Jon Bernodusson
Subject Leader, Research and Development
Icelandic Transport Authority

Rapeseed Cultivation in Iceland for Marine Fuel

Icelandic Transport Authority

2018

Icelandic Transport Authority

2018

Rapeseed Cultivation in Iceland – for Marine Fuel

Autor:
Jon Bernodusson, MSc
Subject Leader, Research and Development
Icelandic Transport Authority

Co-Autors:
Gylfi Arnason, PhD
Olafur Eggertsson, farmer
Einar Einarsson, MSc
Sigurbjörn Einarsson, MSc

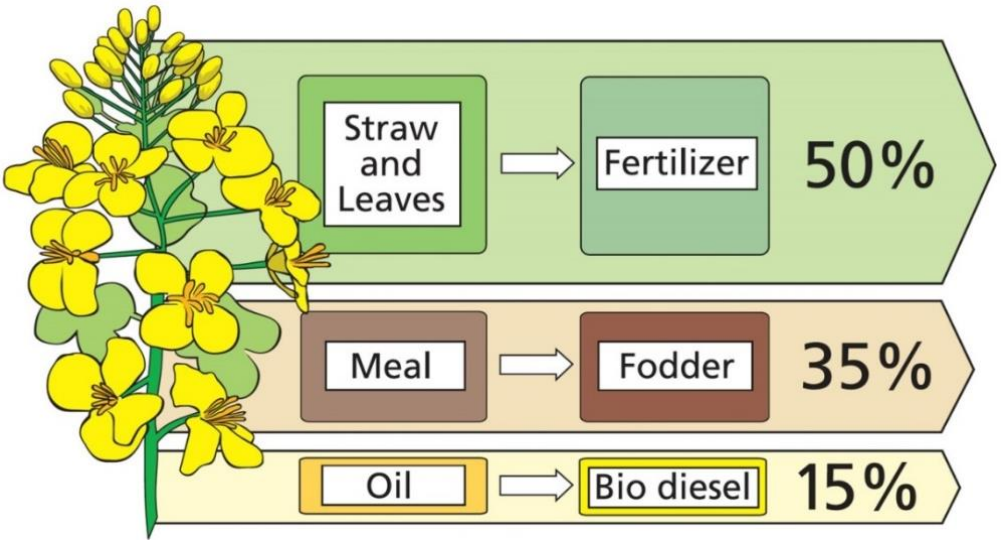
Photo on the Front Page:
Einar Magnus Magnusson (www.emm.is)

Drawings:
Johann Jonsson Listo (www.listo.123.is)

Rapeseed is an Energy Plant

About half the biomass of cultivated rapeseed, an energy plant, is made up of seeds and the other half consists of stalks. The seeds can be pressed to form fodder meal and oil while fertilizer is usually made from the stalks. The meal makes up 35% of the biomass and is used as animal feed for cattle, pigs, sheep and aquaculture. The oil pressed from the seeds makes up about 15% of the total rapeseed biomass. That is, 85% of the harvest may be utilized directly or indirectly to feed animals and people and 15% as energy or fuel. Thus the biomass is used in its entirety in the form of an energy source, foodstuff or fertilizer. Any contention that rapeseed cultivation for the purpose of fuel production is in fact a waste of food, is simply erroneous and misleading with regard to Iceland where arable land is abundant.

The cultivation of rapeseed for the purpose of energy and food production is a good example of an effort toward energy and food security.



Stalks (straw), which are utilized for fertilizer, represent 50% of rapeseed biomass. The fodder meal, approximately 35% of the rapeseed biomass, serves as animal feed and the oil representing the remaining 15%, may be used as biodiesel.

The circumstances in Iceland are quite unique, in that diverting farmland or crops for biofuels production to the detriment of the food supply is not necessary. It is sensible to make use of non-urban land that is not being farmed or otherwise occupied for the cultivation of energy plants such as rapeseed.

Iceland‘s geographical area is 103.125 square kilometres (km^2). According to the Icelandic Agricultural Advisory Centre, arable land totals 600.000 hectares (6.000 km^2), a mere 6% of the total. Approximately 120.000 hectares have been farmed, leaving 480.000 hectares that are available for cultivation. This is a considerable area of land which would allow for biofuel production large enough to meet the needs of the entire Icelandic fishing fleet. Cultivation at this scale would in no way disrupt the production of food as the land concerned is not currently in use. [71]

Iceland therefore enjoys an overabundance of available arable land, avoiding appropriation of any farm land or pasturable lands for rapeseed farming, a novel prospect in Iceland and could be carried out in parallel with other crops. Differing utilization perspectives need not be mutually exclusive as there is no shortage of land.

Annually, the Icelandic fishing fleet consumes 160,000 tonnes of imported diesel fuel which is refined from fossil oil. The fuel is imported at world market price and the fishing companies are completely dependent upon these shipments. That is, the entire fishing fleet‘s energy security is contingent upon the sound delivery of this imported energy source.

The combustion of fossil fuels is one of the main causes of greenhouse gas emissions to air. The combustion of one tonne fossil diesel produces an emission of 3.18 tonnes of carbon dioxide (CO_2) hence the Icelandic fishing fleet‘s total consumption is responsible for the emission of half a million tonnes of this particular greenhouse gas. A “home-grown“ alternative to fossil fuels would simultaneously contribute toward reducing greenhouse gas emissions and increased energy security. Research has shown that rapeseed farming and the production of fuel using rapeseed oil may be a sustainable means to supply the fishing fleet with a greenhouse gas neutral fuel. [37]

Rapeseed farming produces 6 tonnes of biomass per hectare, of which approximately 3 tonnes are seeds which in turn yield roughly 1 tonne of rapeseed oil. Therefore, Iceland would require about 160,000 hectares of arable land in order to produce enough rapeseed oil domestically to meet the current needs of its fishing fleet. [74]

Each hectare of cultivated rapeseed binds 6 tonnes of carbon dioxide (CO_2) within the plants and soil. Thus rapeseed cultivation on 160,000 hectares of land would sequester a total of 960,000 tonnes CO_2. The combustion of one tonne of rapeseed oil produces 2.8 tonnes CO_2 and it is reasonable to assume that the engines used for farming consume about 0.35 tonnes of fossil diesel. The total release would amount to 3.15 tonnes due to the cultivation and consumption of one tonne of rapeseed fuel However, as cultivation binds 6 tonnes, 2.85 tonnes remain contained in soil, products and plant residue. The net CO_2 emission reduction by replacing fossil fuel with rapeseed fuel in Icelandic fishing vessel engines would amount to 460,000 tonnes. In other words, the production and consumption of rapeseed fuel instead of fossil fuel is a favourable example of a method which returns a double carbon offset and that certainly does count for something.

The Icelandic fishing fleet carbon dioxide emissions due to use of fossil fuel and rapeseed fuel		
	Fossil fuel	***Rapeseed fuel***
Fossil fuel and rapeseed fuel: 160.000 tonnes	-500,000 tonnes	-500,000 tonnes
Carbon bound due to sequestration: 160.000 hectares rapeseed	0	960,000 tonnes
Net sequestration:		**460,000 tonnes**
DOUBLE CARBON OFFSET		

Cultivation of Energy Plants and Benefits of Biodiesel

When considering different ideas and means by which to reduce carbon dioxide emissions, the most reasonable approaches include to simply to consume less fuel (via energy efficient engines or fewer trips), exhaust treatment and the use of rapeseed oil and biodiesel.

The search for a renewable energy source(s) to replace fossil fuel has been ongoing for some time. One of the main drivers has been the quickly dwindling level of fossil fuel reserves that are economically recoverable. Another is the fact that renewable energy sources largely generate lower emissions compared to fossil fuels, especially with regard to carbon dioxide and other trace elements harmful to human health.

Rapeseed, an energy and oil rich seed, has been considered a viable successor as it can be transformed via pressing to produce rapeseed oil and further processed into biodiesel, often referred to as first generation biochemical diesel. It is a plant oil produced from the pressed rapeseed (fatty acid methyl esters = FAME) followed by the esterification into biodiesel (rapeseed methyl esters = RME). If renewable energy is to be viewed as a plausible and environmentally sound means of energy provision for the future, the rapeseed plant is worth a look in this context. Biodiesel made from the rapeseed is a renewable energy source, it returns its carbon to the plant and is thus considered 100% carbon neutral. [63]

Biodiesel is a harmless (nontoxic) fuel which is degraded in nature in a matter of weeks. Should fossil fuel, however, be released into the environment it is considered a sizable hazard, having caused long-term pollution and great damage to vulnerable ocean and coastal areas.

Biodiesel does not contain such toxic materials as sulphur. The amount of carbon monoxide (CO) and particulate matter (PM) present in biodiesel exhaust is half that of fossil fuel due to a more favourable combustion efficiency and higher combustion temperature in the case of biodiesel. Further, biodiesel does not produce black smoke and the amount of residual uncombusted fuel is close to three quarters less, and is naturally degraded in two to three weeks. The levels of nitrogen oxides (NOx) is somewhat higher for biodiesel due to the higher temperature of combustion. Nitrogen oxides form when the combustion chamber temperature rises above 1,760°C, independently of which fuel is present. The amount of NOx emitted with exhaust may be reduced through various means. [66][73]

Various blends of biodiesel and fossil diesel have been utilized, the most common being the one referred to as B5 (5% biodiesel and 95% fossil diesel). Rapeseed oil can be added to fossil diesel up to a ratio of 20% (R20) without having any adverse effect on engine performance. For powerful diesel engines (greater than 1,500 kW), the share of rapeseed oil can be increased to nearly 50% (R50) and engines over 2,500 kW can easily run on pure rapeseed oil (R100).

The performance of rapeseed oil and biodiesel combustion is better than fossil fuel‘s due to the 11% oxygen content and the fact that the two former oils require less combustion air. Though the oxygen actually reduces the heating value by nine percent, this difference is barely

observable while engines are running. Low ambient temperatures can cause complications due to the higher melting point of biodiesel‘s fatty acid esters in comparison to fossil diesel‘s carbon compounds, and may require heating. Also, biodiesel should generally be considered to have a limited shelf life of approximately 6 months as a result of bioremediation, since the liquid can grow rancid due to microbial dissolution of its elements. However, with special care, these characteristics should not be problematic. One method would entail mixing biodiesel with propanol in order to reduce the melting point, eliminating any microorganisms and odour while avoiding any effect on the heat value. [65]

Some experience has been gained in rapeseed farming in recent years, in Iceland and abroad and it is important to ensure that this knowledge and progress is further strengthened. Icelandic farmers have clearly demonstrated opportunities involved in the cultivation of rapeseed in addition to the processing of its products. Clearly, efforts should be made to encourage further development in this field. Farmers and experts who have taken part in demonstration projects using rapeseed already possess the necessary knowledge and experience to move forward. In Iceland, experimental production of rapeseed oil using spring and winter types has been ongoing since 2009.

The winter rapeseed type is sown during mid-July allowing for leaf and root growth ahead of the winter months. Once spring arrives, and soil no longer freezes, the plant resumes its growth phase having been dormant over the winter‘s cold stretch. The winter type has a growth period in Iceland of approximately 450 days, requiring two calendar years for cultivation. The spring type however, requires a growth period of only 200 days and is sown in spring season, keeping within the calendar year. The winter type tends to yield 50% more than its spring counterpart as the harvest is in direct proportion to the length of the growth cycle. Rapeseed can be farmed in northerly areas and produces a comparable oil yield to other plants cultivated in warmer climates. [30]

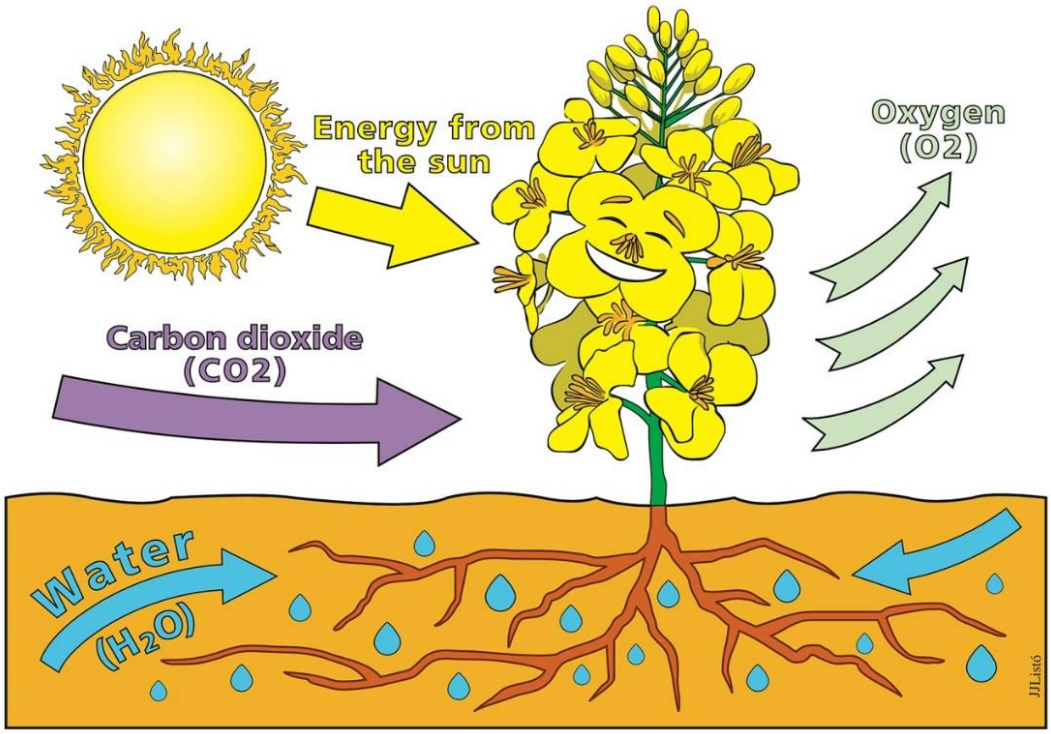
Rapeseed cultivation requires a large area of land. It is important that rapeseed farming does not compete for farmland, food production should take precedence when it comes to land. In fact, rapeseed production is convenient for uncultivated land or as part of crop rotation. Further, it is also a good option for experimental patches of land for reclamation of soilmixed sand, clay and gravelly soil with the addition of organic fertilizer and even ground lupine stalks. [64]

Since cultivation of the rapeseed winter type spans over a full year, crop rotation is necessary as is the cultivation of other types of plants alongside the rapeseed fields. As for the spring type, some farmers have successfully sown rapeseed in the same field three years in a row, then switched to hayfields, followed by barley and finally back to the spring rapeseed. Soil complications may be avoided after winter type harvest by allowing a rest period.

Crop rotation for the winter type can be implemented using a variety of crops. The important criteria here for plants that are sown in autumn are winter endurance, quick growth following seeding and the ability to thrive in Icelandic conditions. The main candidates for crop rotation include winter barley and blue lupine, the former as a food crop and the latter as ploughed fertilizer. [64]

Outside of this particular farming area in Iceland, neglected land and sandy soils that have not previously been used for agriculture are available.

When choosing a location, it is important that the soil be rich, fertile, ventilated and permeable. Both these rapeseed types can be at a disadvantage in sandy soil but the correct amount of fertilizer and tilling can bring success. Spring and winter rapeseed type roots need to reach deep into the soil; this is especially important for the winter types to allow them to mature adequately and develop reserves for the winter, maximise winter resistance and shoot formation come spring season. The frost endurance is considerable while the ice- and water endurance is limited. All the different types are favourable for crop rotation, especially along with grass and corn. Such a cultivation approach, where the fields are left to rest using rotation, can return appreciable harvest increases once the field is once again used to grow rapeseed. [30][60]



Land Reclamation

Rapeseed can be utilized as part of the reclamation of sands in Iceland. Only lupine, fertilizer and rapeseed are needed, in addition to time and patience.

The lupine may be used in sandy soils in preparation for rapeseed cultivation. This opens the opportunity for making use of sandy soil in the future, for both winter and spring types. The methodology involves starting out by growing lupine for a while to allow for nutrient build up in the soil.

When it comes to using plant remains, the blue lupine (Alaska lupine) is suitable for reclamation. In addition, it binds 4.7 tonnes carbon dioxide (CO_2) per hectare annually.

In order to employ the lupine as fertilizer, it is sown in sand, letting the plant develop past deflowering, followed by shredding and ploughing it into the field. It is important that the lupine seeds do not mature so that they do not sprout and compete for nutrition with the rapeseed. Application of animal fertilizer is also necessary for the soil.

Sandy soil is taken over by sown lupine which in turn prepares the soil for rapeseed cultivation.

Two types of fertilizer are generally used for reclamation. Chemical fertilizer (fertilizing salts) is applied via ploughing with the seeds while organic fertilizer, consisting of animal dung or plant remains, may be ploughed into the soil. The most essential compounds include nitrogen (N), phosphorus (P_2O_5) and potassium or potash (K_2O). Other important fertilizers are sulphur (S), calcium (Ca), magnesium (Mg) and boron (B). [64]

The artificial or man-made fertilizer usually has the appropriate composition required for rapeseed cultivation. The chemical fertilizer recommended for rapeseed farming in Iceland is considerably rich in minerals and is also useful for the cultivation of rapeseed for fodder production. Winter types require between 600 and 900 kg per hectare of chemical fertilizer where 300-400 kg are applied to the field during sowing and 300-500 kg when the rapeseed has risen from its winter hibernation, in early May. Spring types need only one fertilizer treatment, during sowing, and the amount depends on the soil. The maximum quantity used amounts to 600 kg, the minimum being around 350 kg. [30]

As for the organic fertilizer, it can be easily composed to fulfil most of the needs for cultivation. The cost varies but store bought, artificial fertilizer can be quite expensive. Thus growers are encouraged to use as much animal fertilizer as possible, resorting only to ready-made fertilizer in order to boost any nutrients the soil lacks.

Liquid manure from pigs is one of the most common and beneficial animal fertilizers to rapeseed cultivation. Approximately 20 tonnes per field hectare would be a realistic amount to

use, for example. Should lupine be applied as organic fertilizer, one should allow for a field of average density.

Following groundwork, the rapeseed is sown. In the case of sandy soil, one should anticipate a three to five year period of preparation for cultivation, and this refers to the time beginning with the first lupine sowing in addition to annual fertilizer application. [60] [64]

There is a remarkable opportunity for the reclamation of Icelandic sandy soil areas. An ambitious project involving the build-up of soil via strategic lupine sowing and fertilization (using animal dung, stalks and/or organic waste) should be kick-started.

Products of Rapeseed Cultivation

Rapeseed production has increased globally in recent years as rapeseeds are rich in oil. The oil is generally used for nutritional purposes in addition to industrial uses such as an ingredient in soap, massage oils, mechanical lubricant, personal lubricant, flavouring, pharmaceutical products and recently, it has increasingly been used as biodiesel (rapeseed diesel) and glycerol. [60]

The average fodder is made up of 32% protein, 7-18% fat (if first cold pressed), 10% fibre and water and the remainder includes minerals such as calcium (Ca), phosphorous (P) and sodium (Na). It is preferable to extract as much oil as possible from the pulp. The rapeseed fodder, considered as some of the best available, can be mixed with other compound feed and is suitable as whole feed for cattle, pigs, chickens, sheep and horses. Furthermore, deposits in tanks and residue from filters are often 35-50% fat, which may be used to boost the energy content of pig fodder.

Rapeseed meal contains less protein but more fibre than soybean meal. And even though the quantity of protein, energy and digestibility of rapeseed meal is less than for that of soybean, its balance of essential amino acids is more beneficial, with the exception of lysine. The proportion of calcium and phosphorus is quite similar and the levels of the latter are considerably higher than for other oil plants.

Nutrient	Rapeseed meal	Soymean meal	Fish meal
Protein	28 - 33%	45 - 47%	62 - 64%

Coarse fodder rarely fulfils the needs of cattle for maintenance, milk- and fetal development any longer due to the growing demands for maximum utilization and constant breeding. In cases such as these, rapeseed meal can be of use. Ruminant digestive organs are made for digesting grasses and similar plants containing a mere 3-5% oil or fat. Therefore it is important to squeeze as much of the oil as possible out of the rapeseed before feeding the pulp to ruminants. In fact, the rapeseed meal used for compound feed in Iceland typically contains 2.5-4% oils or fat.

Most types of plant meal contain about half the protein of fish meal. In addition, plant materials consist of various antinutrients which affect meal digestibility and can even cause symptoms of

illness in fish. The fish fodder protein must fulfil the requirements for amino acids. The use of rapeseed pellets is limited due to the low protein content compared to fish meal; therefore the fish meal is always supplemented in order to meet the demands for usable fish fodder content. Moreover, sustainability must be taken into account and transforming plant proteins into valuable and nutritionally essential fish protein for human consumption is beneficial, especially in regions where animal proteins do not make up a large proportion of the local diet. [38][39]

Protein rich fodder such as fish meal is an expensive product. Should rapeseed fodder meal become a mixing option for compound feed, considerable savings would be realised for farmers as they could grow their own protein rich fodder instead of importing it. According to farmers who use barley for whole feed, the requirement amounts to approximately one tonne per cow on an annual basis. In addition, the barley is mixed with 15% fish meal. The substitution of fish meal with rapeseed fodder meal would offer an excellent opportunity for rapeseed farmers and the producers of rapeseed oil and meal. The share of rapeseed meal would likely amount to 20% in the mixture to replace the 15% fish meal, which translates to roughly 200 kg rapeseed meal annually for each cow. If each hectare yields about 2 tonnes of pulp on average, one can assume that the hectare supplies rapeseed fodder meal for 10 cattle.

On an annual basis, 1500 tonnes of rapeseed fodder meal are imported to Iceland, which demonstrates the scale of demand for this type of product.

Once the oil seeds or grains have been removed, the bulk of the plant is left behind in the field as biomass in the form of straw. While the quantity of straw depends on the plant and soil fertility, one can estimate it at between 3 and 5 tonnes per hectare. This biomass can be utilized in one of several ways, such as ploughing it back into the soil, thereby reclaiming part of its nutrients.

Another option would involve collecting the straw and transporting it elsewhere for further processing, for example briquetting for use as bedding in stables. The straw could also be transformed into methanol via gasification, or one could directly burn the biomass and use it as industrial fuel. In that case, the straw has been pressed into rolls of various sizes and 3 kg of that straw corresponds to the combustion of 1 kg diesel fuel. [33]

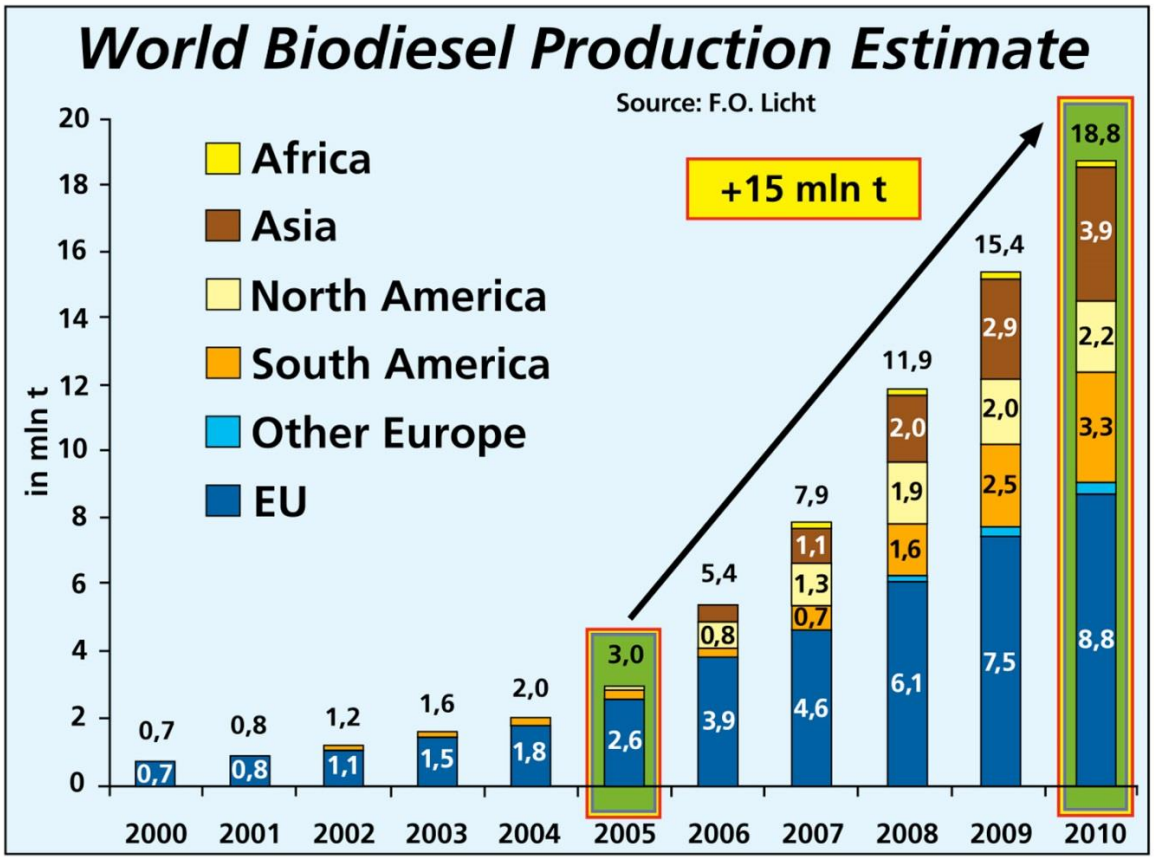
Biodiesel (RME biodiesel) made from rapeseed oil is an organic diesel oil and a renewable energy source. It is considered one of the most environmentally neutral energy options for replacing fossil diesel oil for automobiles, vessels and airplanes. One rapeseed hectare can easily meet the average passenger car‘s requirements per year, that is just over 1,000 litres of 100% RME (B100). Biodiesel is nontoxic and does not belong to the category of dangerous cargo as its auto-ignition temperature is relatively high. Biodiesel is esterified with a mix of methanol and sodium nitrate, which separates the glycerol and oil. Then, excess methanol and soda is removed from the oil via distillation and water rectification. Methanol is corrosive and thus an undesirable part of biodiesel and is eliminated. Biodiesel should be clear and have the density of 883 kg/m^3. [21]

Biodiesel can be combusted in oil burners and any diesel passenger vehicle engine; minor engine modifications are necessary to allow for the switch to biodiesel. Biodiesel functions in

the same way diesel oil does, but it is nontoxic, biodegradable and causes minimal pollution. Furthermore, its cleansing and lubricating properties are superior to those of diesel. Biodiesel is used on its own or mixed with fossil diesel oil and in a variety of different proportions.

Due to the fact that biodiesel dissolves rubber, appropriate hoses and sealing must be used in engines burning pure biodiesel. Appropriate measures must be taken when the temperature approaches freezing point as its cloud point is close to this temperature point (depending on crude oil or crude grease). This is also the reason why fossil diesel or other substances (anti-precipitation chemicals) must be added in cases where pure biodiesel is used. Running on biodiesel actually cleans the engine, making a change of filters necessary prior to the switch. Finally, keeping in mind that biodiesel is oxidized over time, it should not be stored for longer than 6 months, unless mixed with the appropriate antioxidants. [61]

Global use and production of biodiesel has grown tremendously in recent years, from 3 million tonnes in 2005 to over 18 million tonnes in 2010. This development can be partially attributed to the large rise in production in Asia from relatively low levels. On a global basis, 25 to 30 million tonnes of biodiesel are produced annually. [72]



Glycerol ($C_3H_8O_3$) is a by-product of the esterification of oil to biodiesel. It is separated from the fatty acids using methanol and sodium nitrate and precipitated as a secondary product in the process. The excess methanol can be recovered via distillation and reused for further esterification. Glycerol settles at the bottom of the tank as viscous fluid as it is heavier than the oil and is tapped from underneath. Glycerol is nontoxic and decays in nature in a matter of 2-3 weeks. It is water soluble, in any proportion, in addition to being absorbent, allowing it to bind

moisture from the atmosphere. As a result, it can be strewn in fields as fertilizer, burned or used for its energy content. It can also be mixed into soil and used as compost. [39]

Refined glycerol is quite valuable and is used in industrial processes and the food industry, including as a moisturizer and sweetener in food stuffs, as a softener and moisturizer in cosmetics and skin care products. It is also used in the pharmaceutical industry, for health products, in paper production, soaps and as environmentally friendly antifreeze. You will likewise find glycerol is such products as cough medicine, toothpaste, mouthwash, hand lotion, shaving cream and hair products. It is also used in the production of the explosive nitro-glycerine. These countless applications of glycerol are contingent upon it being pure and free of any additives and its refining is complicated and expensive. Glycerol supply is considerable due to rising biodiesel production which has also caused its price to drop. [33][35]

Lastly, it is worth mentioning that the yellow rapeseed flowers attract bees, which in turn produce honey. In many countries, apiaries are placed in the vicinity of rapeseed fields in order for the bees to collect pollen. Honey has various purposes, as a sweetener and in cuisine. In fact, rapeseed honey is considered a diet supplement due to its nutritional value.

Environmental and Economic Sustainability

Sustainable transport is prescribed in the Icelandic government‘s transport plan. It presents goals for the reduction of negative environmental impacts related to transport and stipulates that greenhouse gas emissions due to transport in Iceland should be under 750 Gg (750 thousand tonnes) in 2020, in line with the government‘s climate change action plan.[13]

Research in the field of environmentally friendly energy sources is emphasized as a means by which to reach these goals, in addition to the development and production of eco-friendly fuel. Moreover, resolved actions and concessions should aim for decreased consumption of fossil fuel and that vehicles for transport run on energy of renewable origin. [12]

The main idea behind sustainable development, or the sustainable utilization of natural resources, is simple and not a recent one. It is twofold; firstly, it involves not using nature‘s resources excessively but rather in a moderate fashion, preferably in a manner that allows them to renew in time parallel to their consumption. Secondly, the sustainable use of natural resources pertains to consuming them while avoiding pollution or any other type of destruction of nature. Keeping this in mind, rapeseed cultivation for energy procurement is well aligned with this concept of environmental sustainability, especially as a domestic and renewable source of energy as the cultivation can be repeated without depleting a natural resource. Further, Icelandic production of rapeseed biodiesel and rapeseed oil reduces the need for importing these goods. Their production here in Iceland creates jobs and at the same time, increases the gross national income and the national energy security. [41]

Rapeseed cultivation involves double carbon offset when considering carbon dioxide (CO_2) emissions, that is the cultivation binds double the amount of carbon dioxide due to combustion

of oil used during the process. It is also important to take into account the fact that unused land can be utilized for rapeseed farming and the benefit of land reclamation using rapeseed, lupine and animal fertilizer.

Biodiesel made from rapeseed oil causes roughly 70% less pollution when combusted than its fossil counterpart. This refers mainly to carbon dioxide (CO_2), carbon monoxide (CO) and also particulate matter (PM) which is harmful when inhaled and accumulated in the human body. Sulphur dioxide (SO_2) is a significant pollutant in diesel, but is barely measureable in emissions related to the combustion of biodiesel. [62]

An expert report on prospects for the reduction of Iceland‘s net greenhouse gas emissions highlighted the use of biofuel for the nation‘s fishing fleet and to further strengthen research and innovation within the field of renewables in order for Iceland to become a leading user of renewable energy. The government action plan to usher in an energy transition for sea transport is in agreement with the report and encourages increased production and consumption of domestic renewable fuel to contribute to currency savings, job creation and energy security. [15][16][42]

Directive 2015/1513 of the European Parliament and of the Council touches upon indirect land use and sets a maximum allowed level of 7% of first generation biofuel which is also part of the transport goal in EU Directive 2009/28. The objective of the directive is to reduce the effects of first generation biofuel production on other land use, for example related to food production. Implicit in the directive is the notion that a 100% reduction in carbon dioxide emissions is not possible using biodiesel due to land use considerations. This applies mainly to land use change from food production purposes to rapeseed cultivation or forestry, specifically to sequester carbon dioxide (CO_2). This is usually not applicable to uncultivated land in Iceland as it is not in use and its vegetation is often weak.

The directive does however offer some exemptions and equivalences where the member states and the commission are obliged to encourage the development and use of systems which have been proven to produce a certain amount of biofuel material as part of a specific project without disrupting any other type of production. This is true in the case of biofuel where the marginal production achieved due to investment in improved productivity reaches beyond the quantity produced had no incentives been in place. This also applies to biofuel production in countries where land use change occurred without any negative effect on ecosystem services, including the conservation of carbon stock and biological diversity. The member states and the commission are obliged to explore the possibility for creating benchmarks for distinguishing and certifying systems of production of a certain amount of biofuel material as part of a specific project without disrupting any other type of production. Further, the benchmarks should confirm that the biofuel materials have been produced according to EU standards for the sustainability of biofuel. For these purposes, only material corresponding to the reduction of actual disruption brought about by the system, can be taken into account. [20][47]

Oil and Ship Engines

Biodiesel made from rapeseed, an environmentally friendly and renewable energy source, has very similar characteristics to fossil diesel, the fuel most commonly used for ship engines today. It can be produced in Iceland by cultivating enough rapeseed to economically cover the domestic demand for fuel. [37][61]

Calorific Value / Heat Value

Comparison of the Energy Levels of several Fuel Sources

=> Fuel			=> Energy Carrier	
Fuel / Carrier	MJ/litre	Equivalence	CO_2-Emission	Health Effects
Fossil Diesel	38.6	100%	3.160 kg	Toxic
Canola Oil (Raps)	37.1	96%	2.797 kg	Harmless
BioLiq (BtL)	36.3	94%	3.140 kg	Toxic
Biodiesel (RME)	35.1	91%	2.797 kg	Harmless
Gasoline	34.8	90%	3.160 kg	Toxic
Butanol	31.8	82%	2.378 kg	Toxic
Ethanol	23.5	61%	1.913 kg	Toxic ??
Methanol	17.9	46%	1.375 kg	Highly Toxic
Methane Gases	25.3	66%	2.750 kg	Harmless
DME	19.2	50%	1.913 kg	Toxic
Hydrogen	9.3	24%	0.000 kg	Harmless

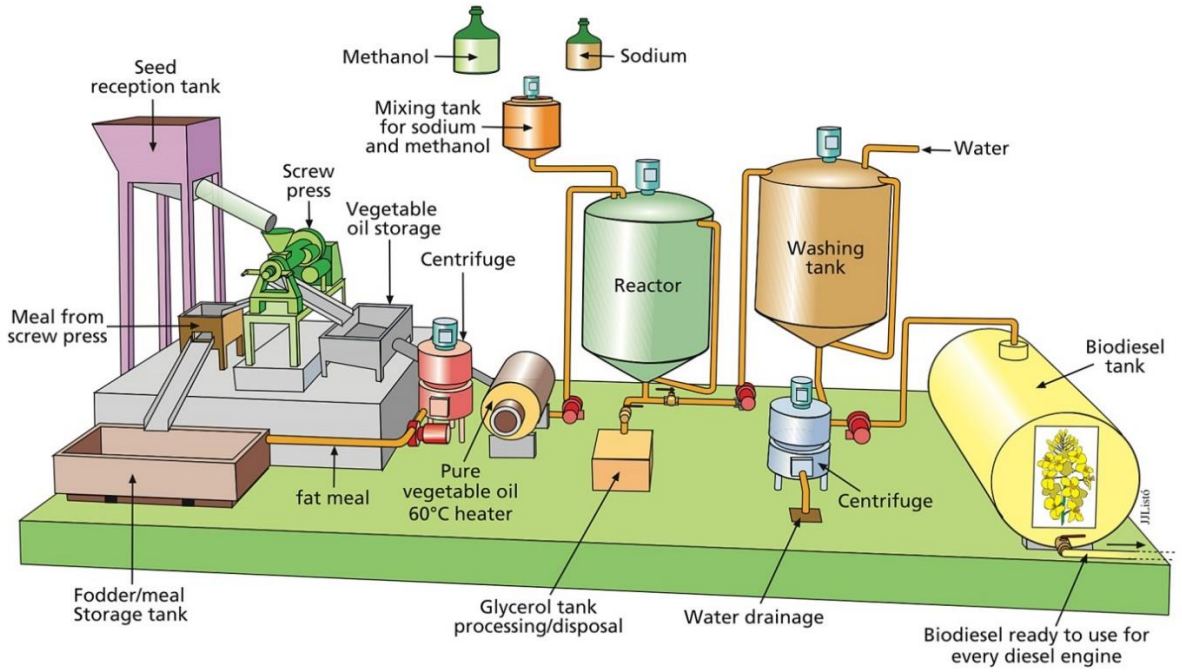
An energy carrier is created through another energy source, often electricity. Therefore, energy carriers typically have low energy density. This table demonstrates that the energy density of fossil diesel and rapeseed oil or biodiesel is close to the same. [39]

Biodiesel is the product of a chemical reaction; due to the esterification of the rapeseed oil, the viscosity of the oil becomes ten times less or approximately the same as that of fossil diesel. The reaction involves rapeseed oil, methanol and caustic soda (NaOH). Caustic soda and methanol are placed in a mixing tank and stirred until the soda has been dissolved, a process that takes 15-20 minutes. The rapeseed oil is warmed up to 55-60°C in a chemical reactor tank, after which the liquid from the mixing tank is added and mixed to begin the esterification reaction. In one or two hours the reaction is complete and the glycerol part (10% of the mixture) has sunk to the bottom of the tank as it is heavier than the oil and is separated by draining from the tank. The oil is moved to the water rectification tank where it is washed with freshwater (30% of the oil). This process, the final step in the biodiesel production process, can take up to 8 hours. Once the rinsing water has been removed from the bottom of the tank, the biodiesel is ready for use in any fuel tank and ship engine running on fossil diesel.

When the oil has been transported to the water rectification tank, the mixing tank is ready for the next batch of rapeseed oil and the process is repeated. The glycerol and rinsing water are

rid of methanol via distillation, recovering part of the methanol for use in the next esterification procedure.

The rinsing water can be neutralised chemically in a simple way and flushed down the drain, causing no pollution. Another common method involves mixing it with phosphoric acid creating an excellent fertilizer, collected in especially designed tanks. [33][34][35][37]



A simple biodiesel production plant showing the necessary components

According to Icelandic law no. 40/2013 on renewable fuels for land transport, domestic producers and sales agents of renewable fuel must demonstrate that the fuel is indeed renewable and that its production process conforms to sustainability standards if it is intended for use in land transport. Certificates of origin or a different means of proof of renewable origin and adherence to sustainability standards must be presented to the National Energy Authority. In the case where the raw materials for production of environmentally friendly fuel, are imported and certified by a recognised issuer of certificates of origin, the biodiesel production taking place in Iceland does not require certification. [10][11]

Biodiesel as Fuel for Ship Engines

In recent years, the Icelandic fishing fleet has consumed annually, on average, about 160 thousand tonnes of marine gas oil. Counting also heavy fuel oil and marine oil purchased off Icelandic shores, the consumption reaches 200 thousand tonnes. The fleet‘s annual oil consumption is expected to remain about the same in the coming decade, approximately 160 - 200 thousand tonnes of fossil oil.

There is nothing to prevent renewable energy sources from replacing fossil diesel as the primary fuel for Icelandic fishing vessels. Biodiesel made from rapeseed oil is completely comparable

in quality to the fossil diesel used today and does not have any detrimental effect on the vessel main engines, in fact, quite the opposite is true.

Changing the fuel choice for vessels is generally viewed as having great potential for using plant oil, biodiesel or another organic fuel in place of marine gas oil or heavy fuel oil. Technically speaking, a reduction of up to 70% in greenhouse gas emissions could be implemented quite easily. Moreover, the fishing enterprises themselves could even cultivate rapeseed and produce biodiesel for their vessels. [43][61]

The cost related to modifications of vessel main engines to allow for plant oil and biodiesel consumption must be taken into account. The biodiesel used in ship engines must fulfil regulations set by the authorities and global institutions and it must be guaranteed environmentally friendly. The implementation of temporary economic incentives for the adoption of biofuel should be evaluated, as should the experience of biodiesel use by foreign fleets.

Ship Engine Modifications for Renewable Energy Sources

Main and auxiliary vessel engines usually require a few modifications to allow for the combustion of pure rapeseed oil or biodiesel. The biodiesel is corrosive to plastic tubing and sealing, as well as to copper installations and heavy metals have been corrupted due to contact with biodiesel. The solution involves replacing the vulnerable metals with no-susceptible ones. Ship engines today are mostly made up of metal compounds other than heavy metals, so relatively recent engines should easily run on rapeseed oil or biodiesel. If using exclusively rapeseed oil as a marine fuel is the intention, a main engine manufactured for heavy fuel oil will require but minimal modification. [61]

In the case where rapeseed oil or biodiesel is mixed in the ratio of 1:3 or 1:4 with fossil diesel, no engine modifications are necessary.

Properly purified biodiesel, mixed with fossil diesel, should not be stored for longer than six months. Condense water in the fuel tank is an issue of concern in boats and ships; hence emptying the tanks thoroughly is advisable ahead of switching from fossil diesel to biodiesel. Also, unmixed biodiesel should never be stored in sub-zero temperatures. A ratio of 20% fossil diesel to biodiesel can help avoid complications due to cold conditions during winter. [36][37][39]

Requirements for use of Biodiesel as Source of Energy for Propulsion Power

Biodiesel must comply with the Icelandic standard ÍST EN 14214 which details conditions biodiesel must adhere to, high and low allowable values for energy density, auto-ignition

temperature and exhaust gas contents. Toxic and harmful substances such as methanol are used in the biodiesel production process, in addition to caustic soda (NaOH), a very toxic compound, which serves as a catalyst. These compounds can do engine damage if they are not properly removed from biodiesel prior to use. Adhering to the standard is very important in order for the product to reflect the level of quality and satisfy requirements. The production standard ensures biodiesel quality, which in turn guarantees the oil‘s quality to third parties. [21]

The European Union has created a number of directives on the use of renewable energy sources. Some of them involve binding goals for specific member states to increase the use of renewable energy and especially to reduce diesel engine exhaust gas contribution to the greenhouse effect. On April 23 2009, the EU adopted two important directives regarding the reduction in use of fossil fuel and the increased use of renewable sources. The goal is for the share of renewable energy sources in transport to reach 20% by 2020 within the Union. A special provision relates the method of calculation for the shares. [20]

The EU has set regulations on the production and utilization of environmentally friendly energy. Moreover, the European community has shown great interest in ensuring the legal foundation and creating market base for environmentally sound energy sources such as biodiesel.

As part of taking steps to reduce greenhouse gas emissions, the International Maritime Organization (IMO) has aired proposals on the increased consumption of environmentally friendly energy in vessels.

Iceland‘s transport plan and parliamentary resolutions demonstrate that the goals are emerging and within a few years, Icelandic authorities will likely encourage further biodiesel use as a marine fuel. The issue of energy transition for vessels will presumably be solved with biodiesel produced using local energy plants such as rapeseed.

Domestic and international requirements for running the fishing fleet on biodiesel testify to the quality and contents of the fuel. Hence, biodiesel fully meets requirements as a factor towards an energy transition in sea transport.

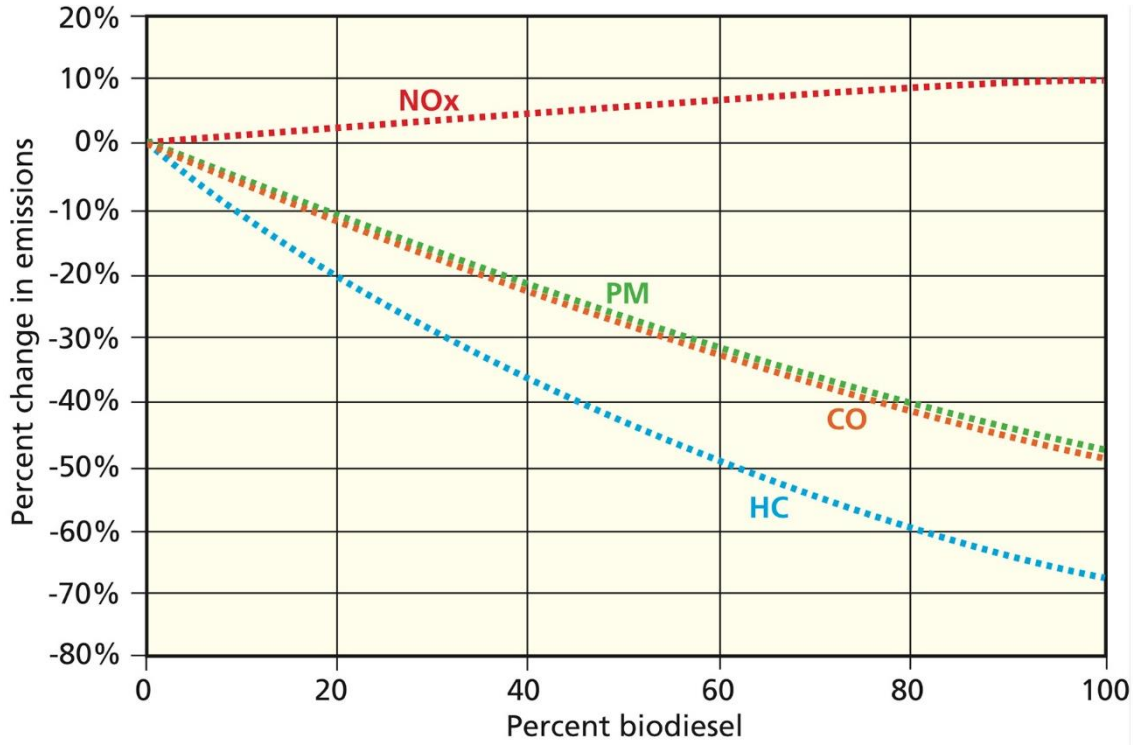
The Benefits of Biodiesel as a Marine Fuel

Biodiesel‘s main benefit as a marine fuel is the fact that it can be locally produced from Icelandic rapeseed oil, it has the same energy density as fossil diesel and next to no engine modifications are necessary prior to use. That is, biodiesel is a viable energy option for Icelandic vessels, today. Also, the infrastructure necessary to guarantee a supply of biodiesel is existing and the fuel is suitable for the current distribution system run by oil companies.

Biodiesel is a nontoxic fuel and pollution caused by its combustion is minimal compared to that of fossil diesel and gasoline, as the table below shows. [39]

Fossil diesel and gasoline emissions compared to biodiesel [36][39]			
Exhaust gas pollutants	Biodiesel	Fossil diesel	Gasoline
Greenhouse gases (CO_2, CH_4, N_2O)[*)]	1.00	3.35	4.50
Particulate matter (PM)	1.00	2.25	0.65
Nitrogen oxides (NOx)	1.00	0.95	0.45
Volatile organic compounds	1.00	2.20	6.00
Carbon monoxide (CO)	1.00	1.80	9.35

[*)] CO2 is carbon dioxide (77%), CH_4 is methane (15%) and N_2O is nitrous oxide (7%).



NOx = Nitrogen Oxides; PM = Particulate matter; CO = Carbon monoxide; HC = Hydrocarbons [75]

Biodiesel does not contain any sulphur compounds such as sulphur oxides (SOx) or hydrogen sulphide (H_2S). Sulphur dioxide is harmful to human health and high levels of it can cause difficulty breathing, even suffocation, irritation to eyes, nose and throat, coughing, respiratory diseases and chest discomfort. The compound also affects plant respiration, can cause discomfort and death in animals and corrosion in metals. Hydrogen sulphide is also dangerous to human health, specifically to people with susceptible eyes, lungs, and airway.

International agreements (MARPOL Annex VI) allow for the designation of special ocean areas where the maximum allowable level of airborne pollutants in vessel exhaust gas is limited. These are referred to as ECA areas (emission control area). The annex covers fuel quality and its combustion in ship engines, in addition to limiting the acceptable level of sulphur oxides (SOx). Currently, the Baltic Sea, the North Sea and the east coast of the United States are ECAs. The cap for sulphur compounds content in fuel has been 0.1% since 2015, down from 1% previously. For other areas the limit for sulphur compounds in fuel is at 3.5% until 2020, at

which point it will be reduced to 0.5%. The use of biodiesel is beneficial in that it does not contain any of the abovementioned sulphur compounds. [16]

Iceland ratified MARPOL Annex VI on November 22, 2017. The annex will come into force on February 22, 2018.

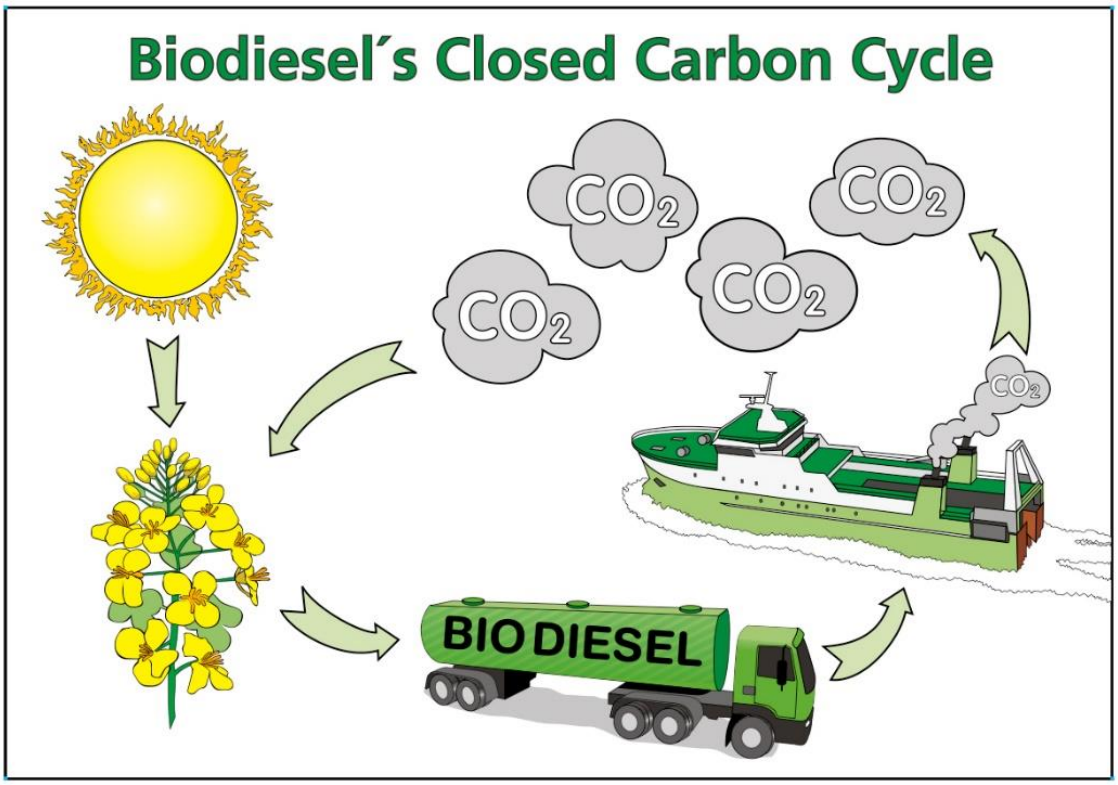
The figure shows current ECA areas in dark green and in light green, the areas working to fully ratify Annex VI (IMO 2014). New Zealand, a nation working on ratification, is missing in the figure.

Fossil diesel takes several years to break down in nature while biodiesel does so in a matter of about 3 weeks. Considering biodiesel from a health perspective is important, as is taking into account its environmental aspects and sustainability. Such a comprehensive evaluation must examine the significance of using environmentally friendly fuel for the Icelandic community as well as the global community.

Environmental and Economic Benefits

Making the switch to biodiesel, the Icelandic fishing fleet must be prepared for with diligence, bearing in mind the crucial factors of efficiency and environmental benefits. Perhaps, a kickoff using smaller vessels would be sensible, moving gradually to larger ships. Another option could involve introducing a low mixing ratio of biodiesel to fossil diesel, 5% (B5) for example, and progressively increasing it as rapeseed cultivation and biodiesel production expand.

The fact that energy plants such as rapeseed can be cultivated in Iceland presents a challenge to commence a large scale cultivation process for energy plants, with the goal of meeting the needs of the Icelandic fishing fleet. The potential to produce fuel domestically rather than importing it calls for a comprehensive analysis of the economic benefits for the national economy, farmers and manufacturers and, additionally, of environmental advantages. Rapeseed cultivation represents a carbon offset. As mentioned previously, each hectare binds double the amount of carbon dioxide emitted upon the combustion of biodiesel produced from the rapeseed.



During cultivation, the rapeseed binds double the amount of CO_2 emitted when the biodiesel is combusted.

Biodiesel and rapeseed oil have an energy density close to that of fossil diesel. The energy transition from fossil to biodiesel is possible immediately and without great expense, in fact current ship engines could run on biodiesel today without complication.

Large, foreign cruise ships operate powerful generators to produce power while in port. These generators run on fossil diesel which, when combusted, results in considerable pollution, including carbon dioxide emissions and particulate matter (soot).

Therefore, it is only logical that Icelandic port authorities explore means by which to put an end to this pollution. Many have suggested shore power as a solution to avoid the need for the operation of generators for docking passenger ships.

However, it is neither clear whether sufficient power is available for vessels of this scale nor that existing infrastructure can manage the demand. Further strengthening of electric infrastructure for vessels is a long-term undertaking and very costly.

One solution involves requiring passenger vessels to run on Icelandic or imported rapeseed oil or rapeseed diesel while docked at Icelandic ports. Rapeseed oil has a similar energy density to that of fossil diesel and its usage does not damage cruise ship generators. Should Icelandic rapeseed oil production not suffice, the oil may be imported or it could be offered as a choice by the vessels themselves.

This is one way to reach the goals of acceptable pollution reduction due to foreign passenger vessels calling in Icelandic ports, a way which would also increase Icelandic agricultural income from rapeseed cultivation.

The first time Icelandic rapeseed oil was used as fuel was aboard a fishing vessel in Hornarfjörður May 23, 2017

In the future, environmentally sound fisheries will be important to markets and the product sales process. Even today, the market is increasingly calling for eco-friendly fishing, that is, where the energy and fishing gear are environmentally sound. The energy issue can be solved by rapeseed cultivation.

A Vision for the Future for Marine Renewable Energy

An estimated one million times more crude oil is extracted from the earth on an annual basis than is formed in the same time period from animal and plant biomass in the earth‘s crust. Despite the belief that some areas hold undiscovered oil reservoirs, one must keep in mind that oil consumption grows faster than its production and thus it is more than likely that the supply of this popular source of energy will become scant in the near future. Moreover, the use of oil for energy purposes involves a great pollution issue which has already brought about significant problems. The global community has collaborated to solve these issues via the Paris Agreement, which was signed in late 2015, one of many steps in a process for change. Due to this critical pollution issue caused by the consumption of fossil fuels, mankind will probably need to cease its utilization thereof before global oil and gas reserves are completely depleted.

One of biodiesel‘s main benefits, beyond those of most eco-friendly energy sources, is its favourable combustion efficiency in diesel engines. Currently though, fossil fuel is in a unique position when it comes to distribution and sales. Sensible and conscious environmental protection, emphasizing the health effects, sustainability, and the reduction of greenhouse gas emissions and discharge of other compounds that are harmful to the environment can change this special status. [37]

The fact that fossil fuel production will be markedly reduced within a few decades, implies that sooner or later a replacement fuel or technology must be identified, whether it is renewable and environmentally friendly and can be produced in Iceland. It is clear that a substitute for fossil diesel must be found.

Considering the existing research on the cultivation of eco-friendly energy sources in Iceland and recognizing the fact that biodiesel made from rapeseed oil can fully replace fossil diesel, it is only logical to launch a project to implement the energy transition between the two fuels. [41]

Biodiesel from rapeseed is quite rightfully among the top options for moving away from fossil fuel. Given that biodiesel can be easily integrated with the current technology for energy consumption in diesel engines and the current distribution systems, there is considerable cause to believe there is a future for this environmentally friendly and renewable energy source. Indeed, biodiesel‘s related rapeseed cultivation and production yields valuable by-products, including animal feed and fertilizer.

Summary and Conclusions on Rapeseed Cultivation

Domestic biodiesel production would reduce the need for imported fossil fuel and prevent CO_2 emissions associated with the combustion of fossil fuel. The combustion of biodiesel is also cleaner with regard to other pollution factors and its carbon footprint is quite positive.

Land use change, where fields used for food production are converted to allow for the production of biodiesel, can cause deforestation (loss of CO_2 storage) elsewhere in the world, an unfortunate development for the total global CO_2 emissions. In Iceland, rapeseed cultivation would take place on unused land or land lacking significant vegetation such as sandy plains or other marginal areas, thus increasing carbon storage. Compound feed is a by-product of rapeseed cultivation thus reducing the need for feed imports and indirectly contributing to the protection of foreign forests. Rapeseed, partnered with lupine, is a suitable plant for land reclamation and in this manner, promoting the cultivation of new land in addition to further carbon storage. Biodiesel oil made from rapeseed in Iceland would be an example of a domestic and renewable fuel, reinforcing currency savings, job creation and increased energy security.

The basic premise of sustainable development, or the sociological sustainable utilization of natural resources, is simple yet not new. It is twofold: firstly, it involves averting the depletion of nature‘s supplies and rather consuming its resources in a moderate manner, preferably allowing for replenishment. Secondly, the sociological sustainable utilization of natural resources requires that the consumption be pollution free and harmless to the environment. With this in mind, rapeseed cultivation as energy procurement fits the definition of renewable energy quite well as the farming can be repeated without depleting a natural resource.

The Icelandic production of biodiesel and rapeseed oil spares the need for importing these goods. Their domestic production creates employment, thereby increasing the sociological sustainability and gross national income, which is in everyone‘s interest. Precise cost analyses have been carried out via business planning, taking into account the process from cultivation to fully processed biodiesel, confirming that rapeseed production can be profitable and self-supported. [46]

The possibilities are unequivocal and the solution is at hand.

What are we waiting for?

References

[10] Lög um endurnýjanlegt eldsneyti í samgöngum á Íslandi, nr. 40/2013.
[11] Reglugerð um viðmiðanir í sjálfbærri lífeldsneytisframleiðslu, nr. 750/2013.
[12] Samgönguáætlun 2015-2018.
[13] Tillaga til þingsályktunar um samgönguáætlun fyrir árin 2015-2026. Lögð fyrir Alþingi á 145. löggjafarþingi 2015-2016. Þingskjal 1706 – 879. mál.
[14] Reglugerð um fljótandi eldsneyti, nr. 560/2007.
[15] Tillaga til þings álytkunar um aðgerðaáætlun um orkuskipti. Lögð fyrir Alþingi á 145. löggjafarþingi 2015-2016. Þingskjal 1405 – 802. mál.
[16] Möguleikar til að draga úr nettóútstreymi gróðurhúsalofttegunda á Íslandi. Niðurstöður sérfræðinganefndar. Umhverfisráðuneytið 2009.
[17] Gerð viðskiptaáætlana. KPMG og Nýsköpunarsjóður, 2005.

[20] Directive (EU) 2015/1513 of the European Parliament and of the council of 9 September 2015 amending Directive 98/28/EC relating to the quality of petrol and diesel fuels and amending Directive 2009/28/EC on promotion of the use of energy from renewable sources.
[21] Biodieselnorm DIN EN 14214. Petrotech. Global Trade Company.

[30] **Jónatan Hermannsson, Þóroddur Sveinsson; 2009:** „Ræktun á repju og nepju til olíuframleiðslu og uppgræðslu“. Rit LbhÍ nr. 24. Landbúnaðarháskóli Íslands, 2009.
[31] **Þórdís Anna Kristjánsdóttir; 2016:** „Nytjaplöntur á Íslandi 2016. Yrki, sem mælt er með fyrir landbúnað, grasflatir, garðrækt og landgræðslu“. Landbúnaðarháskóli Íslands, febrúar 2016.
[32] **Sveinn Rúnar Ragnarsson; 2013:** „Tilraunaræktun á repjufræi í Austur-Skaftafellssýslu“. Ræktunarfélag Austur-Skaftfellinga, janúar 2013.
[33] **Kristján Finnur Sæmundsson; 2009:** „Framleiðsla lífdísils á Íslandi“. Lokaverkefni í vél- og orkutæknifræði BSc, Háskólinn í Reykjavík, 7. desember 2009.
[34] **Ármann Halldórsson; 2010:** „Hönnun lífdísilsverksmiðju á Hvolsvelli“. Lokaverkefni í byggingatæknifræði BSc, Háskólinn í Reykjavík, 8. desember 2010.
[35] **Eiríkur Böðvar Rúnarsson, Jón Trausti Sverrisson; 2011:** „Uppsetning lífdísilsverksmiðju á Hvolsvell“. Lokaverkefni í vél- og orkutæknifræði BSc, Háskólinn í Reykjavík, 7. desember 2011.
[36] **Georg Rúnar Ragnarsson; 2014:** „Samanburðarrannsókn. Eyðsla og útblástur skipagasolíu, repjuolíu og bíódísil.“ Lokaverkefni við Véltækniskólann, 8. desember 2014.
[37] **Jón Bernódusson; 2010:** „Umhverfisvænir orkugjafar. Ræktun á repju og nepju til framleiðslu á lífrænni dísilolíu fyrir íslenska fiskiskipaflotann“. Siglingastofnun Íslands, desember 2010.
[38] **Ólafur Ingi Sigurgeirsson, Jón Árnason, Helgi Thorarensen, Aðalheiður Ólafsdóttir; 2008:** „Plöntumjöl í stað fiskimjöls í fóðri fyrir bleikju af matfiskstærð“. Lokaskýrsla til AVS-rannsóknasjóðs. Verkefni nr.: R031-08, 2008.
[39] **Pálmi Stefánsson; 2010:** „Efnafræði orkugjafa“. Greinargerð samin fyrir Siglingastofnun Íslands, 9/2010. Óbirt.
[40] **Ármann Halldórsson, Andri Þór Arinbjörnsson, Bergmundur Elvarsson, Elfar Fannar Guðjónsson; 2009:** „Líforka – viðskiptaáætlun“. Rekstur, stjórnun og nýsköpun, AT-1003. Háskólinn í Reykjavík 2009.
[41] **Jón Benediktsson, Kristrún Lilja Júlíusdóttir, Ragnhildur Reynisdóttir, Rudkow Andrey A, Sigríður Einarsdóttir: 2010;** „Is Rapeseed oil Production feasible in Iceland?“. Master of Busines Administration, Háskólinn í Reykjavík, 2010
[42] **Samgönguráðuneytið; 2009:** „Losun koltvísýrings (CO_2) í siglingum“. Áfangaskýrsla stýrihóps um losun koltvísýrings (CO_2) í siglingum. Febrúar 2009.
[43] **Sævar Birgisson; 2011:** “Feasibility Study of Converting Rapeseed to Biodiesel for use on a Fishing Vessel”. Business Department, University of Iceland, January 2011.

[44] **Sævar Birgisson; 2011:** „Arðsemismat á mismunandi notkunarmöguleikum repjuolíu“. Lokaskýrsla Nýsköpunarsjóðs námsmanna, 23. september 2011.
[45] **Arnar Halldórsson, Sigursteinn Hjartarson, Halldór Torfason; 2011:** „Lífolía til vegagerðar“. Lýsi hf., Vegagerðin, Höfði hf. 10. febrúar 2011.
[46] **Vífill Karlsson, Ólöf Guðmundsdóttir, Ólafur Sveinsson, Jón Bernódusson: 2017;** „5000 tonna lífdísilverksmiðja á Íslandi. Viðskiptaáætlun“, Samtök sveitarfélaga á Vesturlandi, mars 2017.
[47] **Jón Bernódusson, 2016:** „Sjálfbær ræktun orkujurta á Íslandi til skipaeldsneytis“. Samgöngustofa, 2016

[60] **Christen, O., Fried, W.; 2007:** „Winterraps. Das Handburch für Profis“. Verlag GLG, 2007
[61] **Eder, Barbara, Eder, Franz; 2006:** „Pfanzenöl als Kraftstoff. Autos und Verbrennungsmotoren mit Bioenergie antreiben“. Ökobuch Faktum 2004, 2006.
[62] **Geitmann, Sven; 2005:** „Erneuerbare Energien & alternative Kraftstoffe“. Mit neuer Energie in die Zukunft. H_2YDROGeit-Verlag, 2005.
[63] **Geitmann, Sven; 2008:** „Alternative Kraftstoffe“. Erdgas & Flüssiggas, Biodiesel & Pflanzenöl, Ethanol & Wasserstoff. H_2YDROGeit-Verlag, 2008.
[64] **Holtgreve, Winfried; 2010:** „Möglichkeiten eines mineraldüngersparenden Rapsanbaus für Island“. Greinargerð samin fyrir Siglingastofnun Íslands, 7/2010. Óbirt.
[65] **Schümann, Ulrike, Harndorf, Horst; 2009:** „Kraftstoffe“. Skript zur Vorlesung. Grundlagen der Verbrennungsmotoren, Universität Rostock, 2009.
[66] **Blank, Robert, Harndorf, Horst; 2009:** „Abgasnachbehandlung“. Skript zur Vorlesung. Kraft- und Arbeitsmaschinen, Universität Rostock, 2009.

[70] www.auto-umwelt.at
[71] https://www.rml.is/static/files/Jardraekt/RaektunarlandIB.pdf
[72] https://www.iea.org/media/omrreports/tables/2016-08-11.pdf
[73] https://www2.mst.dk/udgiv/publications/2011/08/978-87-92779-30-4.pdf
[74] http://www.folkecenter.dk/dk/rd/transport/Braendstoffer-og-forsyning/planteoile-til-transport/raps/balance/
[75] http://www.omafra.gov.on.ca/english/engineer/facts/biodiesel.htm