fleet. Based on the thorough investigation carried out herein, WCO was found to be an economically-viable feedstock in Iran for biodiesel production. Accordingly, biodiesel production from the WCO was thoroughly discussed in a separate category because of its different GHG footprint and LUC compared with the other biodiesel feedstocks. After presenting a financial feasibility analysis, a comprehensive collection plan followed by an elaborated integrated utilization strategy called "WO-BUS" was finally proposed for Iran's situation in order to attain sustainable production and consumption of biodiesel.

2. Overview of energy resources and consumption

Iran is a developing country with a total population of over 80 million [12]. The country is ranked as the world's 9th energy producing country [13] possessing the second and fourth largest proven natural gas and petroleum reserves in the world, respectively [14] (Figs. 2 and 3). Hence, the majority of energy demands in Iran is fulfilled by its own conventional energy resources. For instance, natural gas and oil products contribute to nearly 98% of the country's total energy consumption, while coal, hydropower, nuclear, and non-hydro renewable energies have a marginal share on Iran's energy market [14]. Fallaciously, it may be imagined that Iran, having such a huge reserve of fossil fuels, does not need to plan for any other alternative fuels. In contrast, the country is obligated to diminish the present over-dependence on fossil fuels and more importantly the associated environmental impacts. Moreover, Iran is always at high risk of losing its market since the country economy depends to a significant extent on oil export revenues (a political economy). For instance, Iran experienced a shocking decline of about 40% in the petroleum products export revenues in the year 2013 compared with the year 2011 because of the U.S. and EU sanctions [14]. On the other hand, the global fossil oil reserves are anticipated to be depleted within the next 45 years [15].

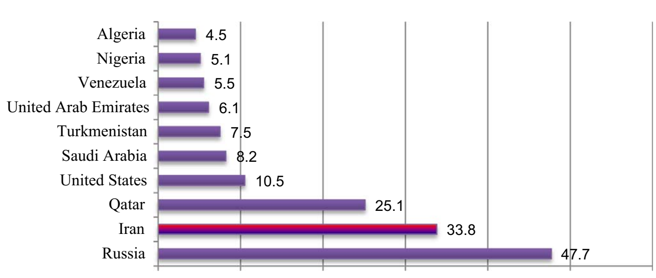

Fig. 2. Largest proven reserve holders of natural gas (billion m^3), January 2014 [14].

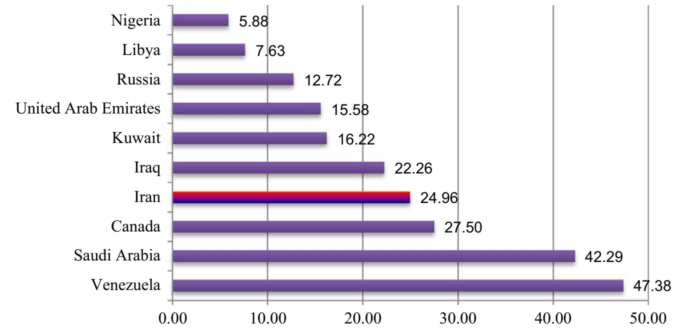

Fig. 3. Largest proven reserve holders of crude oil (billion m^3), January 2014 [14].

These are why the renewable energy production will turn to be one of the most important economic growth criteria of the countries in the near future.

It is worth quoting that as a developing country, Iran is also suffering from tremendous increases in the rate of energy demand and consumption. According to a report published by British Petroleum (BP), Iran's TPEC stood at 3107536 GW h in the year 2015 i.e. 2% of the world's TPEC [16] (Fig. 4). The country experienced a dramatic increase in the energy consumption by more than 50% since 2005 ranking it as the 1st and 10th energy-intensive country in the Middle East and the world, respectively [16]. Iran's TPEC is expected to further grow given the current state policies being implemented in order to boost the population (Fig. 5). It is worth noting that even though the population growth rate of Iran was only 1.27% in the year 2015, its TPEC growth rate was 2.5%. This manifests that the energy consumption pattern in Iran depends on various factors in addition to the population growth rate such as economic growth, uncontrolled urbanization [17], luxury consumption behavior among the Iranian consumers, generous subsidy programs, and weak resource management. These in turns have led to rapidly-growing energy consumption and high-energy intensity levels over the past decades [18].

Based on the statistics released by Iran Energy Efficiency Organization (IEEO), the country's energy consumption per capita in agriculture, housing, transportation and industry sectors were 3.1, 1.8, 1.5, and 1.4 times higher than those of the global averages in the year 2015, respectively [20], drastically complicating its energy management scenarios. As a result, although Iran has a unique status in the global energy supply, this country was one of the biggest petroleum products importers. In the year 2014, the country imported almost 9.7 million liter per day of petroleum derivatives, out of which 94% was gasoline to meet the high demands of the transportation sector [14]. In addition, Iran not only consumes almost all of its exploited natural gas, but also imports a portion of its natural gas demands for household application in cold seasons [14]. Such continuing trend of rising energy consumption will bring about new challenges for Iran by shrinking oil export revenues and subsequently restraining economic activities.

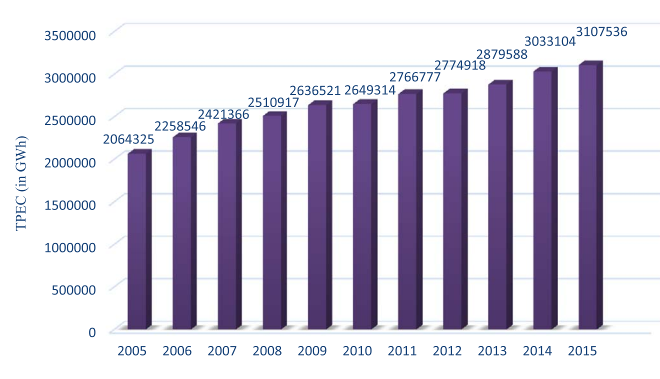

Fig. 4. Trends in TPEC in Iran 2005–2015 [16].

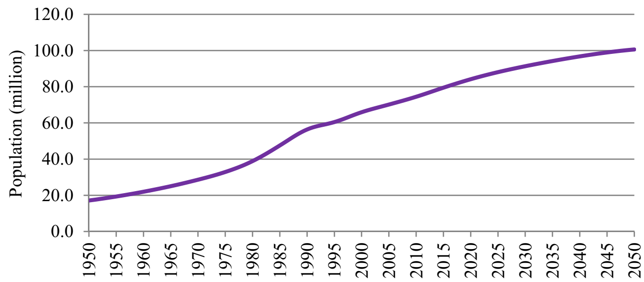

Fig. 5. Iran population growth trend (1950–2050) [19].

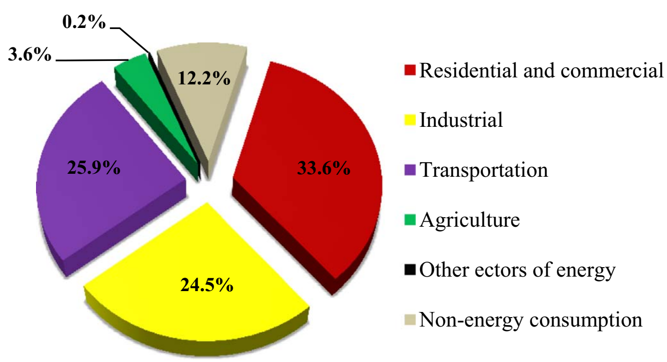

Fig. 6. Iran's energy consumption by various sectors (%), 2015 [20].

Moreover, Iran also faces continued depletion of its oil reserves in a range of 8–13% per year, which will eventually confront the country with innumerable problems in the next few decades [21].

The statistics released by the Ministry of Energy of Iran shows that residential and commercial sectors have the largest contribution to the country's TPEC, followed by industrial and transportation sectors (Fig. 6) [20]. Additionally, the majority of the oil products of about 61.5%, was used in the transportation sector in the year 2015 (Fig. 7) [20]. Indeed, the country's transportation sector is entirely dependent on fossil fuels while there has been no room for renewable fuels in this sector up to date. The main petroleum-derived products used in the Iran's transportation sector included diesel and gasoline, meeting 99.64% and 56.85% of the country's total gasoline and diesel demands, respectively, in the 2015 [20].

Apart from the above-mentioned challenges faced, air pollution associated with using fossil fuels has also become a tragic phenomenon in Iran's megacities. More specifically, fossil fuels were responsible for about 616 million tons of GHG and air pollutants emitted in Iran, mainly by power plants and transportation sector, in the year 2015 (Fig. 8) [20]. It is worth quoting that Iran has shown a remarkable growth in total fossil-fuel CO_2 emissions since 1954 (6.3% per year) [20], to the extent that it became the world's top 9th emitting country in year 2015 [22] (Fig. 9). Iran's CO_2 emission per capita was reported at 7.56 t in the year 2015 whilst the world's average was only 4.6 t [20,23].

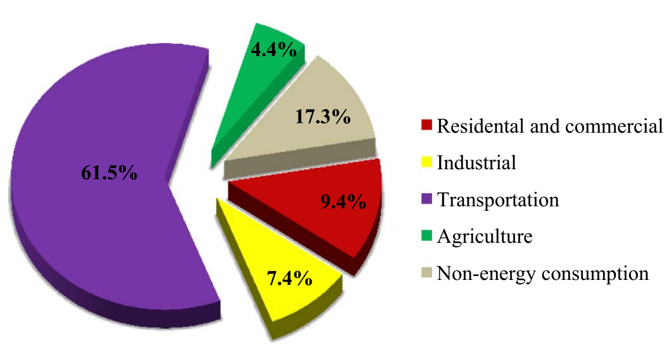

Fig. 7. Iran's petroleum products consumption by various sectors, 2015 [20].

Based on the BP energy outlook, the global emissions in the year 2035 are expected to nearly double the 1990 level, while the World Health Organization (WHO) stated that currently around 7 million people die each year owing to air pollution, i.e., one eighth of the total global deaths [24,25]. In addition, as it can be comprehended from the data presented in Fig. 9, the CO_2 emission is closely proportional to the population size of each country. Accordingly and given the estimated population size of Iran; i.e., over 100 million in the year 2050, the country is expected to face a tremendous amount of CO_2 emissions of over 730 million tons in that year.

2.1. Current production rate and demands for diesel fuel

Diesel is the world's pioneer of petroleum-based fuels. Based on the statistics released by the OPEC, the global consumption of diesel fuel was about 4.1 billion liters per day in the year 2012, accounting for 29% of the total petroleum-based fuels demands. Diesel fuel utilization has been foreseen to grow to about 5.7 million liters (ML) per day (33.2% of the total petroleum-based fuels) by the year 2035 (Fig. 10) [26] as a result of the increasing number of heavy-duty trucks as well as the growing transportation and industrial sectors. Moreover, diesel fuel will play a more significant role in the marine sector from 2020 to 2040, in response to the stricter environmental regulations enforced by marine standards [27]. In parallel with the global trend, Iran's petroleum-based fuels consumption pattern will be accordingly directed toward the use of diesel fuel. According to Fig. 11, diesel fuel accounted for about 41.4% of the total petroleum-derived fuels consumption in the year 2015, in Iran (Fig. 11) [20]. The average global growth rate of diesel fuel consumption has been estimated at 1.9% [26], while it has been found to be 3% for Iran since the year 2005. It is envisaged that this increasing trend will continue at least with the same rate in the future in spite of the government efforts to control energy consumption [20]. This is ascribed to an increase in the country's population growth rate, rapid industrialization, developing country-wide transportation networks, and finally the governmental strategies to encourage the citizens to use public transportation. In the year 2015, Iran's diesel fuel exports experienced a significant decrease of 96.2% in comparison with the same previous year due to the tremendous increase of the transportation sector demand for this fuel [20].

As shown in Fig. 12, the majority of diesel fuels in Iran was consumed by the transportation sector followed by power plants. More specifically, in the year 2015, Iranians utilized 36.4 billion L of diesel, out of which 56.8% was just consumed in the transportation sector and over 24.3% was used by power plants [20]. In fact, the 20.7 billion L diesel fuel consumed in the 2015 by the transportation sector was 1.5% higher than that of the previous year. This large volume of diesel fuel was mainly consumsed by the road transportation sector including approximately 1.2 million on-road diesel vehicles. It is worth quoting that the annual growth rate of on-road diesel vehicles in Iran is estimated to be 12.39%, indicating the serious fuel shortages the country is bound to face in the near future [28]. On the other hand, as a result of natural gas supply shortages experienced in the year 2013, several gas-fired power plants have been switched to use oil and diesel during cold seasons. Therefore, re-occurances of such incidents in the future could greatly jeopardize the energy-supply security in the country.

Beside the risk of petro-diesel depletion, using the huge amounts of this middle distillate petroleum fuel has brought high levels of air pollution, leading to serious environmental and human health concerns and consequently losses of Iran's national assets. The most dangerous air pollutants generally produced by means of diesel combustion are sulfur compounds, nitrogen oxides, and suspended particulate matters (SPM) (Table 1). Sulfur oxides and nitrogen oxides emitted mostly by the utilization of diesel fuel (in the form of acid rains) are the main

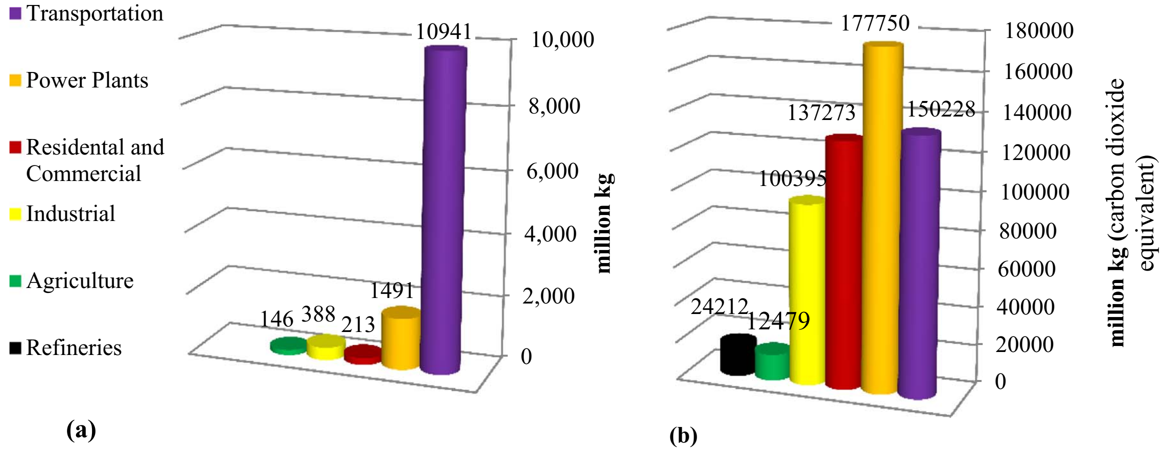

Fig. 8. Total emissions and air pollutants (NOx, SO_3, SO_2, SPM, CO) (a) and total GHG (CO_2, CH_4, N_2O) released in Iran (2015) (b) [20].

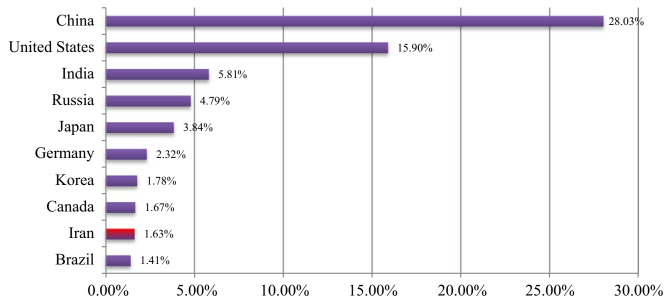

Fig. 9. Top 10 carbone emitting countries in the year 2015. These countries accounted for two-thirds of the world's total CO_2 emission [22].

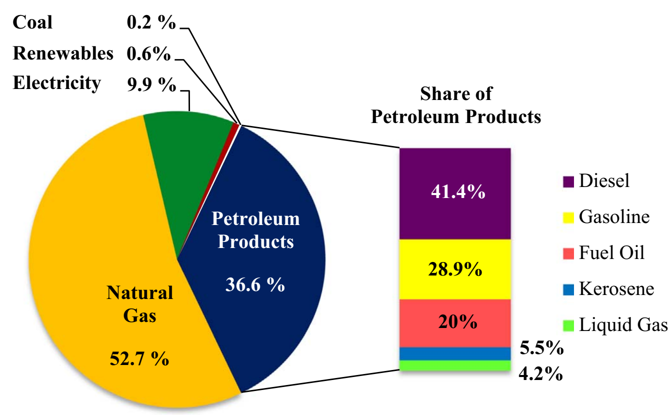

Fig. 11. Breakdown of Iran's energy consumption (2015) [20].

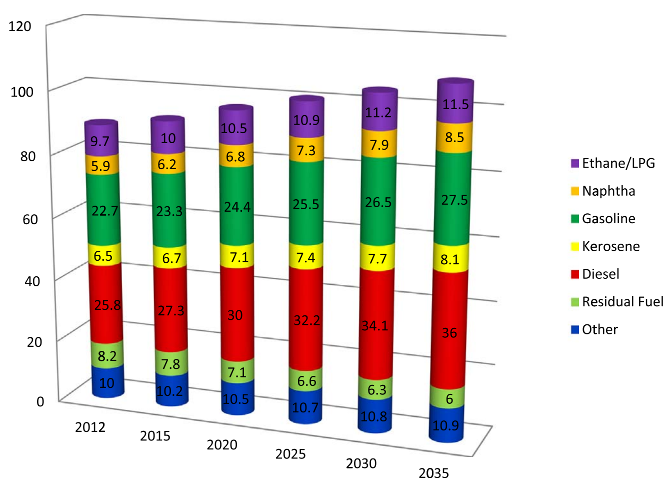

Fig. 10. Global demand outlook for petroleum-based fuels from 2012 to 2035 (in million barrels/day) [26].

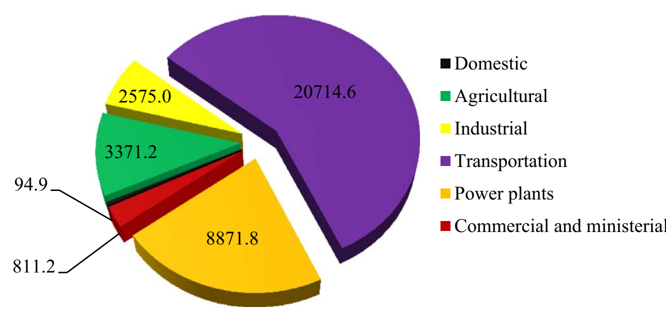

Fig. 12. Breakdown of Iran's diesel consumption by sector (2015) (ML) [20].

contributors to global acidification, corrosion, as well as trees and crops damages [29,30]. Furthermore, diesel exhaust emissions cause ground-level ozone and reduce visibility [31,32]. In addition, it is well documented that organic constituents present in diesel engine exhaust emissions contain some highly carcinogenic compounds such as nitro-polyaromatic hydrocarbons [33]. In fact, diesel fuel has been nominated as the main culprit for more than half of the most dangerous emissions like SO_3, N_2O, and SPM, emitted in the country in the year 2015 (Table 1).

These grave environmental and human health concerns associated with the large-scale petrodiesel consumption plus the growing demands for this energy carrier and its unstable prices are gradually making it economically and ecologically unsustainable. These issues have stimulated the Iranian government to explore for abundant and cleaner alternatives to mineral diesel by considering their compatibility with the existing infrastructures [37].

2.2. Governmental strategies for fuel consumption and emissions control

Emissions policies and energy efficiency trends are strong drivers for limiting the energy consumption growth [1]. In the past decades, the Iranian government allocated tremendous subsidies to energy and some special fuels to boost the economy and improve people's livelihood. Due to this strategy, Iran has the second lowest diesel price (0.1 USD/L) in the world after Venezuela while the average global diesel price is 0.86 USD/L [38]. Contrary to expectations, this policy of subsidizing energy prices has had multidimensional negative effects on the country's economy. Low energy efficiency of the high energy-consuming industries, environment degradation in urban and subur-

Table 1
Diesel fuel emissions [20,30,33–36].

Emission	Associated health problems of the ambient levels of component	Share (%) contributed by diesel exhaust emissions in Iran	Typical diesel exhaust emissions composition
NO_x	– Irritating lungs and lowering resistance to respiratory infection (such as influenza) as well as increasing airway reactivity – Coughing, chest tightness, wheezing, and difficulty in breathing – Eye irritation	40.6[a]	0.003–0.06 (vol%)
SO_2	– Respiratory symptoms and increasing probability of respiratory mortality – Lung diseases and decreasing lung function in Asthmatics – Decreasing birth weight – Increased incidence of sperm abnormalities – Clastogenic and genotoxic for exposed occupational populations	36.3	Proportional to fuel S content
SO_3	– Same effects as SO_2 with 10 times more toxicity mainly for the respiratory system – SO_3 forms sulfuric acid in contact with water which could occasionally lead to skin, eyes, lungs, and digestive tract burns while severe exposures can also result in death.	48.7	Proportional to fuel S content
CO	– Inhalation by the lungs and transmission into the bloodstream – Inhibition of oxygen transfer capacity of hemoglobin – Decreased exercise capacity, slow reflexes, and confusion – Asphyxiation	1.8	0.01–0.1 (vol%)
SPM	– Affecting the immune system by lowering resistance to infectious organisms like viruses and bacteria – Respiratory problems, lung damages, asthma, and lung cancer – Decreasing lung growth and function in children – Eye irritation – Cardiovascular problems – Diminishing reproductive performance – Premature death	75.1	20–200 (mg/m^3)
CO_2	No direct health problems	17.2	2–12 (vol%)
HC[b]	– Respiratory tract irritation – Toxic and carcinogenic	8.1	0.005–0.05 (vol%)
N_2O	– Eye and skin irritation – Respiratory problems	63.7	Not determined

[a] This indicates that 40.6% of the total NOx generated in Iran is contributed by diesel exhaust emissions.
[b] Hydrocarbons such as CH_4.

ban areas, and imposing a huge burden on the government budget resulting in macroeconomic disturbances are some drawbacks of such policy's consequences [39]. To address these concerns, the government commenced an aggressive and ambitious interventive program for reforming energy price in February 2010 in order to control the budget deficit and to mitigate the increasing trend of energy utilization. On the basis of this reform or the so-called "Targeted Subsidies Law" passed by the parliament, fuel prices were increased by up to 90% (currently 75% of the export prices) [39]. In this regard, diesel, historically receiving considerable government subsidies, experienced the first price increase in December 2010, i.e., 9 and 21 fold increases depending on the consumer category. In a study conducted by Shafie-Pour and Ardestani [40] in the year 2007, i.e., three years before the ratification of this plan, they claimed that air pollution and the corresponding costs associated with total health damage could be effectively mitigated by 2019 only through the implementation a price reform adopted by the government, i.e., elimination of energy subsidies without sectoral measures [40]. In fact, they estimated that if the price reform and policy intervention were effectively applied, energy consumption in the domestic sector, GHG emissions, and the associated health damage costs caused by fossil fuels in 2019 would be 50% lower than the business-as-usual scenario in the same year [40].

Beside the increase in energy carrier prices, the Iranian government has also taken serious measures to lead the community towards using the public transportation in order to control the increasing air pollution [41,42]. For instance, through adopting traffic control strategies, the government has put restrictions on the commutation of mostly gasoline-fired passenger vehicles, and instead promoted mostly diesel-fired public transportation system. This in combination with the manifold increase of gasoline price, acted as a lever to lead the community to use the public transportation [43]. However, that in turn elevated diesel consumption throughout the country.

It is worth mentioning that all the passenger vehicles in Iran are equipped with internal combustion engines from which 85% run by gasoline and the rest are flexible fuel cars, i.e., gasoline and compact natural gas (CNG). This is in fact against the current scenario in most parts of the world where on average more than 25% of the driving power of passenger vehicles is met by diesel [44]. This portion reached 60% for new car registrations in European Member states [45]. Based on anticipations, the average global portion of diesel engine passenger vehicles will reach over 35% by 2020 [44]. The global trend of vehicle dieselisation occurred due to the inherent efficiencies of diesel engines and higher energy content of diesel [46]. In fact, diesel engines (direct injection (DI)) have extensive usage compared to otto engines on account of their low-operating and maintenance costs, longer lifetimes, high energy efficiency, durability, reliability, and proper acceleration [33,44,47]. Overall, diesel engines have 35% and 27% lower fuel consumption and CO_2 emissions, respectively, as well as 53% higher fuel economy as compared with gasoline engines [48].

Considering all the above-mentioned advantages of diesel engine vehicles, the Iranian parliament approved the manufacturing and importation of diesel cars from the year 2010 in order to decelerate the increase in gasoline fuel consumption and air pollution [49]. In the same year, Kazemi, the then-CEO of the Iranian Fuel Conservation Organization and later the CEO of the national Iranian oil refining and distribution company (NIORDC), stated that diesel engine passenger vehicles should enter the transportation fleet and make upto 24% of the light-duty vehicles fleet by the end of 2026. Accordingly and based on a plan initiated in 2012, introduction of 600,000 diesel cars into the transportation fleet was targeted. If successfully implemented, an extra amount of about 18 ML diesel per day would be needed [50].

In response to such dieselisation policies, Iran Khodro company (IKCO), the largest car manufacturer in the Middle East, unveiled the first national diesel engine for passenger cars, named EFD, in collaboration with the National Iranian Oil Refining and Distribution Company, on November 17, 2009. The company was scheduled to comence the large-scale manufacturing of this engine by the end of 2015. IKCO's strategy is to increase the manufacturing of diesel engines upto 100,000 sets by 2016 [51].

Passenger diesel vehicles need high quality diesel fuel coinciding with the Euro 4 and 5 standards while despite of all promotionary policies, incentives and acts, the diesel produced in Iran is of extremely low quality and could hardly be used in passenger cars. So, the production of sufficient high quality diesel fuel to meet the fuel requirements of the projected number of diesel vehicles is indispensable. Moreover, based on the new population growth policy adopted by the government aiming to boost the Iraninan population [52], considerably more high quality diesel fuel will be needed in both the transportation and electricity generation sectors in the future.

As a result, the government shows a growing interest in rapid development of facilities capable of producing high quality diesel fuel. Moreover, new policies and incentives came to place in 2015 paving the way to introduce different biodiesel-diesel blends (i.e., B2 and B5) into the Iranian energy market by 2016.

3. Biodiesel as a promising renewable energy carrier

Biodiesel, the monoalkyl ester of long chain fatty acids, is a potential renewable alternative to the non-renewable petroleum-derived diesel fuel [53–55]. This promising renewable fuel has become widely acceptable in the energy market owing to its unique features including higher cetane number in comparison with petrodiesel, lack of Sulfur, inherent lubricity, positive energy balance, higher flash point, compatibility with the existing fuel distribution infrastructure, renewability, and domestic origin [56,57]. Moreover, biodiesel emits 20%, 30%, and 50% less HC, CO, and smoke, respectively, compared with diesel fuel [58,59]. However, it is worth mentioning that brake thermal efficiency (BTE) of biodiesel is 2% lower than that of diesel fuel and its specific fuel consumption is 13% higher than neat diesel [58].

Biodiesel could be blended with fossil-based diesel in any proportions creating a stable fuel blend with premium features that could be used without needing for any engine modifications [60]. Since biodiesel is produced from virgin or used plant oils and animal fats, therefore, it is biodegradable and non-toxic [61]. Moreover, biodiesel could contribute to the mitigation of GHG emissions by reducing most exhaust emissions and therefore, could improve public health, while decreasing dependence on petroleum products [60]. Combustion of neat biodiesel (B100) leads to more than 90% reduction in total unburned hydrocarbons in comparison with petro-diesel, and 75–90% reduction in polycyclic aromatic hydrocarbons (PAHs) [62].

Biodiesel should have a number of certain characteristics to be an excellent substitute for conventional diesel and gasoline as a transportation fuel, i.e., 1) possess superior environmental benefits, 2) be economically competitive, 3) be producible in adequate quantities, and 4) possess a positive net energy balance ratio (NER) [63]. In the year 2014, as the second largest category of global biofuel and because of its widespread acceptance around the world, biodiesel had experienced 10.3% production increase to meet the global level of 29.7 billion L [64]. As shown in Fig. 13, United States is the leading producer of biodiesel with 4.7 billion liters biodiesel production.

3.1. Biodiesel feedstocks and the sustainability controversy

Conventionally, biofuels including biodiesel are classified based on their feedstock and production technologies into four different generations. These generations include biofuels produced from, 1) edible oil seeds, 2) non-food oil crops and wastes, 3) algae, and 4) the genetically engineered oil crops. Indeed, the most important challenging and limiting issue in biodiesel production is feedstock supply, accounting for over 70–80% of the total biodiesel production cost [63,65]. Beside

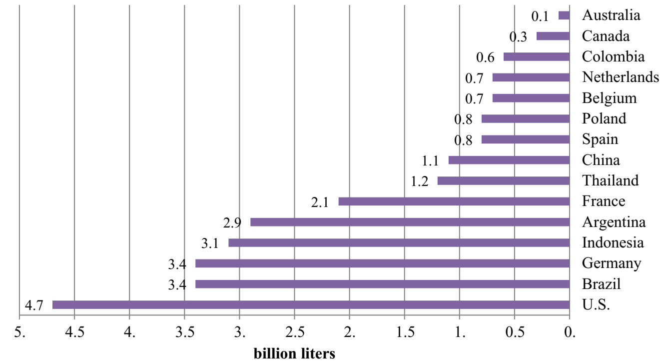

Fig. 13. World's biggest biodiesel producers in the year 2014, by country (in billion L) [64].

cost, the availability of feedstock is also a serious concern which in turn is heavily dependent on various factors such as the region geographical condition where the fuel is produced and the nature of the available oil resources. Currently, the first generation biodiesel accounts for more than 95% of the world total production [66]. For instance, in countries where abundant fertile lands and water resources are easily accessible, first generation biodiesel e.g. soybean and sunflower biodiesels seems to be economically sustainable [67]. This is, however, not agreed upon within the global village framework as the GHG crisis (Fig. 14) and its consequences are highlighted more than ever and many people are also suffering from food shortages all around the world [60,68–70]. More specifically, using food crops for biofuel production has also made a contribution to the large on-going LUC. Consequently, reduced supply of wheat and other essential food crops is increasingly expected in the future [71]. In another word, the development of 1st generation biofuels is also taking place at the expense of the shrinkage of the land area dedicated food crops cultivation. Thus, many studies have portrayed biofuels production as the main culprit for the crop price hikes [71]. Therefore, the main driving force for the migration from food-based biodiesel (first generation) to the next generations has been the fuel vs. food/feed competition over crops, limited arable land, and fresh water [70].

The second-generation biodiesel is derived from non-edible resources or biomass. Such resources include either WCO, grease, and animal fat, or non-edible energy crops. However, as could be clearly comprehended, the latter feedstock must be distinguished from the waste-oriented ones in terms of feedstock sustainability. In fact, although the non-edible energy crops lead to no direct competition over food crops but still could pose serious threats in terms of LUC and water security criteria [73]. Moreover, it should be noted that in spite of the fact that most non-edible energy crops are non-agricultural crops but in order to achieve their maximum productivity/yield, performing agricultural routines such as applying fertilizers, irrigation, harvest and transfer are inevitable [74–76]. Performing such practices contribute to GHG emissions and would consequently increase their carbon

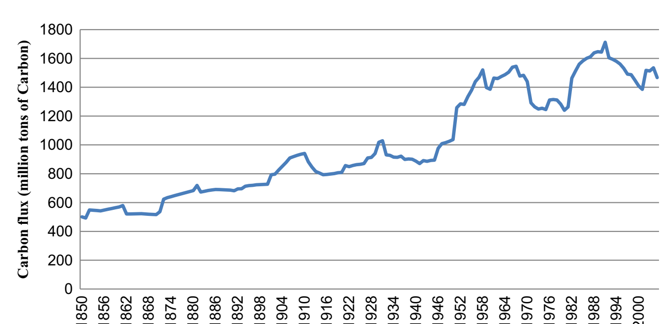

Fig. 14. Annual net flux of carbon to the atmosphere as a result of land use change: 1850–2005 [72].

footprints. LUC for energy crops cultivation could release 17–420 times more CO_2 than the annual GHG reductions that the resultant biofuels would achieve by displacing fossil fuels [63,73,77,78]. As an example, biofuels from switch grass grown on the U.S. corn lands increase emissions by 50% [77]. Such results have raised concerns about widespread crop-originated biofuel utilization and have highlighted the value of using waste products (also known as advanced second-generation biofuels in some literatures) [77–79].

Waste products, i.e., lignocellolusic feedstocks and non-edible waste oil such as WCO and wastes from animal or vegetable residues, are unavoidable consequence of edible oil consumption as an innate portion of human dietary. Since a significant portion of the vegetable oils, i.e., over 80% is used in food applications [80], the amount of waste generated could be remarkable. Therefore, the application of waste-oriented resources for biodiesel production not only imposes no extra cost and environmental threat (carbon footprint), but also triggers no competition whatsoever over food, land, and water. Furthermore, biomass and waste resources are promising sources because of their availability and diversity [81]. On such basis, it would be more conclusive if the biofuels generations (including biodiesel) would be revised from the feedstock sustainability point of view and accordingly, five generations would be considered (Fig. 15).

In the categorization of biodiesel generations presented herein, the 4rd generation biodiesel is produced from microalgae while the 5th generation included genetically-engineered crops and algae. It is worth noting that in spite of the vast studies carried on biodiesel production from microalgae [15,82–87], the cost of the biodiesel produced is still much higher than that of diesel fuel [88]. In a critical review published by Abomohra et.al, it has been emphasized that, algal fuels will only be economically feasible for long term applications [89] and considerable technological developments still need to be made. Therefore, from the feedstock sustainability, economic viability, and environmental impacts point of views, only the 3rd generation biodiesel, i.e., biodiesel produced from waste oil feedstock could be effectively used to partially replace petroleum diesel.

3.2. Biodiesel production in Iran: oil feedstock selection

Since controlling the unbridled non-renewable fuel consumption and the consequent pollutants formation have turned into the main targets of the Iranian Government, biofuel production and utilization has been considered as a key solution [90]. On the other hand, given the increasing rate of the country's population, bioenergy generation from waste materials could be a sustainable strategy for waste management in the country [17]. Nevertheless, studying the essentials of biodiesel production in Iran, i.e., finding sustainable feedstocks and required infrastructures, are still of critical importance in order to ensure the sustainable development of this industry.

Oil crops as potential biodiesel feedstocks have been compared in terms of oil yield, the land area currently under cultivation as well as the land area required for meeting diesel fuel needs of Iran with B2, B5, and B100. Moreover, the irrigation water requirements have also been presented (Table 2).

At the current rate of diesel consumption in Iran, replacing all the

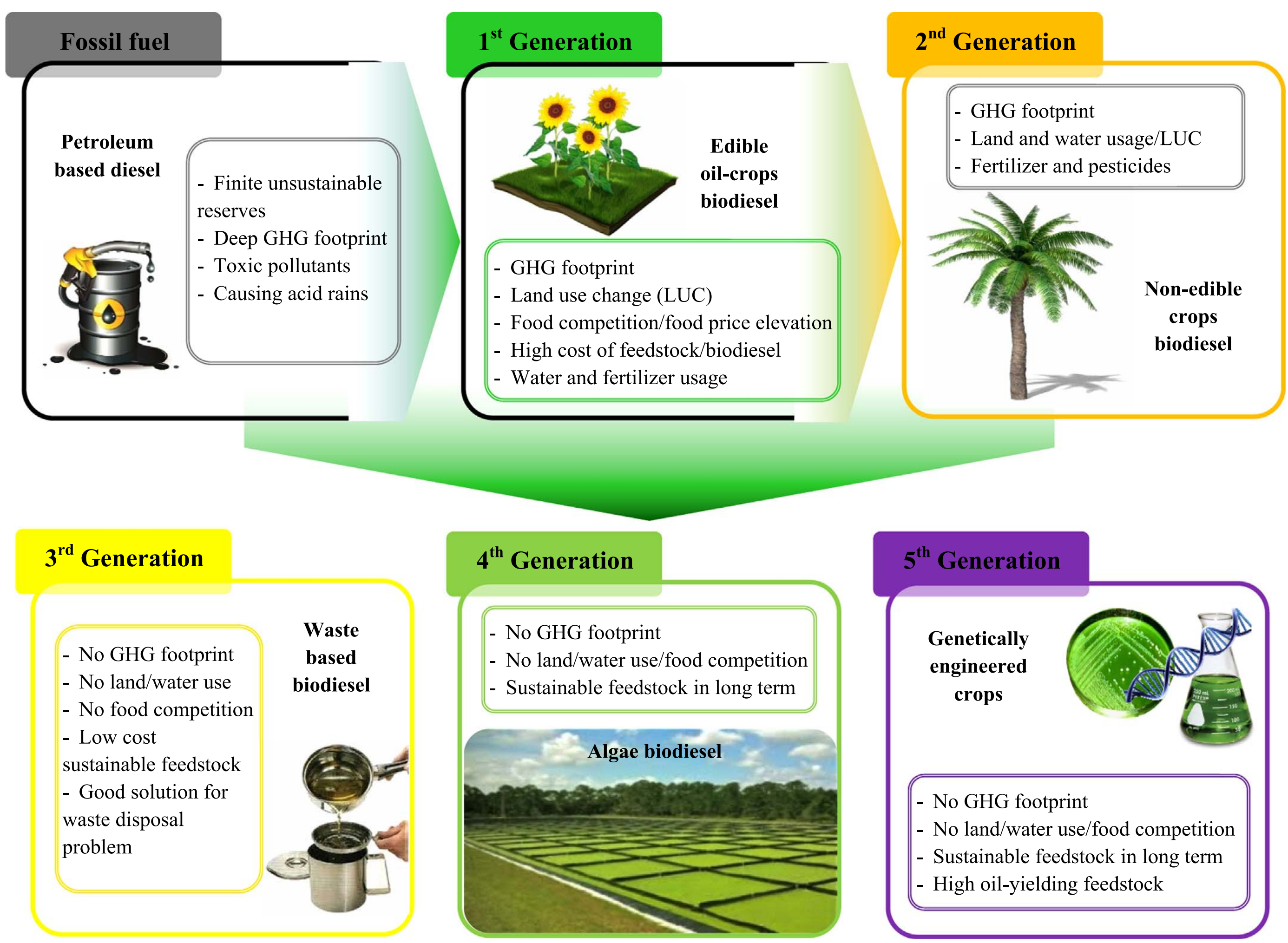

Fig. 15. New classification of biodiesel feedstocks based on the sustainability issue.

Table 2
Comparison of some biodiesel feedstocks including edible and non-edible sources as well as land area and irrigation water needed to produce sufficient amount of oil for replacing country's diesel fuel with B100, B2 and B5 [91–94].

feedstock	Average oil yield[a] (L/ha)	Global average water footprint (m^3/ton oil)	Land dedicated in Iran in 2011 (ha)	Land area needed (ha)			Irrigation water requirement (million m^3)		
				B100[b]	B2[c]	B5[d]	B100[b]	B2[c]	B5[d]
Corn	172	2575	264864	237704906	2725938	6814845	2777	1111	96857
Cotton seed	325	3957	2000	125800751	1442650	3606625	4267	1707	148840
Soybean	446	4190	46	91670951	1051258	2628145	4518	1807	157604
Linseed	478	9415	73398	85533983	980881	2452203	10152	4061	354140
Mustard	572	5600	N/A	71477699	819687	2049218	6039	2415	210641
Sesame	696	21793	N/A	58743166	673651	1684128	23501	9400	819731
Safflower	779	16046	N/A	52484267	601875	1504688	17304	6921	603561
Sunflower	952	6792	N/A	42946685	492501	1231253	7324	2930	255477
Groundnuts	1059	7529	0	N/C	N/C	N/C	N/C	N/C	N/C
Rapeseed	1190	4301	N/A	34357348	394001	985002	4638	1855	161779
Olives	1212	14578	N/A	33733700	386849	967122	15721	6288	548343
Castor	1413	24740	93106	28935063	331819	829547	26679	10672	930581
Jatropha	1892	870	N/A	21609537	247812	619530	938	375	32724
Coconuts[e]	2689	4490	0	15204628	174362	435905	4842	1937	168889
Oil palm[e]	5950	5186	0	N/C	N/C	N/C	N/C	N/C	N/C
WCO	No need to land	No footprint	0	0	0	0	0	0	0
Microalgae[f]	136,900	0	0[h]	298650	3424	8560	0	0	0
Microalgae[g]	58,700	0	0[h]	696512	7987	19967	0	0	0

[a] Conservative estimates – average yields.
[b] To replace the entire diesel consumed in Iran (B100).
[c] To replace the entire diesel consumed in the transportation sector by B2.
[d] To replace the entire diesel consumed in the transportation sector by B5.
[e] Not compatible with the country's climate.
[f] 70% oil (by wt) in biomass.
[g] 30% oil (by wt) in biomass.
[h] Marginal lands or sea plants could replace land area needed.

annual transport diesel fuel consumed in Iran with biodiesel requires over 41000 mL of biodiesel while 470 and 1170 mL of biodiesel would be in demand to replace annual diesel consumption with B2 and B5, respectively. In the year 2011, 490130 ha land was dedicated to oil crops in Iran [93]. Among the cultivated crops and as shown in Table 2, caster is ranked as the highest yielding oil crop for 1st generation biodiesel production in Iran but it has the most water footprint too. Even so, the caster cultivated land area required to replace the diesel consumption throughout the country by B2 would be 331827 ha which is about 70% of the current land dedicated to all edible oil seeds. This is while the country is highly suffering from the lack of edible oils and imports more than 90% of its oil requirement in the food sector [95].

Therefore, in addition to the infeasibility of achieving 1st generation biodiesel in Iran from the feedstock supply perspective, the growing water scarcity in Iran as shown in Fig. 16 will ultimately result in cease of vital agricultural activities to a large extent in the near future. In fact, water is the most limiting factor in the agricultural sector of Iran and higher than 90% of the renewable water in the country is used in agriculture [76], while this amount (i.e., renewable water harvesting) is only at about 30% for high-income countries and 70% for the world [96]. Despite the existence of abundant fertile soils in Iran, it is not therefore reasonable to dedicate any water supply to irrigate neither 1st generation energy crops nor the 2nd ones. On the other hand and as mentioned earlier, the sustainable and economic utilization of the 4th and 5th generation feedstocks does not seem realistic in short- and mid-term runs due to prematurity of the technologies available. As a conclusion, the only currently most-available feedstock in Iran to partially replace diesel fuel consumption would be waste-oriented animal and vegetable oils.

4. Waste oil biodiesel

4.1. Waste oil collection and recycling: a statistical approach

Given the above-presented discussion, the only available low-cost feedstock in Iran would be animal and vegetable waste oils including slaughterhouse wastages, tallow, WCO, chicken fat, and by-products from fish oil. It is worth noting that in case of vegetable oil-importing courtiers like Iran (Table 3), oil wastes recycling issue is further highlighted in order to take the maximum advantage of the revenue spent on edible oil imports (Table 4).

Waste oils could be collected from household and industrial sector where any kind of waste lipid is produced and has to be disposed of. WCO is collected from food manufacturers and industrial deep fryers such as potato processing plants at snack food factories, fast-food establishments, restaurants, catering industries and from all houses where frying is used for food preparation. As an example, restaurants and hotels in the U.S. alone produce more than 11 billion liters of WCO each year, the majority of which is disposed of [102].

It is worth noting that an elaborated marketing network is vital to avoid any future feedstock shortages such as the unpleasant experience of the Mexican waste oil-fed biodiesel plants [103]. Therefore, a complete database about waste oil and fat producers, their waste quality and quantity, and their future production plans must be complied and even guaranteed long-term contracts for waste sales should be signed. Based on a field report released by the United Nation Development Program (UNDP), over 60% of waste oils produced in Iran are collectable and could be recycled for waste-oriented biodiesel production [104]. In the year 2009, the estimated collectable WCO generated in the country stood at about 435000 t [105]. This huge amount of waste oils will continue to further increase with a growing rate proportional to the population growth rate. Chen et al. proposed a model to simulate waste production rate in china [106]. Their model was modified herein in order to predict the collectable waste oil/fats (WOF) produced annually:

$$WOF_t = P_t \times (1 + U_t/100) \times W_t$$

where WOF_t is the WOF generated in year t, P_t is the population in year t, U_t is the urbanization rate (2.07% considered for Iran during 2010–2015) [107], and W_t is per capita waste oil production. By assuming

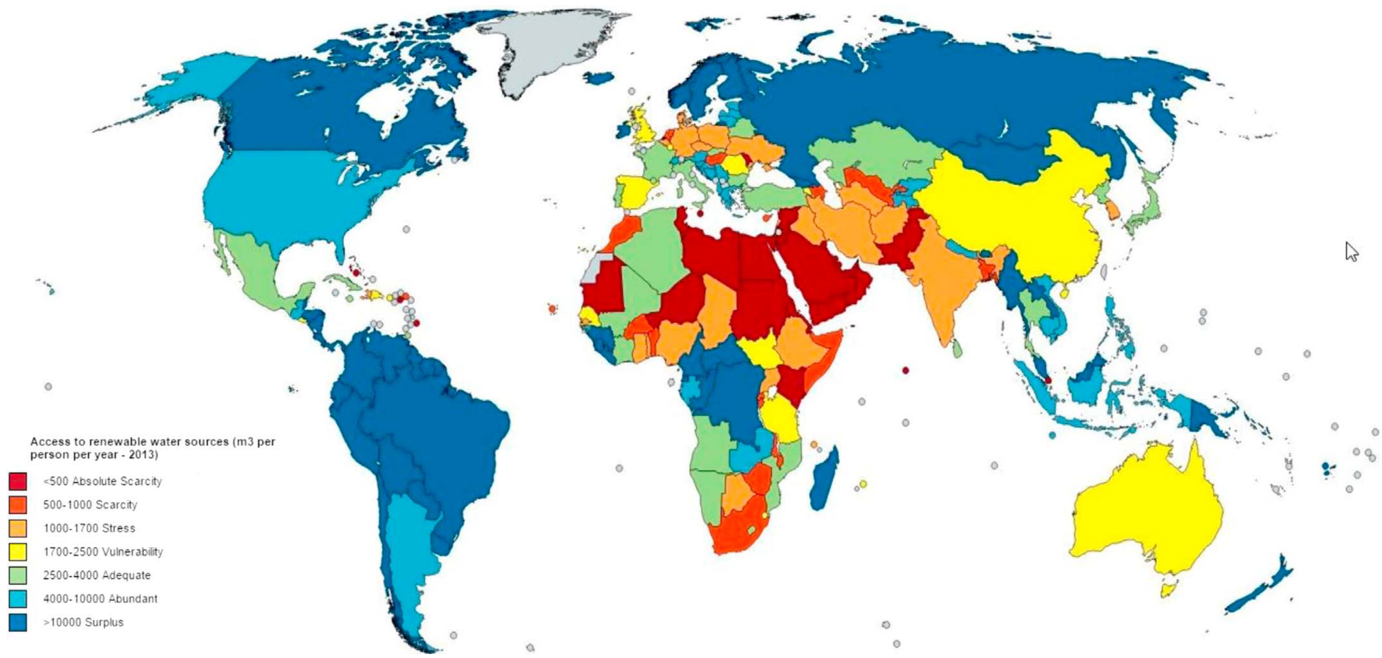

Fig. 16. Per capita renewable water sources accessibility (m^3/person/year).

Table 3
Vegetable oil production and import projections of a number of vegetable-oil importing countries [97,98].

Country	Vegetable oil production (kt)		Vegetable oil import (kt)	
	2012	2022	2012	2022
Developed countries				
United States	11740	13206	3613	3076
European Union	14197	17164	8209	10315
Russian Federation	3543	4160	944	1118
Australia	457	617	381	416
New Zealand	5	5	107	108
Japan	1441	1166	730	940
South Africa	398	762	786	592
Developing countries				
Africa				
Algeria	83	102	560	691
Egypt	433	510	1745	2174
Latin America and Caribbean				
Chile	71	95	309	374
Mexico	1643	1772	750	927
Uruguay	83	192	80	51
ASIA and PACIFIC				
Bangladesh	218	221	1436	2120
China[a]	21320	25733	9101	11418
India	7258	8694	9688	14665
Iran	302	372	1460	1742
Korea	250	256	850	953
Pakistan	1321	1651	2296	2943
Saudi Arabia	11	2	386	581
Turkey	1241	1320	1168	1391
Least developed countries (LDC)[b]	2740	3939	4923	6599

[a] Refers to main land only. Not including the economies of Chinese Taipei, Hong Kong (China) and Macau (China).
[b] LDC Countries list available at http://www.un.org/en/development/desa/policy/cdp/ldc/ldc_list.pdf.

6 kg per capita WOF generation according to the year 2009 database [105], the total amount of WOF generated in the year 2016 could be estimated at about 483000 t.

If recycling process is not performed appropriately, oil wastes often lead to clogged drains, backups, and rancid odors while also imposing extra cost on wastewater treatment facilities by entering into sewerage systems [108]. Recycling of this abundant amount of oil wastes is also crucial from the environmental perspective in order to prevent soil and water resources contamination [63]. Fig. 17 presents the statistics on waste oil resources and their contribution in Iran in 2009 [105].

It is worth noting that currently restaurant grease and animal fats are mostly devoted to several industrial uses, some causing environmental and health concerns. Such applications include production of cosmetics (e.g. shampoo and soap) as well as animal feed production. The former could potentially result in allergy, dermal diseases, and non-compensable injuries [104], while the latter could be a potential cause of human health problems.

Table 4
Edible oil production, import, and consumption as well as waste-oil generation in Iran [98–101].

Factor	Unit	Quantity	Value (million USD)
Per capita oil and fat consumption	kg	21	1.7(USD)
Total oil and fat consumption	Ton	1739000	2956
Oil crop Production in the country	Ton	570000	400
Imported vegetable oil (raw and processed)[a]	Ton	1593600	1775
Total waste oil Production[b]	Ton	483000	251[c]
Biodiesel produced if 60% of annual waste oil is collected and converted to biodiesel[d]	ML	270	175.5[e,f]

[a] Data belonged to 2013.
[b] Average WCO price in Iran=0.52 USD/kg (data gathered from waste oil suppliers for soap plants).
[c] The wasted revenue if waste oil is disposed of.
[d] Assuming 90% conversion rate of waste oil to biodiesel.
[e] Revenue obtained from WCO-biodiesel exports (0.65 USD/Lit; minimum biodiesel price proposed to be set by the government as fixed purchase price based on the WO-BUS program in Iran).
[f] 282.5 million USD if all the 483000 produced waste oil could be converted to biodiesel (assuming 90% conversion of the waste oil).

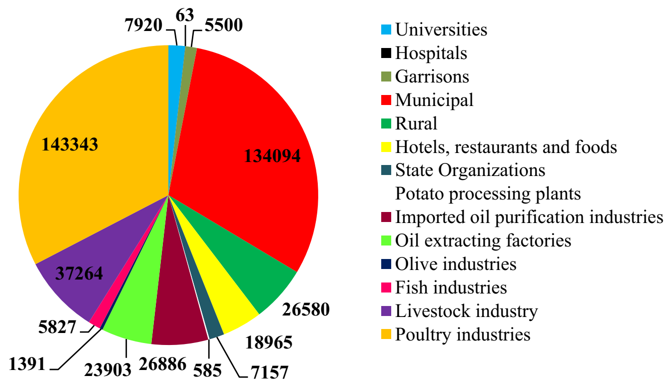

Fig. 17. Waste oil resources and their contribution (ton) in Iran in 2009 [105].

Table 5
Some of the factories use waste oils as feedstock to produce biodiesel [109–111].

Technology	Location	Feedstock	Capacity (ML/Y)
Fuel Bio One LLC	USA	Animal Fats/Yellow Grease	189
High Plains Bioenergy LLC	USA	Animal Fats	114
SeQuential Pacific Biodiesel LLC	USA	WCO	64
Viesel Fuel LLC	USA	Waste Vegetable Oil	60
Performance Biodiesel	USA	Animal Fats	57
Delek Renewables LLC	USA	Animal fat	45
BlackGold Biofuels	USA	Trap Grease/ Wastewater Sludge	1
Rothsay Biodiesel LLC	Canada	Animal Fats/Yellow Grease	45
Australian Renewable Fuels (ARF)	Australia	WCO, tallow	44.5
Next Generation Biomass to Liquid Diesel (NExBTL)	Singapore	residual animal fat/ palm oil	935

4.2. Waste oil biodiesel refining: statistics and production challenges

Some of the major companies that use waste oils as feedstock in the world to produce biodiesel are listed in Table 5.

Various processes used for synthesizing biodiesel in particular the most popular one, i.e., transesterification process, have been extensively reviewed during the last few years [112–117]. Transesterification takes place between a vegetable oil and an alcohol (methanol or ethanol), in the presence of a homogeneous or heterogeneous catalyst. This alkaline-, acidic, or enzymatic-catalyzed reaction produces fatty acid methyl esters (FAME) and glycerol as main product and co-product, respectively [113]. As the enzyme (lipase)-catalyzed reaction is restricted by its rigorous reaction conditions and enzyme activity loss, it cannot therefore be used in large-scale commercial biodiesel production up to date [116]. Tables 6 and 7 provide comparative data on the advantages and drawbacks of homogeneous vs. heterogeneous as well as alkaline vs. acid-catalyzed reactions for biodiesel production from waste oils.

Waste oils, particularly WCO, must be filtered to eliminate solid particles, water, and free fatty acids (FFA) prior to its conversion into biodiesel [118]. In fact, the quantities of FFAs and water are key parameters for determining the viability of the vegetable oil transesterification process. These make biodiesel production from WCO difficult to achieve and have pushed researchers to explore different methods for obtaining optimum production conditions.

Although homogeneous alkaline catalysts lead to high biodiesel yields even at relatively low temperature and pressure, but in case of waste oil feedstocks serious challenges are faced including saponification and consequent low ester yield caused by high levels of FFA and water. To carry the base-catalyzed reaction to completion, the optimum FFA levels for feedstocks are <1 wt% and water <0.5 wt%, while the level of FFAs in waste oil is typically on the order of 10–15% for yellow waste vegetable oil and over 15% for brown waste vegetable oil [122,123]. Therefore, direct alkaline-catalyzed transesterification reaction using conventional processes would be undesirable and different pretreatment methods including steam distillation, extraction by alcohol, and acid-catalytic esterification are required to avoid saponification and yield loss in the reaction vessel [120,121,124]. In the case of the acid-esterification reaction, heterogeneous catalysts do not show the corrosive behaviors observed in the presence of homogenous ones and therefore, less costly process instrumentations are required [118]. Ruhul et.al claimed that zirconium dioxide (ZrO_2) and their compounds can be used as an effective high yielding acid heterogeneous catalyst [118].

Overall, it is worth quoting that most of the biodiesel plants currently in operation are running using homogeneous alkali catalysts, i.e., sodium or potassium hydroxides, carbonates or alkoxides since the application of these catalysts are comparatively cost-effective over the currently-available heterogeneous catalysts [116].

Beside the efforts put into introducing cheap raw materials and more efficient catalysts for commercialization of biodiesel production, numerous investigations have also been focused on process intensification through the implementation of new technologies [121,125]. Such technological improvements in process design have strived to address the technical difficulties associated with the conventional alkali-transesterification reaction such as immiscibility of triglycerides and alcohols and reaction reversibility problems. These are supposed to be able to enhance reaction rate, reduce molar ratio of alcohol to oil, and energy input by intensification of mass and heat transfer [126]. Moreover, some technological improvements and novel methods have been introduced and applied to facilitate the post-treatment severities of biodiesel production like glycerin separation, alcohol and catalyst recovering, and water removal from the final product [126–129]. Some of these successfully commercialized technologies are tabulated in Table 8.

4.3. Waste oil biodiesel properties: standards and characterization

The quality of biodiesel is attributed to many factors such as

Table 6
Comparison of homogeneous- and heterogeneous-catalyzed transesterification reaction [116,118,119].

Factors	Homogeneous catalysis	Heterogeneous catalysis
Reaction rate	Fast and high conversion	Moderate conversion
Post-treatment	Catalyst cannot be recovered, must be neutralized leading to waste chemical production	Catalyst can be recovered
Processing methodology	Mild reaction condition and less energy consumption	Continuous fix-bed operation possible
Presence of water and FFA	Sensitive/Not suitable	Not sensitive/Suitable (water tolerance)
Catalyst reuse	Not possible	Possible
Cost	Comparatively cost-effective than the currently-available heterogeneously catalyzed transesterification	Potentially cheaper, provides the high conversion efficiency, and becomes technologically available

Table 7
Comparison of acid-catalyzed and alkali-catalyzed transesterification process of waste oil to biodiesel [116,118–121].

Transesterification process	Advantages	Drawbacks
Acid-catalyzed reaction	– Feasible in the presence of high levels of FFA and water – No need for esterification pretreatment – Fewer main processing units – Less toxic effect – Fewer environmental problems	– Slow reaction – Higher temperature, pressure, and alcohol/oil ratio – Corrosion of equipment and environment contamination – Need to costly equipment with stainless steel material – Higher amount of methanol resulting in larger equipment volumes
Alkali-catalyzed reaction	– Lower temperature, pressure, and alcohol/oil ratio – Significantly higher reaction rate – Smaller equipment – Good corrosion resistance properties – Fewer stainless steel equipment – Low cost of catalyst	– Requiring pretreatment process – Without pretreating, low ester yield and by-product production occurs because of high levels of FFA and water – Occurrence of saponification

feedstock characteristics and quality, e.g., fatty acid composition of the parent oil or fat, production process and post-treatment parameters, as well as handling and storage conditions. For the inclusion of physicochemical properties of a given biodiesel into the requirements of a standard, different characterization methods must be performed (Table 9). Table 10 lists average values for biodiesel properties produced from four main groups of waste-oriented fuels gathered from a comprehensive literature survey. The average fatty acid compositions of these four groups are also comparably illustrated in Fig. 18 as the main parameter affecting resultant biodiesel properties.

The composition of waste oils used for biodiesel production may vary based on their generation source. For example, frying oils are often produced from different oil crops, consequently having different molecular structures. Moreover, these oils contain water, FFA and other undesired impurities generated by the thermolytic, oxidative, and hydrolytic reactions occurred during heating process [164]. Animal fats mainly obtained from slaughterhouses are composed of higher saturated fatty acids with different physical properties. Generally, waste oil biodiesel plants obtain their feedstock from different sources including animal fats and vegetable oils, resulting in a wide range of FAME composition fed to the process units. Therefore, different pretreatment techniques must be employed to improve the feed quality to a level required by transesterification process equipment. As a conclusion, it is crucial to determine feedstocks quality using various standard methods or reliable modeling techniques for obtaining some important parameters.

4.4. Waste oil biodiesel utilization in Iran

4.4.1. Economic feasibility analysis of WCO-biodiesel production

Generally, the first step in feasibility analysis of the utilization of an alternative product is to analyze the most important factor affecting its acceptance, i.e., the cost. In countries such as Iran where fuel prices are very low, the main reason to move towards using expensive renewable fuels is the environmental mandates. Among all the renewable liquid fuels compatible with the country's current transportation fleet, WCO-biodiesel is the most affordable one because of the low feedstock price. Waste oils could be obtained at about half of the price of virgin oils in Iran which in turn significantly reduces the finished price of biodiesel. In order to maintain an optimum capacity for a biodiesel plant, an economic modeling is needed to be performed based on the investment model chosen by an investor.

Herein, a medium-sized plant with a biodiesel production capacity of about 90 t/day was assumed based on the modeling study carried out by Haas et al. [180] to ensure the sufficiency of the plant capacity for guaranteeing its profitability. Capital and operating costs for the same plant working under Iran's conditions are provided in Tables 11 and 12 using the national market data. The life time of the plant was assumed to be 10 years and was operated three shifts per day. Plant location was also explored in order to find the optimum distance from the waste oil collection centers as well as the distribution points. An average of 90 km transport distance from the feedstock collection centers in Tehran and Karaj (two major highly populated cities of Iran with a lot of slaughterhouses and large industries producing waste oils and lipids) to the plant was considered [181]. The land price and

Table 8
Some of the successful process intensification technologies used in WO transesterification to biodiesel.

Technology	Application	Refs.
Low frequency ultrasonic irradiation	Emulsification of immiscible oil and alcohol to enhance mixing efficiency	[130–134]
Microwave irradiation	Heating reactants to the required temperature quickly, uniformly, and efficiently	[135–139]
Static mixer	Providing rigorous radial mixing by motionless geometric elements enclosed within a pipe or a column and thus bearing the advantages of low maintenance and operating costs as well as low space requirements	[140–142]
Micro-channel reactors/ capillary micro-reactors	Accelerating reaction rates by improving the efficiency of heat and mass transfer and utilizing high surface area/volume ratio and short diffusion distance	[143–146]
Oscillatory flow reactors	Intensifying radial mixing and heat and mass transfer as well as maintaining plug flow condition and achieving long residence time, lower capital and pumping cost, and easier control.	[147]
Rotating/spinning tube reactors	Producing a very large interfacial contact area, lowering reaction time, and mixing power input required	[148]
Cavitational reactors	Using acoustic energy or flow energy to generate cavitation in which the violent collapse of the cavities releases large magnitude of energy over a small location, and brings about very high temperatures and pressures and also intensifies the mass transfer rate by generation of local turbulence and liquid micro-circulation in the reactor	[149–151]
Supercritical process	Catalyst elimination, shorter reaction time, and easier purification	[152–154]
Membrane reactors	Increasing the conversion of equilibrium-limited reaction by removing some products from the reactants stream *via* the membrane.	[155–157]
Reactive distillation	Providing continuous in situ product removal for equilibrium-controlled reactions. Integration of reaction and separation reduces capital investment and operating costs.	[158–161]
Centrifugal contactors	Integrating reaction and centrifugal separation into one unit.	[162,163]

Table 9
ASTM D 6751 and EN 14214 specifications for biodiesel [165–167].

Properties	ASTM D 6751		EN 14214	
	Limit	Method	Limit	Method
Density at 15 °C	870–890 kg/m^3	ASTM D4052-91	860–900 kg/m^3	EN ISO 3675, EN ISO 12185
Flash point	130 °C minimum	ASTM D93	> 101 °C (minimum)	EN ISO 3679
Viscosity @40 °C	1.9–6.0 mm^2/s	ASTM D445	3.5–5.0 mm^2/s	EN ISO 3140
Sulfated ash	0.020% m/m maximum	ASTM D874	0.02% m/m (maximum)	EN ISO 3987
Cloud point	Report to customer	ASTM D2500	Based on national specification	EN ISO 23015
Copper strip corrosion	Class 3 maximum	ASTM D130	Class 1 rating	EN ISO 2160
Cetane number	47 (minimum)	ASTM D613	51 (minimum)	EN ISO 5165
Water content and sediment	0.050 (%v) maximum	ASTM D2709	500 mg/kg (maximum)	EN ISO 12937
Acid number	0.50 mg KOH/g maximum	ASTM D664	0.50 mg KOH/g (maximum)	EN 14104
Free glycerin	0.02% (m/m) maximum	ASTM D6584	0.02% (m/m) (maximum)	EN 1405/14016
Total glycerol	0.24% (m/m) maximum	ASTM D6548	0.25% (m/m)	EN 14105
Methanol content	0.20% (m/m) maximum	EN 14110	0.20% (m/m) (maximum)	EN 14110
Phosphorus	10 mg/kg maximum	ASTM D4951	10.0 mg/kg (maximum)	EN 14107
Distillation temperature	360 °C	ASTM D1160	–	–
Sodium and Potassium	5.00 ppm maximum	EN 14538	5.00 mg/kg (maximum)	EN 14108, EN 14109
Oxidation stability	3 h minimum	EN ISO 14112	6 h (minimum)	EN ISO 14112
Carbon Residue	0.05 maximum wt%	ASTM D 4530	0.30% (m/m) (maximum)	EN OSO 10370
Calcium and Magnesium	5 ppm maximum	EN 14538	5 ppm (maximum)	EN 14538
Iodine number	–	–	120 g/100 g (maximum)	EN 14111

Table 10
Different waste-oil biodiesel properties [119,168–179].

Property	WCO	Waste fish oil	Waste poultry fat	Tallow (lard, mutton, beef, etc)	Petrodiesel
Density at 40 °C (kg/m^3)	0.87	0.86	0.87	0.86	0.82
Viscosity at 40 °C (mm^2/s)	4.7	5	4.5	6.4	3
Cetane number	50	51	61	59	51 (Euro 3,4,5)
Heating value (MJ/kg)	40	41.5	40	40	LHV=43, HHV=47
Acid value (mg KOH/g)	2	1.2	0.3	0.6	–
Sulfur content (ppm)	Various	–	–	0.2	350 (Euro 3) 50 (Euro 4) 10 (Euro 5)
Cloud Point (°C)	20	−5	−6	−4	−5
Pour point (°C)	16	4	−6	−5	–
Flash point (°C)	85	–	–	–	50
Short chain saturated fatty acids (C:14-C:18) (%)	20–45	15–30	20–35	40–60	–
Short chain unsaturated fatty acids (C:14-C:18) (%)	40–80	30–60	65–80	35–65	–
Long chain saturated fatty acids (≥C:20) (%)	0–1	0–7	0–2	0–1	–
Long chain unsaturated fatty acids (≥C:20) (%)	0–1	25–40	0 to −2	0–0.5	–

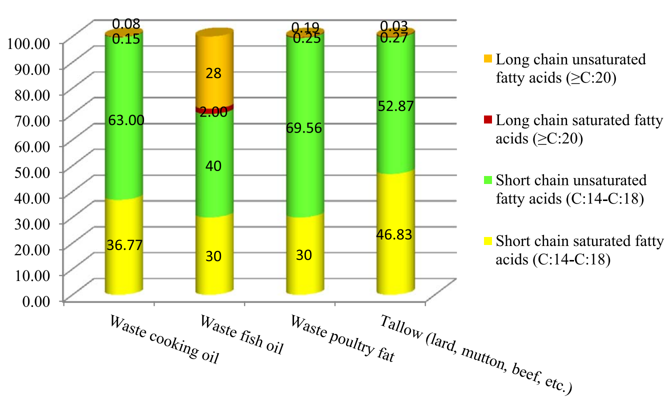

Fig. 18. Average fatty acid composition of the four groups of waste-oil feedstocks used for biodiesel production.

availability was also taken into account in the analysis. In order to benefit from tax exemption and free waste-water disposal system, the plant location was selected in a neighboring tax-free industrial park. Moreover, in order to minimize water consumption (as the country is suffering from water scarcity), biodiesel wash-water microfiltration-based recycling strategy (30% wash-water and 70% fresh water) proposed by Jaber et al. [182] was assumed in the cost analysis model.

Table 11
Capital costs for the construction of a 90 t/d WCO-biodiesel plant.

Factor	Cost (Thousand USD)
Equipment	
Process equipment[a]	2599
Utility equipment	403
Storage facilities[b]	1047
Total equipment cost	4049
Civil and construction[c]	
Land acquisition	55
Building and structure	161
Total civil cost	216
Installation[d]	8098
Shipment and loading[c]	7
Total capital cost	12370

[a] Equipment required for transesterification of waste oil feed plus 20% over estimation because of filtration of waste oil, FFA removal, and waste water recycle.
[b] 25-day capacity of feedstock and product.
[c] Data gathered from market.
[d] 200% of equipment costs including engineering design cost, construction labor, piping, electrical and control instruments and their programing and other expenses.

The process chosen for the biodiesel units included an esterification process to remove excess FFA using 1% w/w acidic catalyst (H_2SO_4) followed by a conventional transesterification process by means of an

Table 12
Operating costs, taxes, and revenues from byproduct sales for a 90 t/day WCO-biodiesel plant.

Factor	Consumption/d	Cost[a] (USD/ Unit)
Raw Materials and utility		
WCO[b,c]	100000 kg	0.52/kg
Water[d]	121 m^3	0.18/m^3
Alcohol (methanol)	18198 kg	0.2/kg
Transesterification alkali catalyst (KOH)	115 kg	1.37/kg
Esterification acid catalyst (H_2SO_4)	1034 L	0.27/L
Diesel fuel for transportation[e]	86 L	0.1/L
Electricity	5227 kW h	0.018/kW h
Glycerol (byproduct)[f]	13028 kg	− 0.24/kg
Additional operating costs		
Labor[g]	6 Person/d (in 3 shift)	28/person
Supervision and general administrative costs		138/d
Maintenance supplies	(1% of capital cost annually)	339/day
Total Operating cost	53719 USD	0.519/L biodiesel[h]

[a] All given prices are based on Iran market data – 2016 October.
[b] Assuming 90% conversion efficiency for transesterification process.
[c] 50% of fresh vegetable oil price.
[d] Assuming 30% waste-water recycle.
[e] Subsidized price.
[f] The revenue from crude glycerol (80% solution) sales as byproduct were subtracted from the total operating cost.
[g] Including basal labor payment and other expenses based on Iran's ministry of labor laws.
[h] Biodiesel density=0.87 gr/cm^3.

alkali catalyst (KOH) at 60 °C. The equipment cost were considered for the main process including transesterification, biodiesel purification, and glycerol recovery.

As reported in Table 13, the obtained price for WCO-biodiesel, i.e., 0.611 USD/L is somewhat lower than the global average price of petrodiesel (0.86 USD/L) [38]. This means that, in addition to the benefits counted for WCO-biodiesel production in Iran, it can be also exported to diesel-importing countries especially those having good trading relations with Iran such as Turkey, China, etc. The financial model presented herein showed that waste oils and fats utilized as feedstocks accounted for 85% of the total costs spent for biodiesel production from these feedstocks. If the produced biodiesel is to be utilized for domestic consumption in Iran, by taking into account the governmental strategies to completely remove energy subsidies in the near future (which will consequently lead to increased diesel price), Iran is not far from experiencing biodiesel introduction into its transportation fleet. This will be more decisive when environmental mandates come to action by the international forces.

4.4.2. Comparison of international experiences

Much effort has been put into the development of biodiesel in Iran since early 2000s. However, these activities have failed or rebuffed as a result of cheap supply of fossil-based energy carriers in the country. In fact, the trend has been mostly limited to research activities at laboratory scale, development of production process technologies, and standardization. But recently, as elaborated earlier owing to the subsidies-removal plan, biodiesel production and utilization particularly from waste feedstocks have gained a renewed interest. In line with that, several pioneering Iranian research institutions have been focused on research/extension and commercialization of waste-oriented biodiesel. Those include Biofuel Research Team (BRTeam), Iranian Biofuel Society (IBS), renewable energy center of Tarbiat-Modarres University, and Research Institute of Petroleum Industry (RIPI) as well as a number of private companies. In order for these efforts to be materialized, a national-wide implementation program including promotion and public awareness, binding rules and regulations, and supporting policies for collection, transformation and commercialization of biofuels including biodiesel should be put in place and mandated.

Table 13
Constituent parameters included in calculating the finished price of 1 L of WCO-biodiesel.

Parameter	USD/L biodiesel
Capital cost[a]	
ROI[b] effect	0.082
Equipment depreciation effect	0.01
Operating cost	0.519
Biodiesel price	0.611

[a] Assuming 4 years for ROI calculations and 10 years for equipment depreciation.
[b] Return on investment.

In order to frame a comprehensive enforceable scenario for Iran that encompasses all the necessary infrastructures for sustainable utilization of waste oil biodiesel, some of the successful biodiesel development programs conducted by leading biodiesel producing countries have been scrutinized in Table 14. Some of these countries have appropriate climate enabling them to benefit 1st and 2nd generation feedstocks to the extent that they can export vast amounts of crop-oriented oil. It is while others import vegetable oil to meet the biofuel-related obligations set by their governments or use sustainably and domestically supplied waste oil feedstocks.

By abstracting political and social similarities of the programs executed in biofuel pioneering countries and in the context of economical, political, and cultural infrastructures of Iran, a reliable localized scenario for the country is proposed herein. More specifically, based on the fact that waste oil biodiesel is currently the only reasonable feedstock in Iran, the most compatible frameworks to the Iran's situation would be the Renewable Transport Fuel Obligation (RTFO) and NRDDI enacted previously in the UK and Canada, respectively. These programs were successful illustrations of taking full advantages of WCO generated in the UK and Canada through the implementation of well-managed collection systems [191–193]. Moreover, incentives and penalties used by the Brazilian government are largely applicable for Iran because of the structural similarities of the two countries. Fig. 19 describes the targets and strategies through which the waste oil biodiesel utilization was achieved in UK.

4.4.3. Proposed national program of “waste oil biodiesel utilization scenario” (WO-BUS)

The first step to benefit the advantages of utilization of waste oil biodiesel in Iran is to establish a systematic managed program on the collection of waste oil and fats. Hereof, there must be a public awareness about the benefits of recycling waste oils and using vehicles powered by biodiesel while striving to facilitate the collection and delivery of such wastes. Therefore, convenient disposal systems must be designed that do not impose significant financial burdens, etc. Fig. 20 describes essential steps to establishment of an integrated waste oil collection strategy for Iran.

As the collected oils have different origins with different qualities, depending on the type of restaurant or manufacture and the time of year, a system for classifying the oils would also be required, which should be based on the measurement of objective parameters [194].

For the utilization of renewable energy and specifically biofuels nationwide, state mandates have already come into place in Iran's 6th national development plan (6th NDP; 2016–2020). Based on the outcomes of the present investigation, to meet the target set forth for diesel fuel, i.e., replacement of country's diesel with B2, WO-BUS program seems to be most promising (Fig. 21).

Table 14
Biodiesel programs and action plans in different countries [183–190].

Country	Program/s	Targets	Environmental targets	Biodiesel Feedstocks Used	Financial incentives and investments	Obligations and penalties
Argentina	Argentine Biofuel Law 26.093	B5 in 2010	–	–	–	–
Brazil	– National Program on Biodiesel Production and Usage (PNPB) inaugurated in 2005. – Social Fuel Stamp[a] (SFS) program	B2 in 2008–2013 and at least B5 thereafter	–	– Soybean 73% – Animal tallow 20% – Cottonseed 3%	– Brazil's National Petroleum Agency (ANP) buys given quantities of biodiesel in auctions – 73–100% tax exemption incentives especially for family farmers – Provided research incentives	– Through SFS, biodiesel producers must purchase a certain level of soy feedstock from family farmers and get stamps. – Large energy providers must only purchase from the biodiesel companies that have the stamp.
Canada	– National Renewable Diesel Demonstration Initiative (NRDDI) (2008) – EcoENERGY for biofuels – Next-Generation Biofuels Fund (2007)	B2 by 2012	–	– Tallow grease (49%) – Yellow grease (37%) – Canola (14%) (2009)	– Investment of up to USD1.5 billion over 2008–2017 on all biofuels through EcoENERGY – Subsidies are set at CANUSD0.20 per liter for 2008–2010 decreasing ANUSD0.04 every year until valued at CANUSD0.06 in 2016 – Recipients can receive funds for up to 7 consecutive years. – USD500 million for investment in collaboration with the private sector through NextGen Biofuels Fund program	–
Colombia		– B5 by 2008 – B10 by 2010 – B20 by 2012	–	– Mainly Palm oil	– Sales tax and fuel tax exemptions. – Tax exemption for income obtained from biodiesel crops.	–
France		–	–	– Vegetable oils especially rapeseed	– 0.33 h/l tax rebates in 2005 – 0.15 h/l tax rebates in 2009 – Fiscal rebates reduced over years to phase-out by the end of 2011.	–
Indonesia	–	– 2005–2010: B10 – 2011–2015: B15 – 2016–2020: B20	– High quality biodiesel by 2020	– Palm and Jatropha	– biofuel subsidies of 30 cents/liter paid for by a USD 50/barrel levy on crude palm oil (CPO) exports	–
India		17% biodiesel by 2017	–	–	–	–
Malaysia		B5 by 2008	–	–	–	–
Thailand	15-year Renewable Energy Development Plan (REDP)	B2 nationwide by April 2008, B5 by 2011, B10 by 2012 and 4.5 MLs by 2022	–	– Palm, coconut, Jatropha based on the country's tropical climate	– 13406 million USD investment – Some cities offer free parking and waived congestion charges to flex-fuel vehicles	–
United States	Renewable Fuel Standard (RFS2) (mostly focused on bioethanol)	– B5 in New Mexico; B2 in – Louisiana and Washington State; – Totally 1 billion gallons biomass based biodiesel	– Reduction of life-cycle GHG emissions by at least 50%	– Mostly soybean oil	– The subsidy is set at USUSD1 per gallon for biodiesel produced from virgin oils or fats, and USUSD0.50 per gallon for recycled oils	– All renewable fuels should certify the type of feedstock used and comply with regulations on land-use. – Taxes levied against imported Biofuel

[a] The Stamp is essentially a certification for biodiesel companies showing that the companies have met a set of criteria regarding business relationships with small-scale farmers.

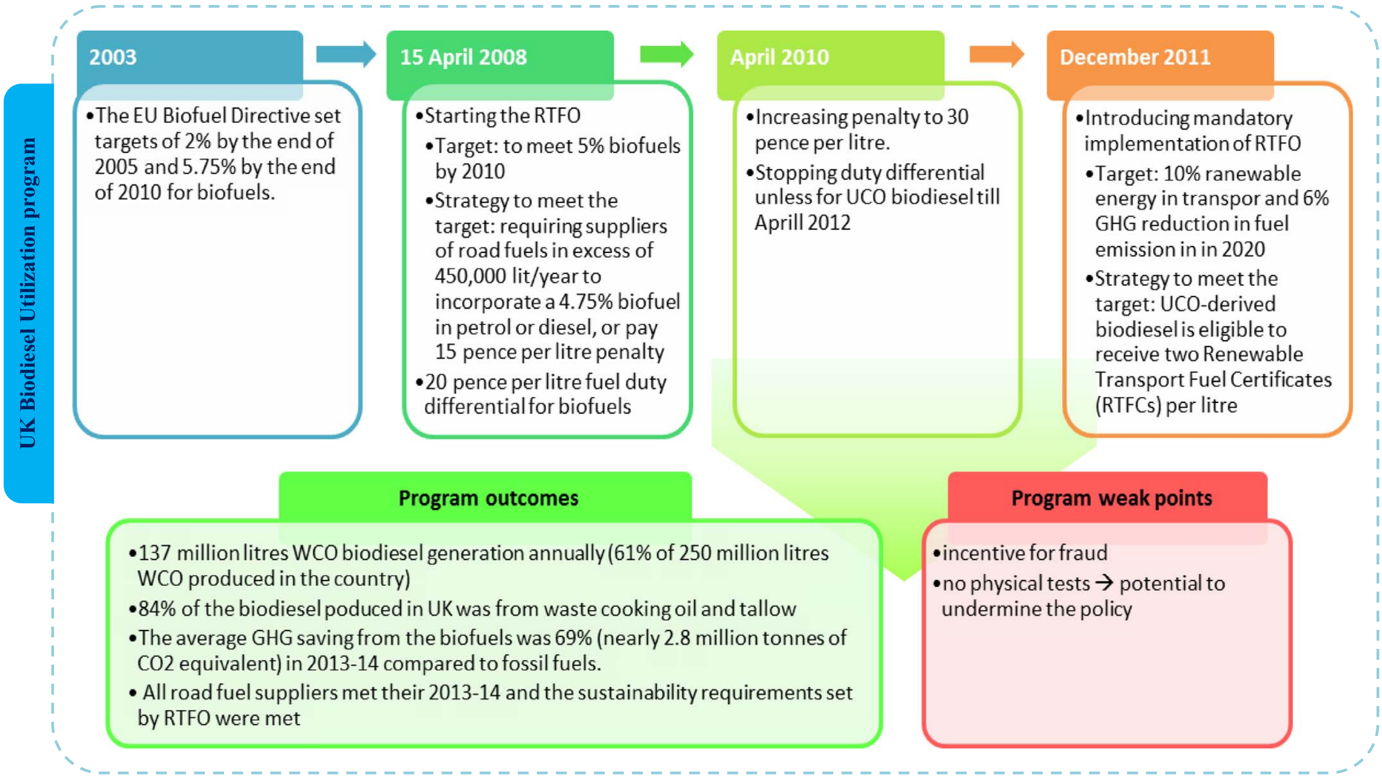

Fig. 19. Waste oil biodiesel utilization supporting strategies in the UK.

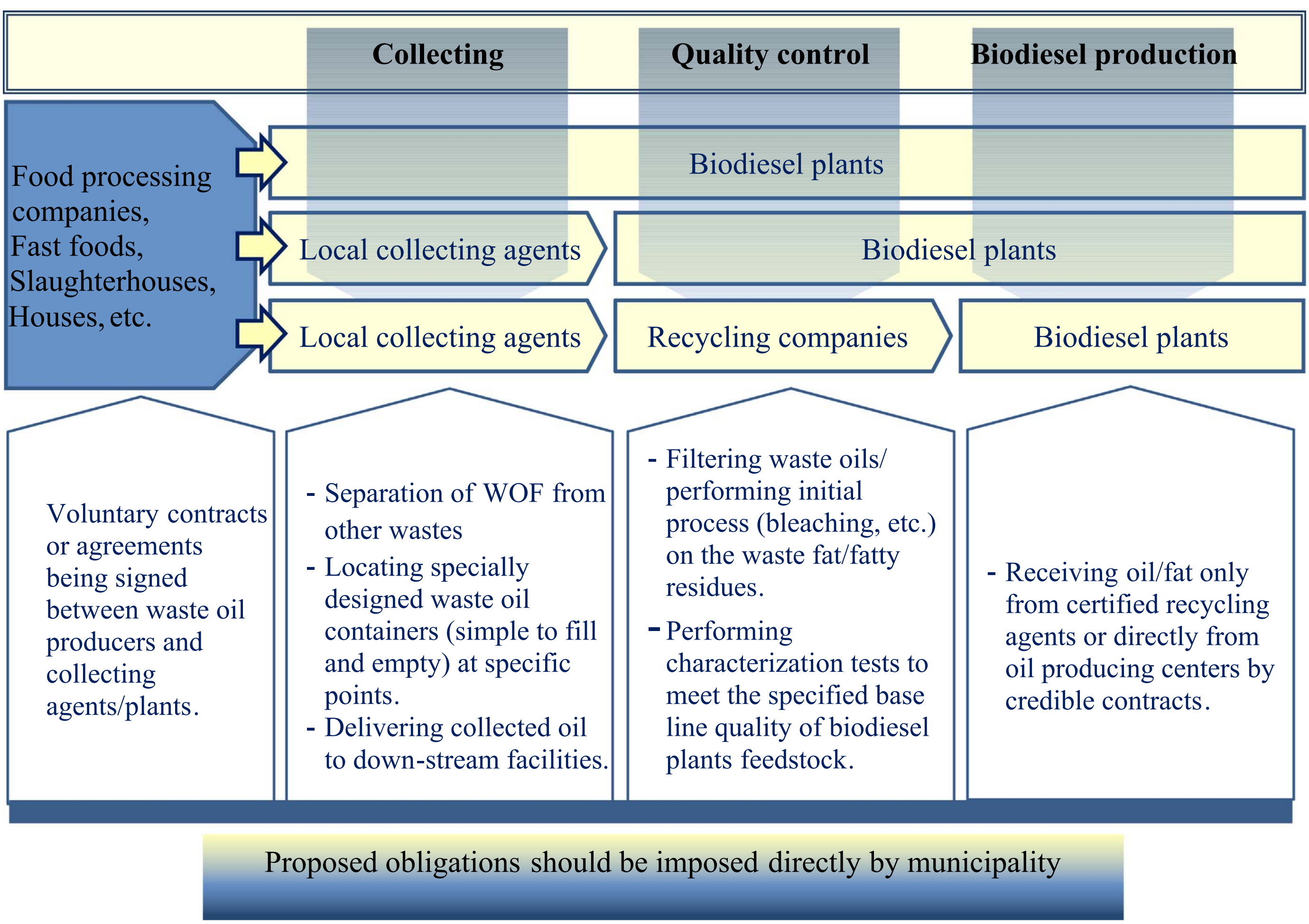

Fig. 20. Integrated waste oil collection strategy for Iran.

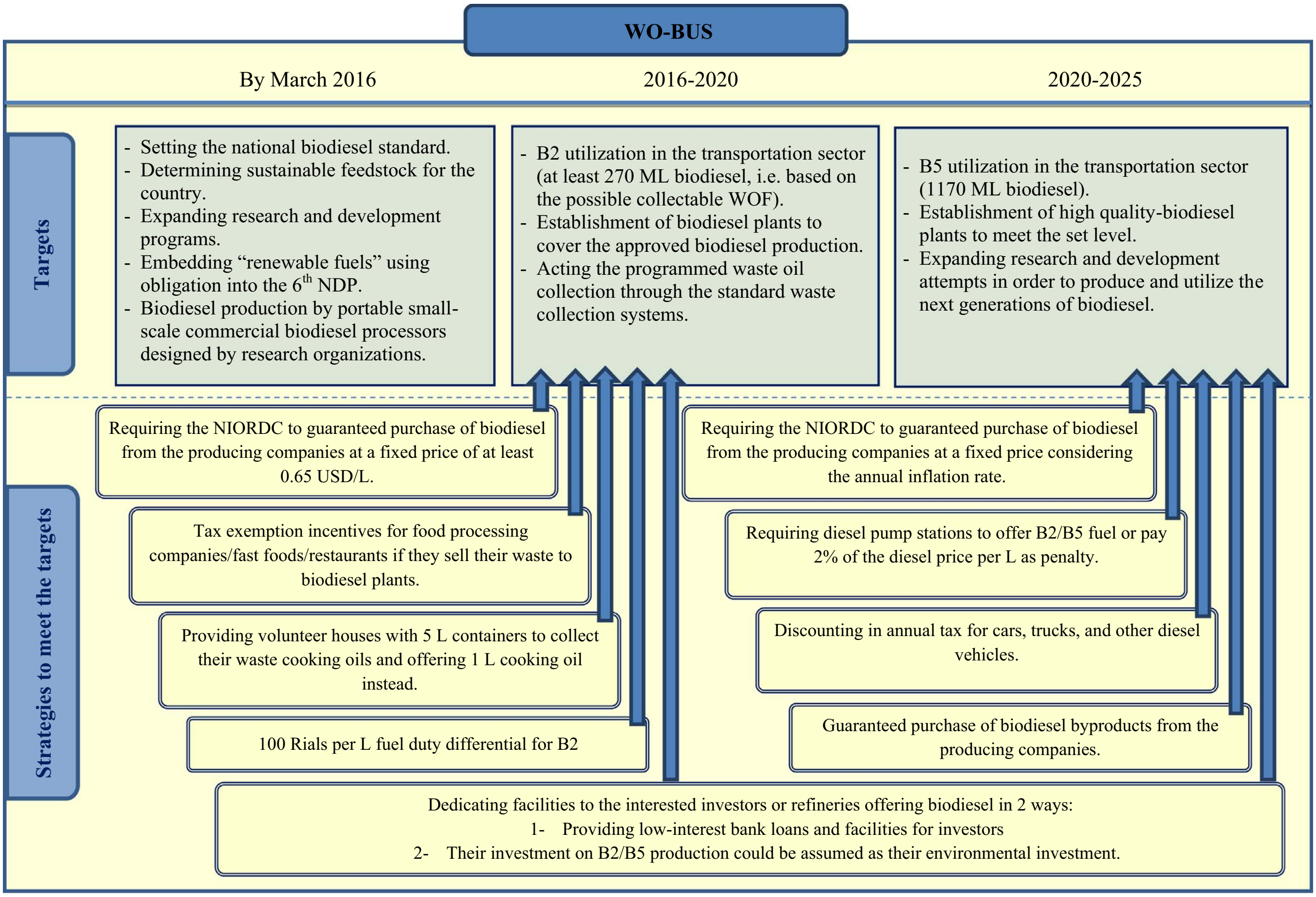

Fig. 21. Proposed national program for Iran called "waste oil biodiesel utilization scenario" (WO-BUS).

5. Conclusions

Waste-oriented oil/fats are the most appropriate feedstocks for biodiesel production in terms of feedstock availability and cost, energy balance, GHG footprint, LUC, and more importantly sustainability. According to the findings of this study, among all the feedstocks being used for biodiesel production, waste oil and fats are the most feasible feedstocks which could be introduced to the biodiesel production industry in Iran within the shortest possible timeframe. In fact, owing to their specific feedstock characterization, cost, sources, and impacts, waste-oil biodiesel could be regarded as a separate generation of biofuels (third generation in the new biofuel categorization presented earlier (Fig. 15). Through the establishment of a systematic governmentally-managed waste oil collection service in Iran, about 300000 t waste oil can be collected, yielding 270 ML waste-oriented biodiesel, i.e., about 60% of the B2 fuel needed to replace all the diesel demands in the country. This waste oil can be collected by means of private agents or biodiesel plants working under direct supervision of municipalities.

Further to the feedstock availability and environmental perspectives discussed in the present paper, an economic feasibility analysis was also performed by considering the investment and operating costs as well as byproduct sales revenues. Accordingly, a reasonable price of 0.611 USD/L was obtained for WCO-biodiesel production in Iran which was somewhat lower than the average global petrodiesel price. Therefore, the produced biodiesel can be exported to the countries where mandatory laws already exist for using renewable fuels in their transportation system or to the countries with high petrodiesel price. For instance, Turkey can be one of the best markets for biodiesel produced in Iran because of having a diesel dependent transportation fleet, governmental mandate of using 3% waste-oriented biodiesel in diesel fuel since 2016, high diesel price of 1.37USD/L, and short distance from Iran [195].

In order to meet the targets discussed in the current study, some of the successful strategies adopted by different countries were also scrutinized and a promising scenario was taken and localized by mimicking both the U.K. and Brazil biofuel utilization programs in order to model the biodiesel utilization program in Iran. The proposed model called "WO-BUS" can also be adopted and localized by the other countries having conditions and preferences listed below:

– Countries in which edible oils and fried food consist of a large portion of population dominant diet.
– Countries facing water and agricultural land shortage, limiting their ability to expand their oil-seed cultivation capacity to secure their elementary food needs.
– The net edible oil importing countries as well as the oil-rich countries having no priority to cultivate energy crops.
– Countries having environmental obligations to utilize renewable energy as well as low GHG life cycle fuels.

Acknowledgements

The authors would like to thank Mr. Daryoush Alizadeh (South Raadab Eng. Co.) for his kind assistance with the economic analysis. We also would like to acknowledge the support provided by Biofuel Research Team (BRTeam), Agricultural Biotechnology Research Institute of Iran (ABRII), University of Tehran, and Iranian Biofuel Society (IBS).

References

[1] Energy and Climate Outlook, MIT Joint Program on the Science and Policy of Global Change. 2014. [accessed on 20th November 2016, Available at:⟨http://globalchange.mit.edu/files/2014%20Energy%20%26%20Climat%20Outlook.pdf⟩].
[2] Hosseini SS, Aghbashlo M, Tabatabaei M, Najafpour G, Younesi H. Thermodynamic evaluation of a photobioreactor for hydrogen production from syngas via a locally isolated Rhodopseudomonas palustris PT. Int J Hydrog Energy 2015;40(41):14246–56.
[3] kumar M, Pal Sharma M. Selection of potential oils for biodiesel production. Renew Sustain Energy Rev 2016;56:1129–38.
[4] Aghbashlo M, Tabatabaei M, Hosseini SS, Younesi H, Najafpour G. Exergy analysis for decision making on operational condition of a continuous photobioreactor for hydrogen production via WGS reaction. Int J Hydrog Energy 2016;41(4):2354–66.
[5] Aghbashlo M, Tabatabaei M, Mohammadi P, Pourvosoughi N, Nikbakht AM, Goli SAH. Improving exergetic and sustainability parameters of a DI diesel engine using polymer waste dissolved in biodiesel as a novel diesel additive. Energy Convers Manag 2015;105(328–37):328–37.
[6] Dadak A, Aghbashlo M, Tabatabaei M, Younesi H, Najafpour G. Exergy-based sustainability assessment of continuous photobiological hydrogen production using anaerobic bacterium Rhodospirillum rubrum. J Clean Prod 2016;139:157–66.
[7] Aghbashlo M, Hosseinpour S, Tabatabaei M, Hosseini SS, Najafpour G, Younesi H. An exergetically-sustainable operational condition of a photo-biohydrogen production system optimized using conventional and innovative fuzzy techniques. Renew Energy 2016;94:605–18.
[8] Salehian P, Karimi K. Alkali pretreatment for improvement of biogas and ethanol production from different waste parts of pine tree. Ind Eng Chem Res 2013;52(2):972–8.
[9] Salehi SA, Karimi K, Behzad T, Poornejad N. Efficient conversion of rice straw to bioethanol using sodium carbonate pretreatment. Energy Fuel 2012;26(12):7354–61.
[10] Bateni H, Karimi K, Zamani A, Benakashani F. Castor plant for biodiesel, biogas, and ethanol production with a biorefinery processing perspective. Appl Energy 2014;136:14–22.
[11] Zarifi F, Mahlia TMI, Motasemi F, Shekarchian M, Moghavvemi M. Current and future energy and exergy efficiencies in the Iran's transportation sector. Energy Convers Manag 2013;74:24–34.
[12] Iran Population. [accessed on 20th November 2016. Available at: ⟨http://www.worldometers.info/world-population/iran-population/⟩].
[13] Key world energy statistics, International Energy Agancy. 2016. [accessed on 20th November 2016, Available at: ⟨https://www.iea.org/publications/freepublications/publication/KeyWorld2016.pdf⟩]
[14] International energy data and analysis for Iran, U.S. Energy Information, 19 June 2015. [accessed on 20th November 2016. Available at: ⟨https://www.eia.gov/beta/international/analysis_includes/countries_long/Iran/iran.pdf⟩].
[15] Ahmad AL, Mat Yasin NH, Derek CJC, Lim JK. Microalgae as a sustainable energy source for biodiesel production: a review. Renew Sustain Energy Rev 2011;15(1):584–93.
[16] BP-statistical Review of World Energy June 2016-full Report. [accessed on 20th November 2016, Available at: bp.com/statisticalreview#BPstats].
[17] Hosseini SE, Mahmoudzadeh Andwari A, AbdulWahid M, Bagheri G. A review on green energy potentials in Iran. Renew Sustain Energy Rev 2013;27:533–45.
[18] Moshiri S, Atabi F, Panjehshahi MH, Lechtenböehmer S. Long run energy demand in Iran: a scenario analysis. Int J Energy Sect Manag 2012;6(1):120–44.
[19] World Population Prospects: The 2012 Revision., [accessed on 20th November 2016, Available at: esa.un.org/unpd/wpp/index.htm, updated 13th June 2013].
[20] Energy balance sheet 1393, Deputy of electricity and energy planning, Iran's energy ministry. 2016.
[21] International Energy Outlook 2013–2040. EIA.
[22] Burck J, Marten F, Bals C, The Climate Change Performance Index Results 2016, Germanwatch- Climate Action Network (CAN). 2016. [accessed on 20th November 2016, Available at: ⟨https://germanwatch.org/en/download/13626.pdf⟩].
[23] Global Carbon Emissions. [accessed on 20th November 2016, Available at: ⟨https://www.co2.earth/global-co2-emissions⟩].
[24] BP energy outlook 2035, British petroleum (BP). 2014. [accessed on 20th November 2016, Available at: ⟨http://www.bp.com/content/dam/bp/pdf/energy-economics/energy-outlook-2016/bp-energy-outlook-2014.pdf⟩].
[25] World Health Organization. 25 March 2014. [acessed on 20th November 2016, Available at: ⟨http://www.who.int/mediacentre/news/releases/2014/air-pollution/en/⟩].
[26] OPEC-2012 world oil outlook_. 2013. [accessed on 20th November 2016, Available at: ⟨http://www.opec.org/opec_web/static_files_project/media/downloads/publications/WOO_2013.pdf⟩].
[27] The Outlook for Energy – A View to 2040, Exxonmobile. 2015. [Accessed on 20th November 2016, Available at: ⟨http://cdn.exxonmobil.com/~/media/global/files/outlook-for-energy/2016/2016-outlook-for-energy.pdf⟩].
[28] Ten-year Analysis of the Automibile Industry in Iran. [accessed on 20th November 2016, Available at: ⟨http://www.shana.ir/fa/newsagency/217438/⟩].
[29] Kikuchi R. Environmental management of sulfur trioxide emission: impact of SO_3 on human health. Environ Manag 2001;27(6):837–44.
[30] Bernard SM, Samet JM, Grambsch A, Ebi KL, Romieu i. The potential impacts of climate variability and change on air pollution-related health effects in the United States. Environ Health Perspect 2001;109(2):199–209.
[31] Grewea V, Dahlmanna K, Matthesa S, Steinbrechtb W. Attributing ozone to NOx emissions: implications for climate mitigation measures. Atmos Environ 2012;59:102–7.
[32] Twigg MV. Progress and future challenges in controlling automotive exhaust gas emissions. Appl Catal B: Environ 2007;70(1–4):2–15.
[33] Reşitoğlu IA, Altinişik K, Keskin A. The pollutant emissions from diesel-engine vehicles and exhaust aftertreatment systems. Clean Technol Environ Policy 2015;17(1):15–27.
[34] Ammann H, Kadlec M. Concerns about adverse health effects of diesel engine emissions. Washington: Department of Ecology Air Quality Program; 2008.
[35] Brecher R, Sulphur Oxides, Annex-Newcom. 2002 1st June. [accessed on 20th November 2016, Available at:⟨http://www.hazmatmag.com/features/sulphur-oxides/⟩].
[36] Kennes C, Veiga MC. Air pollution prevention and control: bioreactors and bioenergy. Chichester, United Kingdom: John Wiley & Sons; 2013.
[37] Necessity of the utilization of biofuels in Iran, Vice Presidency for Science and Technology of Iran. [accessed on 20th November 2016, Available at: ⟨http://www.isti.ir/index.aspx?Siteid=1 & fkeyid= & siteid=1 & pageid=172 & newsview=6405⟩].
[38] Diesel Prices, Liter, Global Petrol Prices, 24th October 2016. [Accessed on 20th November 2016, Available at: ⟨http://www.globalpetrolprices.com/diesel_prices/⟩].
[39] Moshiri S. Energy price reform and energy efficiency in Iran. Int Assoc Energy Econ 2013:133–7.
[40] Shafie-Pour M, Ardestani M. Environmental damage costs in Iran by the energy sector. Energy Policy 2007;35(9):4413–23.
[41] Talaei A, Ahadi MS, Maghsoudy S. Climate friendly technology transfer in the energy sector: a case study of Iran. Energy Policy 2014;64(C):349–63.
[42] The public transportation development and fuel consumption management act. Transportation and Fuel Management Office. [accessed on 20th November 2016, Available at: goo.gl/naov2c].
[43] Houri Jafari H, Baratimalayeri A. The crisis of gasoline consumption in the Iran's transportation sector. Energy Policy 2008;36:2536–43.
[44] Statistics on Fuels Consumption in Iran. [accessed on 20th November 2016, Available at: ⟨www.jonoubiran.com/print-12128.html⟩].
[45] Passenger Cars in the EU. July 2014. [accessed on 20th November 2016, Available at: ⟨http://ec.europa.eu/eurostat/statistics-explained/index.php/Passenger_cars_in_the_EU⟩].
[46] An F. Global overview on fuel efficiency and motor vehicle emission standards policy options and perspectives for international cooperation. New York; 2011. [accessed on 20th November 2016, Available at: ⟨http://www.un.org/esa/dsd/resources/res_pdfs/csd-19/Background-paper3-transport.pdf⟩].
[47] Neeft J, Makkee M, Moulijn J. Diesel particulate emission control. Fuel Process Technol. 1996. vol. 47(1), p. 1–69
[48] Sullivan JL, Baker RE, Boyer BA, Hammerle RH, Kenney TE, Muniz L, et al. CO_2 emission benefit of diesel, (versus gasoline) powered vehicles. Environ Sci Technol 2004;38(12):3217–23.
[49] New Govermental Policies on Fuels: Gasoline Replacement with Diesel. [accessed on 20th November 2016, Available at: goo.gl/7y8NDn].
[50] The Innitiation of Diesel-fueled Cars in Iran. [accessed on 20th November 2016, Available at: goo.gl/yvTAVc].
[51] IKCO diesel engine comes in 2015. Farsnews. [accessed on 20th November 2016, Available at: ⟨http://english.farsnews.com/newstext.aspx?Nn=13920523000239⟩].
[52] Iran’s presidential guidelines on national policies on population. Mehr News Agency. 28 May 2014. [accessed on 20th November 2016, Available at: goo.gl/0Ip6m1].
[53] Atabani AE, Mofijur M, Masjuki HH, Badruddin IA, Chong WT, Cheng SF, et al. A study of production and characterization of Manketti (Ricinodendron rautonemii) methyl ester and its blends as a potential biodiesel feedstock. Biofuel Res J 2014;4:139–46.
[54] Hosseinpour S, Aghbashlo M, Tabatabaei M, Khalife E. Exact estimation of biodiesel cetane number (CN) from its fatty acid methyl esters (FAMEs) profile using partial least square (PLS) adapted by artificial neural network (ANN). Energy Conv Manag 2016;124:389–98.
[55] Aghbashlo M, Tabatabaei M, Mohammadi P, Mirzajanzadeh M, Ardjmand M, Rashidi A. Effect of an emission-reducing soluble hybrid nanocatalyst in diesel/biodiesel blends on exergetic performance of a DI diesel engine. Renew Energy 2016;93:353–68.
[56] Hajjari M, Ardjmand M, Tabatabaei M. Experimental investigation of the effect of cerium oxide nanoparticles as combustion-improving additive on biodiesel oxidative stability: mechanism. RSC Adv 2014;4(28):14352–6.
[57] Aghbashlo M, Shamshirband S, Tabatabaei M, Yee L, Larimi YN. The use of ELM-WT (extreme learning machine with wavelet transform algorithm) to predict exergetic performance of a DI diesel engine running on diesel/biodiesel blends containing polymer waste. Energy 2016;94:443–56.
[58] Datta A, Mandal BK. A comprehensive review of biodiesel as an alternative fuel for compression ignition engine. Renew Sustain Energy Rev 2016;57:799–821.
[59] Shamshirband S, Tabatabaei M, Aghbashlo M, Yee L, Petković D. Support vector machine-based exergetic modelling of a DI diesel engine running on biodiesel–diesel blends containing expanded polystyrene. Appl Therm Eng 2016;94:727–47.
[60] Silitonga AS, Atabania AE. A review on prospect of Jatropha curcas for biodiesel in Indonesia. Renew Sustain Energy Rev 2011;15:3733–56.
[61] Aghbashlo M, Demirbas A. Biodiesel: hopes and dreads. Biofuel Res J

2016;3(2):379.
[62] Demirbas A. Importance of biodiesel as transportation fuel. Energy Policy 2007;35(9):4661–70.
[63] Gude VG, Grant GE, Patil PD, Deng S. Biodiesel production from low cost and renewable feedstock. Cent Eur J Eng 2013;3(4):595–605.
[64] Renewables 2015 Global status report. page 129. REN21. [accessed on 20th November 2016, Available at: ⟨http://www.ren21.net/wp-content/uploads/2015/07/REN12-GSR2015_Onlinebook_low1.pdf⟩].
[65] Tabatabaei M, Karimi K, Kumar R, Sárvári Horváth I. Renewable energy and alternative fuel technologies. BioMed Res Int 2015:2, [pages].
[66] Sajjadi B, Abdul Raman AA, Arandiyan H. A comprehensive review on properties of edible and non-edible vegetable oil-based biodiesel: composition, specifications and prediction models. Renew Sustain Energy Rev 2016;63:62–92.
[67] Panichelli L, Dauriat A, Gnansounou E. Life cycle assessment of soybean-based biodiesel in Argentina for export. Int J Life Cycle Assess 2009;14(2):144–59.
[68] Harvey M, Pilgrim S. The new competition for land: food, energy, and climate change. Food Policy 2011;36(1):S40–S51.
[69] Demirbas MF. Biofuels from algae for sustainable development. Appl Energy 2011;88(10):3473–80.
[70] Sims REH, Mabeeb W, Saddlerc JN, Taylor M. An overview of second generation biofuel technologies. Bioresour Technol 2010;101(6):1570–80.
[71] Mitchell D. Policy research working paper: a note on rising food prices. Washington, DC: The World Bank; 2008, [accessed on 20th November 2016, Available at] ⟨https://openknowledge.worldbank.org/bitstream/handle/10986/6820/WP4682.pdf?sequence=1⟩.
[72] Canadell JG, Le Qué C, Raupach MR, Field CB, Buitenhuis ET, Ciais P, et al. Contributions to accelerating atmospheric CO_2 growth from economic activity, carbon intensity, and efficiency of natural sinks. Proc Natl Acad Sci USA 2007;104(47):18866–70.
[73] Havlik P, Schneider UA, Schmid E, Bottcher H, Fritz S, Skalsky R, et al. Global land-use implications of first and second generation biofuel targets. Energy Policy 2011;39:5690–702.
[74] Luoma J. Hailed as a miracle crop, Jatropha falls short of hype. Yale Environment 360, Guardian Environment Network. 2009. [accessed on 20th November 2016, Available at: ⟨http://www.guardian.co.uk/environment/2009/may/05/jatropha-biofuels-food-crops⟩].
[75] Mang HP. Perspective of bioenergy and Jatropha in China, international consultation on pro-poor Jatropha development. Int Fund Agric Dev 2008, [accessed on 20th November 2016, Available at] ⟨www.ifad.org/events/jatropha/country/HP_Mang.ppt⟩.
[76] Achten WMJ, Almeida J, Fobelets V, Bolle E, Mathijs E, Singh VP, et al. Life cycle assessment of Jatropha biodiesel as transportation fuel in rural India. Appl Energy 2010;87(12):3652–60.
[77] Searchinger T, Heimlich R, Houghton RA, Dong F, Elobeid A, Fabiosa J, et al. Use of U.S croplands for biofuels increases greenhouse gases through emissions from land-use change. Science 2008;319:1238–40.
[78] Fargione J, Hill J, Tilman D, Polasky S, Hawthorne P. Land clearing and the biofuel carbon debt. Science 2008;319(5867):1235–8.
[79] Fischer G, Prielera S, van Velthuizena H, Berndesb G, Faaijc A, Londod M, et al. Biofuel production potentials in Europe: sustainable use of cultivated land and pastures, Part II: land use scenarios. Biomass Bioenergy. 2010. vol. 34(2), p. 173–87.
[80] Rosillo-Calle F, Pelkmans L, Walter A. A global overview of vegetable oils, with reference to biodiesel, IEA bioenergy. J Food Compos Anal 2009:42.
[81] Akia M, Yazdani F, Motaee E, Han D, Arandiyan H. A review on conversion of biomass to biofuel by nanocatalysts. Biofuel Res J 2014;1(1):16–25.
[82] Talebi AF, Tohidfar M, Bagheri A, Lyon SR, Salehi-Ashtiani K, Tabatabaei M. Manipulation of carbon flux into fatty acid biosynthesis pathway in Dunaliella salina using AccD and ME genes to enhance lipid content and to improve produced biodiesel quality. Biofuel Res J 2014;1(3):91–7.
[83] Beetul K, Bibi Sadally S, Taleb-Hossenkhan N, Bhagooli R, Puchooa D. An investigation of biodiesel production from microalgae found in Mauritian waters. Biofuel Res J 2014;1(2):58–64.
[84] Tabatabaei M, Tohidfar M, Salehi Jouzani G, Safarnejad M, Pazouki M. Biodiesel production from genetically engineered microalgae: future of bioenergy in Iran. Renew Sustain Energy Rev 2011;15(4):1918–27.
[85] Talebi AF, Tohidfar M, Mousavi Derazmahalleh SM, Sulaiman A, Baharuddin AS, Tabatabaei M. Biochemical modulation of lipid pathway in microalgae Dunaliella sp. for biodiesel production. BioMed Res Int Hindawi Publ Corp 2015:12.
[86] Talebi AF, Mohtashami SK, Tabatabaei M, Tohidfar M, Bagheri A, Zeinalabedini M, et al. Fatty acids profiling: a selective criterion for screening microalgae strains for biodiesel production. Algal Res 2013;2(3):258–67.
[87] Talebi AF, Tohidfar M, Tabatabaei M, Bagheri A, Mohsenpor M, Mohtashami SK. Genetic manipulation, a feasible tool to enhance unique characteristic of Chlorella vulgaris as a feedstock for biodiesel production. Mol Biol Rep 2013;40:4421–8.
[88] Chisti Y. Constraints to commercialization of algal fuels. J Biotechnol 2013;167(3):201–14.
[89] Abomohra AF, Jin W, Tu R, Han SF, Eid M, Eladel H. Microalgal biomass production as a sustainable feedstock for biodiesel: current status and perspectives. Renew Sustain Energy Rev 2016;64:596–606.
[90] The Announcement of the Implementation of National Projects on the Ulitization of Biofuels in the Transportation Sector in Iran. [accessed on 20th November 2016, Available at: ⟨http://www.isti.ir/index.aspx?siteid=1 & fkeyid= & siteid=1 & pageid=172 & newsview=7066⟩].
[91] Addison K. Vegetable Oil Yields, Handmade Projects. 2001. [accessed on 20th November 2016, Available at: ⟨http://journeytoforever.org/biodiesel_yield.html⟩].
[92] Chisti Y. Biodiesel from microalgae. Biotechnol Adv 2007;25(3):294–306.
[93] Iran's agricultural statistics sheet, Volume 1, crops, agricultural year 1389–90. Ministry of agriculture, Department of Planning and Economic, Centre for Information and Communication Technology, Tehran; 2012.
[94] Mekonnen MM, Hoekstra AY. The green, blue and grey water footprint of crops and derived crop products. Value of Water Research Report Series No. 47, UNESCO-IHE, Delft, The Netherlands; 2010. [accessed on 20th November 2016, Available at: ⟨http://temp.waterfootprint.org/Reports/Report47-WaterFootprintCrops-Vol1.pdf⟩].
[95] Oils and fats in Iran. Euromonitor International. October 2015. [accessed on 20th November 2016, Available at: ⟨http://www.euromonitor.com/oils-and-fats-in-iran/report⟩].
[96] Water for People, Water for Life - UN World Water Development Report (WWDR). World Water Assessment Programme. 2003. ⟨http://unesdoc.unesco.org/images/0012/001295/129556e.pdf⟩.
[97] OECD-FAO agricultural outlook 2013-chapter 5: oilseeds and oilseed products. OECD/FAO. 2013. [accessed on 20th November 2016, Available at: ⟨http://www.fao.org⟩].
[98] Annual statictis. The Islamic Republic of Iran Customs Administration (IRICA). [accessed on 20th November 2016, Available at: ⟨http://www.irica.gov.ir/Portal/Home/Default.aspx?CategoryID=fd61187e-a080-4800-bb4b-0a3d0946cc10⟩].
[99] OECD-FAO Agricultural Outlook. 2015. [accessed on 20th November 2016, Available at: ⟨http://www.oecd-ilibrary.org/agriculture-and-food/oecd-fao-agricultural-outlook-2015/vegetable-oil-projections-consumption-per-capita-food-use_agr_outlook-2015-table132-en⟩].
[100] Cooking Oil Price Forcasts. [accessed on 20th November 2016, Available at: ⟨http://price.forsatnet.ir/food/oil-price.html⟩].
[101] Statistics of oilseed production in Iran. Iranian Oilseed Extraction Industry Association. [accessed on 20th November 2016, Available at: ⟨http://www.oilepa.com/statistics/production-statistics/⟩].
[102] Used cooking oil could be turned into cosmetics, Technology news 28th February. 2007. [accessed on 20th November 2016, Available at: ⟨http://www.newscientist.com/article/mg19325936.400-used-cooking-oil-could-be-turned-into-cosmetics.html⟩].
[103] Chavarria-Hernandez J, Ordóñez L, Barahona-Pérez LF, Castro-Gomez M, Paredes-Cervantes M. Perspectives on the utilization of waste fat from beef cattle and fowl for biodiesel production in Mexico. J Chem Technol Biotechnol 2016.
[104] Khatamifar M, Tabatabaei M. Current state of waste cooking oil production and the potentials of biodiesel production in Iran. United Nation Development Program (UNDP). 2013. Project No. IRA/SGP/OP5/Y2/STAR/CC/12/04(170).
[105] Ghobadian B. Iranian Fuel Conservation Company, Potential Survey of Biodiesel Fuel Production in Iran and Check the Engines/vehicles Available for Biodiesel Utilization (in Persian). 2009.
[106] Chen W, Wn F, Zhang J. Potential production of non-food biofuels in China. Renew Energy 2016;85:939–44.
[107] The World Factbook - Countries urbanization rate, Central Intelligence Agency. 2016. [accessed on 20th November 2016, Available at: ⟨https://www.cia.gov/library/publications/the-world-factbook/fields/2212.html⟩].
[108] Costa Neto PR, Rossi L, Zagonel G, Ramos L. Produçao de Biocombustiyel Alternativo ao oleo diesel Atraves da Transesterificaçao de oleo de Soja Usado em Frituras, Quím. Nova 2000;23:531–7.
[109] Five Major Biofuels Companies Around the World. 2nd September 2010. [accessed on 20th November 2016, Available at: ⟨http://www.energydigital.com/renewables/2845/Five-major-biofuels-companies-around-the-world⟩].
[110] World's Largest Biodiesel Plant Starts Production in Singapore. 22nd November 2010. [accessed on 20th November 2016, Available at: ⟨http://cleantechnica.com/2010/11/22/worlds-largest-biodiesel-plant-starts-production-in-singapore/⟩].
[111] Biodiesel Magazine. [accessed on 20th November 2016, Available at: ⟨http://www.biodieselmagazine.com/plants/listplants/USA/⟩].
[112] Mohadesi M, Hojabri Z, Moradi G. Biodiesel production using alkali earth metal oxides catalysts synthesized by sol-gel method. Biofuel Res J 2014;1(1):30–3.
[113] Chouhan A, Sarma A. Modern heterogeneous catalysts for biodiesel production: a comprehensive review. Renew Sustain Energy Rev 2011;15(9):4378–99.
[114] Moradi GR, Mohadesi M, Ghanbari M, Moradi MJ, Hosseini Sh , Davoodbeygi Y. Kinetic comparison of two basic heterogenous catalysts obtained from sustainable resources for transesterification of waste cooking oil. Biofuel Res J 2015;2(6):236–41.
[115] Sharma YC, Singh B, Madhu D, Liu Y, Yaakob Z. Fast synthesis of high quality biodiesel from 'Waste Fish Oil' by single step. Biofuel Res J 2014;1(3):78–80.
[116] Lin L, Cunshan Z, Vittayapadung S, Xiangqian S, Mingdong D. Opportunities and challenges for biodiesel fuel. Appl Energy 2011;88:1020–31.
[117] Verma P, Sharma MP. Review of process parameters for biodiesel production from different feedstocks. Renew Sustain Energy Rev 2016;62:1063–71.
[118] Ruhul AM, Kalam MA, Masjuki HH, Rizwanul Fattah IM, Reham SS, Rashed MM. State of the art of biodiesel production process: a review of the heterogeneous catalyst. RSC Adv 2015;5:101023–44.
[119] HuaTan Y, Abdullah MO, Nolasco-Hipolito C. The potential of waste cooking oil-based biodiesel using heterogeneous catalyst derived from various calcined eggshells coupled with an emulsification technique: a review on the emission reduction and engine performance. Renew Sustain Energy Rev 2015;47:589–603.
[120] Hassani M, Amini G, Najafpour GD, Rabiee M, Two-step A. Catalytic production of biodiesel from waste cooking oil. Int J Eng 2016;26(6):563–70.
[121] Zhang Y, Dub MA, McLean DD, Kates M. Biodiesel production from waste cooking oil: 1. Process design and technological assessment. Bioresour Technol 2003;89:1–16.

[122] Canakci M, Van Gerpen J. Biodiesel production from oils and fats with high free fatty acids. Am Soc Agric Eng 2001;44(6):1429–36.
[123] Suwannakarn K. Biodiesel production from high free fatty acid content feedstocks [All Dissertations]. Clemson University, TigerPrints; 2008. p. 207.
[124] Tahira F, Hussain ST, Ali SD, Iqbal Z, Ahmad W. Homogeneous catalysis of high free fatty acid waste cooking oil to fatty acid methyl esters (biodiesel). Int J Energy Power 2012;1(1):31–6.
[125] Chuaha LF, Klemešc JJ, Yusupa S, Bokharia A, Majeed Akbar M. A review of cleaner intensification technologies in biodiesel production. J Clean Prod 2017. http://dx.doi.org/10.1016/j.jclepro.2016.05.017, [in Press].
[126] Qiu Z, Zhao L, Weatherley L. Process intensification technologies in continuous biodiesel production. Chem Eng Process 2010;49:323–30.
[127] Shirazi MMA, Kargari A, Tabatabaei M, Mostafaei B, Akia M, Barkhi M, et al. Acceleration of biodiesel–glycerol decantation through NaCl-assisted gravitational settling: a strategy to economize biodiesel production. Bioresour Technol 2013;134:401–6.
[128] Noureddin A, Shirazi MMA, Tofeily J, Kazem P, Motaee E, Kargari A, et al. Accelerated decantation of biodiesel–glycerol mixtures: optimization of a critical stage in biodiesel biorefinery. Sep Purif Technol 2014;132:272–80.
[129] Kong PS, Aroua M Kh, Wan Daud WM Ai. Conversion of crude and pure glycerol into derivatives: a feasibility evaluation. Renew Sustain Energy Rev 2016;63:533–55.
[130] He B, Van Gerpen JH. Application of ultrasonication in transesterification processes for biodiesel production. Biofuel 2012;3(4):479–88.
[131] Hingu SM, Gogate PR, Rathod VK. Synthesis of biodiesel from waste cooking oil using sonochemical reactors. Ultrason Sonochem 2010;17(5):827–32.
[132] Armenta RE, Vinatoru M, Burja AM, Kralovec JA, Barrow CJ. Transesterification of fish oil to produce fatty acid ethyl esters using ultrasonic energy. J Am Oil Chem Soc 2007;84:1045–52.
[133] Teixeira LSG, Assis JCR, Mendonça DR, Santos ITV, Guimarães PRB, Pontes LAM, et al. Comparison between conventional and ultrasonic preparation of beef tallow biodiesel. Fuel Process Technol 2009;90(9):1164–6.
[134] Thanh LT, Okitsu K, Sadanaga Y, Takenaka N, Maeda Y, Bandow H. Ultrasound-assisted production of biodiesel fuel from vegetable oils in a small scale circulation process. Bioresour Technol 2010;101:639–45.
[135] Rahmanlar İ, Yücel S, Özçimen D. The production of methyl esters from waste frying oil by microwave method. Asia-Pac J Chem Eng 2012;7(5):698–704.
[136] Lertsathapornsuk V, Pairintra R, Aryusuk K, Krisnangkur K. Microwave assisted in continuous biodiesel production from waste frying palm oil and its performance in a 100 kW diesel generator. Fuel Process Technol 2008;89:1330–6.
[137] Zhang S, Zu YG, Fu YJ, Luo M, Zhang DY, Efferth T. Rapid microwave assisted transesterification of yellow horn oil to biodiesel using a heteropolyacid solid catalyst. Bioresour Technol 2010;101:931–6.
[138] Refaat AA, El Sheltawy ST, Sadek KU. Optimum reaction time, performance and exhaust emissions of biodiesel produced by microwave irradiation. Int J Environ Sci Technol 2008;5(3):315–22.
[139] Patil PD, Gnaneswar Gude V, Reddy HK, Muppaneni T, Deng Sh. Biodiesel production from waste cooking oil using sulfuric acid and microwave irradiation processes. J Environ Prot 2012;3(1):107–13.
[140] Thompson JC, He BB. Biodiesel production using static mixers. Am Soc Agric Biol Eng 2007;50(1):161–5.
[141] Alamsyah R, Tambunan AH, Purwanto YA, Kusdiana D. Comparison of static-mixer and blade agitator reactor in biodesel production. Agric Eng Int: CIGR E J 2012;12(1):99–106.
[142] Frascari D, Zuccaro M, Paglianti A. A pilot-scale study of alkali-catalyzed sunflower oil transesterification with static mixing and with mechanical agitation. Energy Fuel 2008;22:1493–501.
[143] Kobayashi J, Mori Y, Kobayashi S. Multiphase organic synthesis in microchannel reactors. Chem Asian J 2006;1:22–35.
[144] Canter N. Making biodiesel in a microreactor. Tribol Lubr Technol 2006;62:15–7.
[145] Sun J, Ju J, Ji L, Zhang L, Xu N. Synthesis of biodiesel in capillary microreactors. Ind Eng Chem Res 2008;47:1398–403.
[146] Wen Z, Yu X, Tu S-T, Yan J, Dahlquist E. Intensification of biodiesel synthesis using zigzag micro-channel reactors. Bioresour Technol 2009;100:3054–60.
[147] Harvey AP, Mackley MR, Seliger T. Process intensification of biodiesel production using a continuous oscillatory flow reactor. J Chem Technol Biotechnol 2003;78:338–41.
[148] Lodhar H, Jachuck RJJ. Intensified biodiesel reaction using continuous rotating tube reactor technology. Proceedings of the AIChE annual meeting, Salt Lake City, USA; 2007.
[149] Kelkar MA, Gogate PR, Pandit AB. Cavitation as a novel tool for process intensification of biodiesel synthesis. in: Proceedings of the 6th international symposium on catalysis in multiphase reactors, Pune, India; 2007.
[150] Kozyuk OV, Apparatus and method for producing biodiesel from fatty acid feedstock, US 2009/0043118A1 [access on 29th November 2916, Available at: ⟨http://www.google.com/patents/US20090043118⟩].
[151] Mancosky DG, Armstead DA, McGurk T, Hopkins G, Hudson K. The use of a controlled cavitation reactor for bio-diesel production. In: Proceedings of the AIChE spring meeting, Houston, USA; 2007.
[152] Patil P, Deng S, Rhodes JI, Lammers PJ. Conversion of waste cooking oil to biodiesel using ferric sulfate and supercritical methanol processes. Fuel 2010;89:360–4.
[153] Demirbaş A. Biodiesel from waste cooking oil via base-catalytic and supercritical methanol transesterification. Energy Convers Manag 2009;50:923–7.
[154] Tan KT, Lee KT, Mohamed AR. A glycerol-free process to produce biodiesel by supercritical methyl acetate technology: an optimization study via response surface methodology. Bioresour Technol 2010;101:965–9.
[155] Dube MA, Tremblay AY, Liu J. Biodiesel production using a membrane reactor. Bioresour Technol 2007;98:639–47.
[156] Cao P, Tremblay AY, Dube MA, Morse K. Effect of membrane pore size on the performance of a membrane reactor for biodiesel production. Ind Eng Chem Res 2007;46:52–8.
[157] Cao P, Tremblay AY, Dube MA. Kinetics of canola oil transesterification in a membrane reactor. Ind Eng Chem Res. 2009. vol. 48, p. 2533–41.
[158] Kiss AA, Dimian AC, Rothenberg G. Biodiesel by catalytic reactive distillation powered by metal oxides. Energy Fuel 2008;22:598–604.
[159] He BB, Singh AP, Thompson JC. A novel continuous-flow reactor using reactive distillation for biodiesel production. Trans ASAE Am Soc Agric Eng 2006;49:107–12.
[160] He BB, Singh AP, Thompson JC. Experimental optimization of a continuous flow reactive distillation reactor for biodiesel production. Trans ASAE Am Soc Agric Eng 2005;48:2237–43.
[161] Singh AP, He BB, Thompson JC. A continuous-flow reactor using reactive distillation for biodiesel production from seed oils. Proceedings of the ASAE/CSAE annual international meeting, Ottawa, Canada; 2004.
[162] Kraai GN, van Zwol F, Schuur B, Heeres HJ, de Vries JG. Two-phase (bio)catalytic reactions in a table-top centrifugal contact separator. Angew Chem Int Ed 2008;47:3905–8.
[163] Kraai GN, Schuur B, van Zwol F, van de Bovenkamp HH, Heeres HJ. Novel highly integrated biodiesel production technology in a centrifugal contact separator. Chem Eng J 2009;154:384–9.
[164] Anuar MR, Zuhairi Abdullah A. Challenges in biodiesel industry with regards to feedstock, environmental, social and sustainability issues: a critical review. Renew Sustain Energy Rev 2016;58:208–23.
[165] Specification for Biodiesel (B100) – ASTM D6751-07b. 2007. [Accessed on 20th November 2016, Available at: ⟨http://www.glycerintraders.com/ASTM%206751%20spec.pdf⟩].
[166] EN 14214:2003 (E) Automotive Fuels – Fatty Acid Methyl Esters (fame) for Diesel Engines – Requirements and Test Methods. [Accessed on 20th November 2016, Available at: ⟨http://www.aascarburants.com/assets/files/pdf/Biodiesel-EN14214.pdf⟩].
[167] Doğan TH. The testing of the effects of cooking conditions on the quality of biodiesel produced from waste cooking oils. Renew Energy 2016;94:466–73.
[168] Anh AN, Phan TM. Biodiesel production from waste cooking oils. Fuel 2008;87:3490–6.
[169] Yahyaee R, Ghobadian B, Najafi G. Waste fish oil biodiesel as a source of renewable fuel in Iran. Renew Sustain Energy Rev 2013;17:312–9.
[170] Haq Nawaz Bhatti HN, Hanif MA, Ata-ur-Rehman Qasim M. Biodiesel production from waste tallow. Fuel 2008;87:2961–6.
[171] Ozsezen AN, Canakci M. Determination of performance and combustion characteristics of a diesel engine fueled with canola and waste palm oil methyl esters. Energy Convers Manag 2011;52:108–16.
[172] Can Ö. Combustion characteristics, performance and exhaust emissions of a diesel engine fueled with a waste cooking oil biodiesel mixture. Energy Convers Manag 2014;87:676–86.
[173] Behçet R. Performance and emission study of waste anchovy fish biodiesel in a diesel engine. Fuel Process Technol 2011;29(6):1187–94.
[174] Graboski MS, McCormick RL. Combustion of fat and vegetable oil derived fuels in diesel engines. Prog Energy Combust Sci 1998;24:125–64.
[175] Canakci M, Van Gerpen JH. Comparison of engine performance and emissions for petroleum diesel fuel, yellow grease biodiesel, and soybean oil biodiesel. Trans ASAE Am Soc Agric Eng 2003;46(4):937–44.
[176] Cunha A, Jr., Feddern V, De Prá MC, Higarashi MM, de Abreu PG, Coldebella A. Synthesis and characterization of ethylic biodiesel from animal fat wastes. Fuel 2013;105:228–34.
[177] Canakci M. The potential of restaurant waste lipids as biodiesel feedstocks. Bioresour Technol 2007;98(1):183–90.
[178] Alptekin E, Canakci M, Sanli H. Evaluation of leather industry wastes as a feedstock for biodiesel production. Fuel 2012;95:214–20.
[179] Ghazali WNMW, Mamat R, Masjuki HH, Najafi G. Effects of biodiesel from different feedstocks on engine performance and emissions: a review. Renew Sustain Energy Rev 2015;51:585–602.
[180] Haas MJ, McAloon AJ, Yee WC, Foglia TA. A process model to estimate biodiesel production costs. Bioresour Technol 2006;97:671–8.
[181] Pradhan A, Shrestha DS, McAloon A, Yee W, Haas M, Duffield JA, et al. Energy life-cycle assessment of soybean biodiesel. Washington DC: US Department of Agriculture; 2009.
[182] Jaber R, Shirazi MMA, Toufaily J, Hamieh AT, Noureddin A, Ghanavati H, et al. Biodiesel wash-water reuse using microfiltration: toward zero-discharge strategy for cleaner and economized biodiesel production. Biofuel Res J 2015;2(1):148–51.
[183] Sorda G, Banse M, Kemfert C. An overview of biofuel policies across the world. Energy Policy 2010;38:6977–88.
[184] EPA finalizes new regulations for the national renewable fuel standard program for 2010 and beyond. Energy Policy Administration (EPA). 2010. [Accessed on 2016 November 20, Available from: ⟨https://www.epa.gov/sites/production/files/2015-08/documents/420f10007.pdf⟩].
[185] Kagami M. New development strategies for MRBCs: a possibility of biomass energy development. in: Ueki Yasushi, Bhongmakapat, Teerana. Industrial readjustment in the Mekong river basin countries: toward the AEC, BRC Research Report No. 7. Bangkok Research Center, IDE-JETRO, Bangkok, Thailand; 2012.
[186] Hall J, Matos S, Severino L, Beltrao N. Brazilian biofuels and social exclusion:

established and concentrated ethanol versus emerging and dispersed biodiesel. J Clean Prod 2009;17:S82–S83.

[187] Brazil Biofuels Annual, Global Agricultural Information Network, USDA Foreign Agricultural Service. 2014. No. BR14004. [Accessed on 20th November 2016, Available at: goo.gl/Yavxwz].

[188] Cremoneza PA, Feroldia M, Nadaletia WC, de Rossia E, Feidena A, de Camargob MP, et al. Biodiesel production in Brazil: current scenario and perspectives. Renew Sustain Energy Rev 2015;42:415–28.

[189] Kligermana DC, Bouwerb EJ. Prospects for biodiesel production from algae-based wastewater treatment in Brazil: a review. Renew Saust Energy Rev 2015;52:1834–46.

[190] Rico JAP, Sauer IL. A review of Brazilian biodiesel experiences. Renew Sust Energy Rev 2015;45:513–29.

[191] Toop G, Alberici S, Spoettle M, Van Steen H. Trends in the UCO market, Ecofys, 2013; by order of: Department for Transport (DfT). 2013. [Accessed on 20th November 2016, Available at: ⟨https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/266089/ecofys-trends-in-the-uco-market-v1.2.pdf⟩].

[192] Hood J. UK experience of the renewable transport fuel obligation (RTFO) and policies to promote the development of waste-derived and advanced biofuels. Department for Transport of the United Kingdom; 2014, [Accessed on 20th November 2016, Available at] ⟨http://www.biofuelstp.eu/spm6/docs/jonathan-hood.pdf⟩.

[193] Renewable transport fuel obligation annual report 2013–14. Department of Transport. 2015. [Accessed on 20th November 2016, Available at: ⟨https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/415132/cm-9026_accessible.pdf⟩].

[194] Recycled cooking oils- assessment of risks for public health. European parliament, Scientific and Technological Options Assessment, Luxembourg; 2000. [Accessed on 20th November 2016, Available at: http://nehrc.nhri.org.tw/toxic/news/1030905-3.pdf].

[195] Eryilmaz T, Yesilyurt MK, Cesur C, Gokdogan O. Biodiesel production potential from oil seeds in Turkey. Renew Sustain Energy Rev 2016;58:842–51.