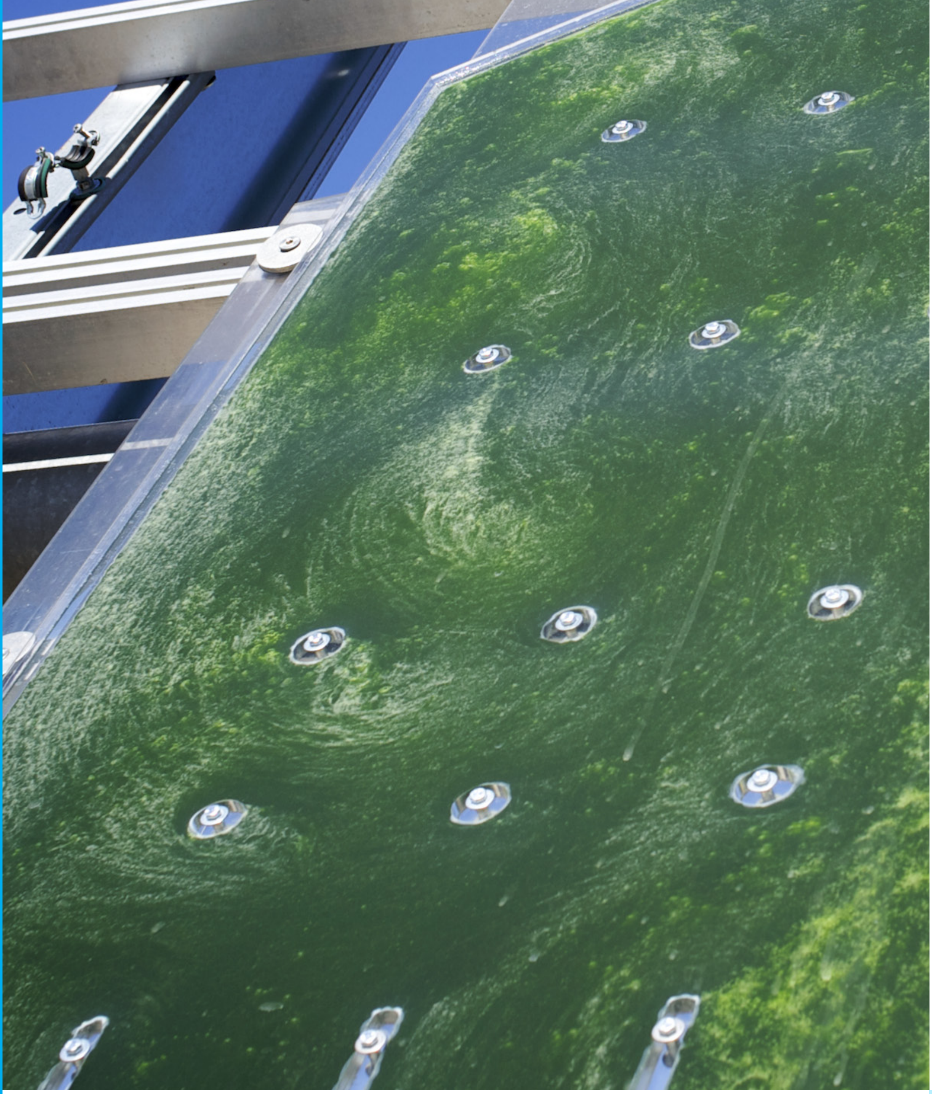

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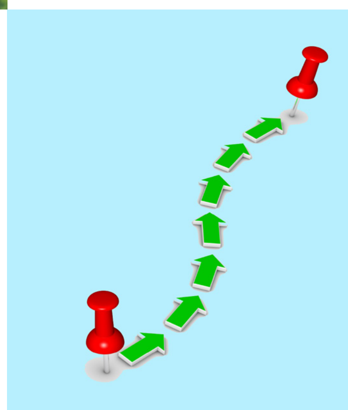
158



Algal energy roadmap in India

Opportunities for Finnish industries and SMEs

Eemeli Hytönen | Ari Jussila | Sari Kuusikunnas

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Algal energy roadmap in India
Opportunities for Finnish industries and SMEs

Eemeli Hytönen, Ari Jussila & Sari Kuusikunnas. Espoo 2014. VTT Technology 158. 34 p.

Abstract

Use of microalgae as a biofuel source has many advantages, as is acknowledged worldwide. Many countries are eager to offset carbon dioxide emission and develop indigenous and sustainable energy sources, especially countries which are dependent on imported energy. The relatively high growth rate and ability of microalgae to sequester carbon dioxide are main factors driving the development of future algal based biofuels. Microalgae also have potential to be a more sustainable source of energy, compared to other crops such as rapeseed or oil palm and lignocellulose. This results partly from the fact that algae can be cultivated on wasteland and the cultivation does not need fresh water but instead lower-quality water such as saline or wastewater can be used. This also leads to the possibility of wastewater bioremediation, since microalgae are able to utilize nitrogen and phosphorus from wastewater and absorb some heavy metals.

Rising energy prices and increasing global energy demand are key driving forces for alternative energy solutions. Algal-based energy is one of the options being considered, but at the moment the production costs are significantly higher than the market price of energy. However, there are many ways to narrow this gap. Developing more efficient production technology is one way to achieve this goal. Integrated solutions, for example obtaining essential, expensive nutrients from wastewater, is another. Furthermore, if algae can be used to produce some high-value products or by-products as well, the operation could already be profitable. To support the development of algal energy, government subsidies are in place, however market-driven development of the industry is important.

Currently microalgae are not cultivated at commercial scale for energy purposes only. There are however many companies and research institutes developing solutions to all of the main challenges.

This report presents the findings of a roadmap work carried out in 2013 based on interviews with Indian experts and VTT expert workshops. The roadmap target is the potential role of Finnish SMEs in algae-based energy system in India.

Keywords Roadmap, India, algae, energy, driver, barrier, SME

Preface

Renewable energy is a global and fast growing industry, with business and research networks still in a phase of transition. Large companies are closely watching technological advances and looking for potential investment and business opportunities. Understanding the big picture, including both technological and business aspects, is essential for choosing strategic alternatives. Market development is heavily influenced by national politico-economic drivers and technological breakthroughs.

This publication is part of the outcome from the Tekes Groove programme project ALGIND Algae energy business opportunities in India for Finnish companies, executed 01/2012–04/2014. The project aimed to form the best possible big picture for enhanced business opportunities in algal biofuel markets. This was realized through activities on several levels including foresighting, business model development, partnership and research cooperation with Indian organisations.

ALGIND has been carried out as collaboration between three Finnish research organisation and three Indian organisations. The research partners in addition to VTT were University of Helsinki (Prof. M. Romantschuk) project coordinator and LAMK Lahti University of Applied Sciences (Dean Dr S. Kostia). VTT's role in the project concentrated on creation and verification of the roadmap, business opportunity analysis and concept development

This report describes the drivers and barriers related to algal energy development and draws a roadmap for algal energy in India.

Espoo 17.3.2014

Mona Arnold
project manager

Contents

1. Introduction

1.1 Algal energy business – opportunities and challenges in India

India ranks as the fifth-largest emitter of greenhouse gases in the world, behind China, the United States, the European Union and Russia. The biggest source of emissions in 2007 was the energy sector, including electricity, transportation, residential and other energy generation. The second biggest source was the industrial sector, followed by the agriculture and waste sectors. (Ministry of Environment and Forests, Government of India, 2010)

Many sectors of the Indian economy are climate sensitive, especially since about 51% of the Indian workforce makes a livelihood in agriculture and related activities (Papola & Sahu, 2012). An awareness of the impacts of climate change drives the need for cleaner, renewable energy solutions. In the best case scenarios, biofuels from indigenous sources have the potential to provide energy with no emission of greenhouse gases or other air pollutants. Algae could also provide a sustainable tool to reduce CO_2 emission levels because of their significant capacity to convert CO_2 into biomass. (Demirbas, 2011)

In major Indian cities 38 million cubic metres of wastewater is generated every day, out of which approximately 35% is treated (Kaur et al., 2013). Wastewater contains a lot of nutrients, such as N, P, K and other minor nutrients that microalgae need for growth. Using wastewater for algal cultivation can also reduce production costs and overall environmental performance, since manufactured fertilizers are expensive and have a huge carbon-footprint. (Chanakya et al., 2012)

India has a total area of approximately 328 million hectares (M ha), of which approximately 297 M ha are land. About 179 M ha, i.e. about 60% of the land, is in agricultural use (FAOSTAT, 2011). In India arable land is primarily needed for cultivation. The availability of land for alternative uses is low and there are also other competitive uses (Chanakya et al., 2012). The wastelands, including degraded crop and pasture land, degraded forest, industrial and mining wastelands, and sandy, rocky or bare areas, account for 44 M ha, i.e. almost 15% of the total geographical area of the country (Ministry of Rural Development, 2010).

India has a population of approx. 1.22 billion people, of which more than 50% are below the age of 25. With an annual population growth rate of 1.58%, the population is expected to reach more than 1.53 billion people by the end of the year 2030. Most of the population, about 72%, live in villages, the rest in urban areas (Population of India 2013, 2013). Approximately 40% of the population belonged to the labour force in 2011–2012 (41% in rural areas and 37% in urban areas), with about 49% of workers engaged in the agricultural sector, 24% in the manufacturing and construction sector (secondary sector) and 27% in the service sector (tertiary sector). The unemployment rate was nearly 2% of the eligible work force, which means that there were about 28 million unemployed people in India seeking work. The unemployment ratio was slightly higher in urban areas, about 3%, than in rural areas, about 2% (Ministry of Statistics & Programme Implementation, Government of India, 2013).

India recognises the advantages of biofuels, and microalgae are included in their research and development. India's tropical climate favours microalgal cultivation and since the food demand of the country is increasing and arable land not available, microalgal cultivation could offer a bioenergy source that would not threaten land use for food production. India's rural development is also very crucial, since so much of the population still earns their livelihood in the agricultural sector. Microalgal production systems could enhance rural development through employment opportunities for the landless rural population and farmers and provide new products.

The Government of India has released a National Biofuel Policy that includes biofuel blending regulations which promote biofuels, but the microalgal-based energy field does not have an active, specific set of regulations. In order to develop the field effectively and sustainably, policies are necessary. India had identified jatropha as a main source for biodiesel, but because of production and sustainability related problems this industry is still in its infancy. In order to avoid similar problems in the microalgal energy field, more research must be done now to develop a sustainable and successful future for microalgae. The government is also currently funding research and development work in the field of algae. However, even though government support exists, the required investments related to scaling up of technology are significant and it may be hard to gather sufficient governmental project funding to achieve a viable algal energy industry.

India imports the majority of its oil, and this is a key driver of development of energy solutions in India. India's huge population, combined with the rising standard of living, creates a very large domestic market demand.

Key areas requiring future focus in India regarding algal systems are (Chanakya et al., 2012):

- Development and improvement of algal strains and testing the species in the field in different conditions in order to have algal strains with high oil yield and strains that are well suited to Indian conditions.
- Development of algal cultivation technologies, aiming at simplified production system and decentralized value chains, in order to bring the technologies to villages.

- Effective policies for development of microalgal energy into large scale production in a sustainable way, without threatening food security.

1.2 Methodology

The roadmap is constructed using a workshop-based approach. The main data gathering method was semi-structured interviews carried out by two of the authors in India in October 2013. During the visit 15 organizations (5 universities, 5 companies and 5 research institutes) were interviewed. The VTT expert group analysed the interviewees' perception of the drivers and barriers in India for algal-based energy production in general, and opportunities for SMEs in that context. Then, the vision was formulated and a roadmap with technological, market-based and overall solution/product related responses to the identified barriers was constructed in two workshops.

1.3 Structure of the report

The identified drivers and barriers have been classified into 3 main groups: environmental and socio-ethical, technological and economic. These groups of drivers and barriers are presented and explained in Chapters 2–4. In Chapter 5 the roadmap is presented, followed by conclusions in Chapter 6.

2. Environmental and socio-ethical drivers and barriers

Figure 1 illustrates identified environmental and socio-ethical factors affecting the development of algal biofuel production.

Environmental drivers	Climate Change
	Potential for CO_2-capturing
	Potential for bioremediation
	Algae can be grown on non-arable land
	Algae do not need fresh water
	Tropical Climate
Environmental barriers	Land use
	Water

Socio-ethical drivers	Rural development
	Man power
	Governmental Policies
Socio-ethical barriers	Governmental Policies
	The lack of data for sustainability assessment

Figure 1. Environmental and socio-ethical drivers and barriers.

2.1 Environmental drivers

There are many environmental drivers for the development of microalgal industries. Concern about climate change and increasing carbon dioxide-emissions has led to demand for alternative energy sources. Some microalgae are able to grow on wasteland and do not need fresh water to grow, so they do not necessarily compete with crop cultivation and food production. Algae cultivation can be utilized in wastewater treatment and biosorption of heavy metals.

2.1.1 Climate change

Climate change is a very important driver in the algal energy field. Global warming caused by greenhouse gases (carbon dioxide, methane and nitrous oxide) generated from use of fossil fuels appears to be seriously impacting climate and thus the natural world. In India the main energy source is coal. About 54% of electricity is based on coal and it is expected to reach over 70% in the future, since the demand for electricity is growing rapidly (Arora, 2013). Another important energy source for India is crude oil. In 2007 India consumed 128,5 Mt crude oil. To meet the demand, India had to import about 80% of the oil. It is estimated that about 70% of total petroleum consumption is derived from automobiles, and that fuel requirements will increase with transport demands in the future. India consumes almost five times more diesel than gasoline, so the need for biodiesel is obvious. (Khan et al., 2009)

2.1.2 Potential for CO_2-capturing

Microalgal cultivation can be harnessed to offset increasing levels of carbon dioxide (CO_2) emissions. Many algal species can tolerate and utilize high levels of CO_2, i.e. higher than occur in the atmosphere. Microalgae are able to fix CO_2 from the atmosphere, including CO_2 from discharge gases from heavy industry, and from soluble carbonates (Chanakya et al., 2012). The most suitable sources for CO_2-capture are large stationary sources with high concentrations of CO_2. In an Indian context this would mean thermal power plants, cement plants, fertilizer plants, refineries and petrochemical plants, which are located pretty much all over the country. (Milbrandt & Jarvis, 2010)

2.1.3 Potential for bioremediation

Microalgal production for biofuels can be integrated with bioremediation. The nutrients that microalgae need to grow are often found in waste, e.g. nitrogen and phosphorous in wastewater. Microalgae are able to sequester some heavy metals in their cell walls through adsorption or ion-exchange processes, and the ability can be utilized for bioremediation of heavy metals. (Priyadarshani et al., 2011)

2.1.4 Algae can be grown on non-arable land

Algae grow in water, and the land on which it is grown does not need to be fertile. This is a clear environmental benefit over other bioenergy alternatives since algae-based energy systems do not compete for arable land used for growing food and feed. 15% of Indian land area could potentially be used for growing are for microalgae and finding land which also meets other requirements for algal growth therefore has a reasonable probability.

2.1.5 Algae do not need fresh water

One of the advantages of growing algae over non-edible oil seed crops is that instead of fresh water it can utilize low-quality water, including brackish and saline groundwater and wastewater. It is also possible to grow microalgae in open seas, if marine and salt tolerant algal species are used.

Renewable water resources in India are estimated at 1869 km^2, out of which 1123 km^2 are estimated to be utilizable. This includes 690 km^2 of surface water and 433 km^2 of ground water. (Central Water Commission, Ministry of Water Resources, 2011) Water availability in India is challenged due to growing water scarcity. This results partly from decreasing ground water levels and river discharge trends. (UNEP Finance Initiative, 2009)

2.1.6 Tropical Climate

The growth conditions of algae, including climate and weather affect algal productivity. Hours of sunshine and solar radiation have direct influence on productivity, whereas water supply is affected by precipitation and evaporation. Floods, hail and other extreme weather conditions affect water quality. (Milbrandt & Jarvis, 2010)

In many parts of India, the climate is suitable for algal cultivation. Solar radiation of 40 kWh/m^2/day is adequate to cultivate algae, and annually India receives enough solar radiation, apart from some specific parts of the country. Hours of sunshine vary from less than five to more than nine hours per day, which on average is more than the six per day considered to be the limit for feasible algae production.

Many microalgal species can also cope with different temperatures, but most of them are sensitive to freezing.

2.2 Environmental barriers

2.2.1 Land use

This barrier is the same as the driver above; land is a scarce resource in India and land degradation puts land use questions under the microscope. In a country like India where agriculture plays an important role for people to earn their living land use is a very important factor for the development of the country (von Braun et al., 2005). There are many issues that affect land availability for large scale algal production, including physical, economic, legal, social and political factors. For sustainable algal cultivation, agricultural land, environmentally sensitive areas, as well as areas with cultural and historical value have to be excluded. (Milbrandt & Jarvis, 2010)

2.2.2 Water

In India water use is often unsustainable. Water scarcity is growing and one major reason is groundwater exploitation. It is estimated that one-third of agriculture is irrigated and levels of irrigation efficiency are low. The declining surface water supplies results in a growing use of underground reserves and already the greater part of irrigation water is sourced from groundwater. The agricultural sector is dependent on groundwater, which makes it vulnerable to the declining supplies. (UNEP Finance Initiative, 2009) For sustainable growth of microalgae, competing for the same water resources as agriculture is not an option.

In microalgal cultivation, especially in open ponds, evaporation needs to be taken into account. Up to 1 m^3 of water can be evaporated per 1 kg of algal biomass produced. In many parts of India the water budget is not balanced: annual rainfall is much lower than the potential annual evaporation. If fresh water is used for sustainable algal cultivation, cultivation should be practiced during times when cumulative water loss does not exceed the total annual precipitation. This could vary from 60 days to 270 days. If the area has surplus water that could be used for algal cultivation, raising food crops needs to be prioritized to maintain food security.

2.3 Socio-ethical drivers

2.3.1 Rural development

The share of agriculture in total employment in India has dropped significantly over the past four decades. At the same time, the economic importance of the agricultural sector has declined. This makes a difference for the country, since nearly three-quarters of the families still depend on rural incomes and also the majority of poor people live in rural areas (The World Bank, 2012).

The Government of India is taking actions towards diminishing rural poverty through several actions. One of the focus areas is employment creation in rural areas (Planning Commission, Government of India, 2013). Biofuel business could bring more public and private investments to rural areas, generate additional employment and income for farmers and landless people. The ability of algae to be grown on underutilized land enhances the potential rural impacts compared to other bioenergy systems.

Microalgal production for small scale energy, wastewater treatment or biodiesel production could provide new employment opportunities. These come in both direct (e.g. plant workers and operators and their families) and indirect (e.g. education, infrastructure development or overall stimulation of the local economy through investments) forms.

2.3.2 Man power

One main reason for rural development activities in India is the large amount of unemployed people living in rural areas. This, combined with relatively low added value generated in rural areas of the agricultural value chain, increases poverty. The available man power could be harnessed in the algae-based energy sector. The same applies naturally to all other bioenergy systems.

2.3.3 Governmental policies

The Government of India has promoted the utilization of biofuels by making it mandatory to blend bioethanol with gasoline and biodiesel derived from non-edible oils with diesel (5% blending) since October 2008 (Ministry of New & Renewable Energy, Government of India, 2009). In December 2009 the Government of India released a National Policy on Biofuels formulated by the Ministry of New and Renewable Energy with the vision of accelerating development and promotion of the cultivation, production and use of biofuels to increasingly supplement petrol and diesel consumption. The goal is to ensure that a minimum level of biofuels become readily available in the market to meet the demand at any given time. The new blending target of the policy is to reach 20% blending with biofuels by 2017.

The policy emphasizes the importance of using nonedible sources for biofuels, which could be grown on degraded soils or wastelands. The policy supports innovation, research and development on biofuel feedstock production and it declares a Minimum Support Price for nonedible oil seeds to provide fair price to growers. The Government of India also proposes to consider creating a National Biofuel fund for providing financial incentives, such as subsidies and grants for new and second generation feedstocks, advanced technologies and conversion processes if necessary. Furthermore, biodiesel and bioethanol are proposed to be left outside of central taxes and duties, with an exception of 16% excise duty for bioethanol. (Ministry of New & Renewable Energy, Government of India, 2009)

The Government of India sees indigenous biofuels and especially biodiesel in the transportation sector as the key for the energy issues the country is facing. The National Policy on Biofuels and the National Biodiesel Mission (launched in 2003) encourage further actions in developing biofuels.

2.4 Socio-ethical barriers

2.4.1 Government policies

Although the Government of India has formulated policies that regulate the biofuel sector and favour the usage of biofuels, they seem to be inadequate with regard to future biofuels, such as algal energy. The focus is on molasses as a source for bioethanol and jatropha for biodiesel. The original mandate of the government was

20% biodiesel blending by 2012, but the target has not been met, despite the efforts of the government and private sector. Reasons include the lack of sufficient jatropha seeds as well as lack of high-yielding, drought-tolerant cultivars, land ownership issues, and inefficient progress by state governments (Aradhey, 2013; Zafar, 2013).

At the moment microalgal-based energy is waiting for the government's next steps. There are no strict laws and policies supporting microalgal energy and how the government will react towards the field will be significant for its development. When policies for microalgal energy are formulated, it is important to learn from the mistakes that occurred with jatropha.

2.4.2 The lack of data for sustainability assessment

Although microalgae could provide a strong solution for India's energy demand, there are still sustainability related questions that need to be answered. For the life-cycle analysis, social life-cycle analysis and life-cycle cost analysis more data is needed. Since algal-based energy systems are still at the laboratory and pilot scale R&D phase, actual data normally needed in these analyses is not available. Theoretical studies have been conducted based on best estimates but a higher degree of certainty is needed and it requires experience from demonstration scale operations and actual value chains developed with implementation of the algae systems.

3. Technological drivers and barriers

Figure 2 presents the identified technological factors affecting the development of algal biofuel production.

Technological drivers	Wastewater treatment
	CO_2 capture potential
	Indian climate
	Potential for multi-product system
Technological barriers	Lack of low cost land with access to water, CO_2 and cheap nutrients
	Low overall technology development level and up-scaling
	Harvesting and down-stream processing of algae are very energy intensive
	Algal strain diversity and specie applicability to different wastewaters
	CO_2 availability
	Overall cost of production
	Competition with other technologies

Figure 2. Technological drivers and barriers.

3.1 Drivers

3.1.1 Wastewater treatment

Microalgae, and macroalgae, are potential organisms for treating nutrient rich wastewaters as part of the overall wastewater treatment system. The advantage of algae over the bacteria that are commonly used in wastewater treatment is that algae can capture nitrogen in their biomass, rather than convert it to nitrate and subsequently reduce it to N_2, releasing it into the atmosphere. This enables nutrient recovery and recycling. Furthermore, some heterotrophic and mixotrophic algal species are able to use wastewater carbohydrates as carbon source and therefore reduce the chemical oxygen demand (COD) of wastewaters. Even though algae may not survive in very concentrated wastewaters, they could still play an important role as part of overall treatment plant.

3.1.2 CO_2 capture potential

Autotrophic algae use carbon dioxide (CO_2) as a source of carbon and thus represent a method for CO_2 capture. The CO_2 needs to be dissolved in water in which the algae grow. This CO_2 capture method is different from other carbon capture and storage methods in that that it is biological. The captured CO_2 has also many application possibilities, ranging from fuels to food and feed and materials, providing different carbon cycle options.

3.1.3 Indian climate

Efficient year-round autotrophic microalgal farming is possible in countries with sufficient sun light and moderate temperatures.

3.1.4 Potential for multi-product system

Algal biomass consists of several fractions (the main fractions are lipids, proteins and carbohydrates) and this enables production of several products. Moreover, the production system can be controlled to produce biomass of different composition even using the same algal specie. The different fractions have been shown to be usable in different applications such as fuels, paper fillers, animal feed, or fertilizers, and with suitable processing two or more products can be produced at the same time.

3.2 Barriers

3.2.1 Lack of low cost land with access to water, CO_2 and cheap nutrients

The production of microalgae requires water, carbon and nutrients. Large scale commercial production using the open pond design would also require large land areas. These requirements all are not necessarily available within economic distance from each other. CO_2 (e.g. from fluegas) and nutrient rich wastewaters are commonly found near each other in industrial locations. They are also often located near municipalities and thus land availability at low cost is not guaranteed. On the other hand, where land is available (e.g. non-arable and therefore also inexpensive), the other needed streams are often not close by. Technologies supporting CO_2 purification from flue gas for longer distance transportation, or low land footprint cultivation are thus needed.

3.2.2 Low overall technology development level and up-scaling

Overall microalgal production processes, even though they have a long history of development, are still generally at the R&D stage. Some of the process technologies which are being demonstrated and scaled up are not technologically challenging, but the high cost of current technological solutions drives R&D to search for lower cost options. Moreover, certain processing steps still have challenges, such as prevention of contamination in open pond cultivation, evaporation in open pond cultivation or prevention of overheating in photobioreactors in warm conditions or low cost harvesting and dewatering of algal biomass. When combining the controlled, laboratory-proven cultivation with real world wastewaters and natural conditions, case specific solutions are required and the exact same overall solution might not function in all cases.

3.2.3 Harvesting and down-stream processing of algae are very energy intensive

Separating microalgae from water is challenging due to two factors: 1) algae grow in very dilute systems and 2) they are very small. Especially algal species which use sunlight as energy source need to be cultivated in dilute conditions to enable light penetration. The harvesting processes proposed often combine different technologies to lower the energy requirement of the process. In addition, certain technological approaches (e.g. solvent extraction of lipids from algal biomass, or drying the residual biomass based products for better storage properties) require high amounts of energy.

3.2.4 Algal strain diversity and specie applicability to different wastewaters

Even though the high number of naturally occurring algal species is an advantage, it is also a great challenge: in principle there exist several species in many different natural environments that might function in industrial applications. The identification of the exact specie most suitable for the available waste streams and targeted compounds/fractions to be produced in high amounts needs significant effort. Moreover, the flexibility and tolerance of different algal species towards different wastewaters is not very high and this makes the search for the best specie for specific cases even more difficult.

3.2.5 CO_2 availability

The CO_2 capture potential of algae is considered one of the main drivers of the sector, however the availability of CO_2 is also a significant barrier. Clean CO_2 to be dissolved in the growth medium is not available in large quantities without purification. For example power plant flue gases contain large amounts of nitrogen oxides and potentially harmful compounds that should be removed prior to their use in algal cultivation. On the phenomena level, CO_2 availability for the microalgae in the water is also constrained by the water-gas CO_2 balance and CO_2 dissolution rate. Adding the CO_2 to the water requires energy.

3.2.6 Overall cost of production

The majority of the required processing steps in algal production systems involve processing very high volumes of water compared to the final dry product's production rate. Therefore unit investment costs are very high except in the case where the scale is optimized. Furthermore, variable production costs are high due to the energy requirement. Benefits from potential side-products can offset part of the costs but often they incur additional costs and their value might not be very high.

3.2.7 Competition with other technologies

Several bioenergy technologies are either under development or being implemented around the world. E.g. jatropha-based biodiesel and 1st generation bioethanol production are both targeted as transportation fuels from plants grown on arable land. Both these alternatives have currently lower production costs than algal cultivation. On the other hand, they use land that is also useful for food production. Cellulosic ethanol and synthetic diesel production from lignocellulosic materials are, even though still in the R&D stage, have been developed further than microalgal-based energy systems. A clear competitive edge of microalgae over the other technologies is their significantly faster biomass growth rates, compared to plants, and therefore smaller land requirement per ton of biomass produced.

4. Economic drivers and barriers

Figure 3 shows the identified economic factors affecting the development of algal biofuel production.

Economic drivers	India imports majority of its oil
	Increasing crude oil prices and rising energy prices
	Demand for high-value bio-based products
	Government funding
	Amount of labour
	Large domestic market
	The potential for small production units
Economic barriers	High cost of nutrients
	Expensive down-stream processes
	Mismatch of locations
	High cost of production
	Technology development funding
	The suitability of algae species is very case specific
	Subsidy issues

Figure 3. Economic drivers and barriers.

4.1 Drivers

4.1.1 India imports the majority of its oil

Relaying on the import of fossil fuel is a relevant bioenergy developing driver for many countries. For any country, energy security is very important. Bioenergy carriers provide various alternatives, which would contribute to increased energy security. Bioenergy carrier production could also create more jobs locally and increase the gross domestic product. Algae can be one source of oils together with other solutions such as jatropha or palm oil.

4.1.2 Increasing crude oil prices and rising energy prices

In a situation with high oil prices the production of products with similar applications will become more attractive. Hence, if the price of crude oil will continue to increase in the future possibilities for algal-based energy production will open. This will probably take place even if technology development would not succeed in lowering price of production significantly. Furthermore, in an Indian context, where both GDP and quality of living are rising, a small increase in energy price will probably not lower the overall demand. The current rather high crude oil price is also a good motivator to boost research in the sector of alternative energy sources.

4.1.3 Demand for high-value bio-based products

Residue algal biomass, above all the potentially high value polysaccharides and proteins, represent typically 10–50% of defatted microalgae. Industries that could utilize algae based, high-value products include for instance the food industry, pharmaceutical industry and chemical industry. In these fields non-bulk products can be sold with good margins if the product qualities are unique and/or the brand is widely recognized. These products include for example food supplements, medicines and specialty chemicals. High-value by-products fit well to small-scale production, but production at very large-scale may create market oversupply problems and lower the prices. This could happen for example if algae are produced for biodiesel production and one of the by-products is produced in large quantities and it is a high-value pharmaceutical product with a limited demand. One solution in such cases could be to produce several different by-products from that specific alga biomass fraction. This however requires additional investments in various different production technologies.

4.1.4 Government funding

At the moment the Indian government and its agencies have several programs that provide funding for algal research. Public research generally results in open information that is available to all interested. This will provide a good basis for further development in the field of algae, in both private and public sectors. In addition, private companies are also carrying out their own research and development activities in this field. In the long-run when the solutions of this field are financially profitable the government's role can and should be reconsidered.

4.1.5 Amount of labour

A population of well over one billion provides a large work force. However, if the level of automation is very high in algal production and the field is not very labour intensive for down-stream processing processes, there is a risk that jobs are provided mainly for people with a certain educational level. On the other hand, when considering small-scale systems that involve manual work, algal solutions may have a more significant effect on employment in rural areas.

4.1.6 Large domestic market

India has a huge home market. This means that algal business could become a very large industry in India alone. However, the opportunity for exporting may evolve as well quite soon for niche products (higher value compounds) that are targeted to a very small target group.

A large domestic market usually means a rather homogenous zone in regard to taste and legislation for instance. Therefore, there is not much need for the producer to modify the products or offer more variants. In addition, a huge market also means that there is a demand for a wide variety of products in different price ranges. This is important when considering branding issues. Bulk products and low-value products may be sold without a specific brand or at least without major branding efforts. High-value products on the other hand need a good brand image and marketing efforts. This applies especially to food and pharmaceutical products.

4.1.7 The potential for small production units

Algae-based energy products can (also) be produced in rather small production units. This results in some benefits. Smaller units are usually easier and quicker to modify than large units and therefor can be adapted if, for example, a market change requires immediate actions. Further, the economy of small scale, production can increase by integration with other businesses e.g. fish farming.

4.2 Barriers

4.2.1 High cost of nutrients

Algal production requires nutrients. Commercial nutrients are generally costly and therefore alternative nutrient sources are also needed. In fact, wastewater is a very good source of nutrients and using algae for wastewater treatment is actually a win-win situation. A common view is that an integrated system that combines algal production with some other beneficial activity, like wastewater treatment or CO_2 capture, is a promising set up at least for now. In this kind of solution, at least part of the algal production costs would be covered by fees collected from the wastewater or CO_2 source. Alternatively, an industrial site that needs wastewater treatment or aim for a lower carbon footprint through CO_2 capture could construct its own algal-based solutions and either produce the algae-based end products by itself or outsource these activities.

4.2.2 Expensive down-stream processes

Commercial scale production of algae is still quite far away. Producing oils and/or high value products from the residual biomass demands large investments in production facilities and technology. The company producing the algae can either produce the end products itself or try to find a suitable partner for the down-stream processing. To avoid high transportation costs the facilities of the partners should be co-located and their capacity should be aligned.

4.2.3 Mismatch of locations

Even though there is plenty of land in India, it may be difficult to find a piece of land that is located in a place where wastewater treatment, for instance, could take place. A common problem especially in urban areas is that production units are located in industrial areas with no extra space between the buildings. On the other hand, on coastal areas, there is a lot of non-arable land, but less factories or suitable municipal wastewater sources. When considering the whole supply chain, the next operators should also be located within a reasonable distance; so in fact there are quite many operators that should be located in a favourable manner.

One additional challenge is the land cost. Prices have been increasing in the past 5–7 years and the price increase is likely to continue in the future due to increasing population and economic development. Land prices vary a lot depending on location, availability of water and availability of transportation access. Data on prices is hard to obtain (Milbrandt & Jarvis, 2010). It might also be difficult for a foreign company to buy land in India, except from the rural areas where land ownership is, on the other hand, divided between many small farmers, which This may lead to challenges with, e.g. language and dealing with many landowners. Having a local partner might be necessary.

4.2.4 High cost of production

High production costs are especially problematic with bulk products, such as oil based products, where the producer cannot affect the market price. In these situations the only way for profitable production is to lower the production costs below the market price. At this moment the production costs of many algal products well exceed the possible market price, so there is a clear need for further development and support for first demonstrations Besides technological development there are also other means for lowering production costs, for example using economies of scale is one of these. Larger production units generally result in lower unit costs.

4.2.5 Technology development funding

Currently some of the technologies needed are expensive and only large companies or institutions can afford to purchase these for further development. As discussed above, the needed investments and production costs are so high that even the large players are not willing to take the necessary steps. Many of the technologies can be demonstrated at lab or pilot scale, but full or market scale demonstration is too expensive and financially risky without external support. Further, it may be that although one solution works well in lab conditions, it may not work at all at pilot scale when algae are exposed to natural conditions. One opinion was that small-scale experiments should be kept minimal and that one should move to pilot, or preferably even large scale, as soon as possible to find out whether the solution is suitable for production at a commercially meaningful scale.

4.2.6 The suitability of algae species is very case specific

The best algal species for a certain purpose depends on the climate conditions (sunlight, temperature) and water. This can mean that solutions successful in one environment are hard to duplicate. This is a great challenge, since an algal based solution that is working, for instance for water treatment purposes, in one place may not work so well in a different location due to differences in wastewater, inhibitory or varying loads. So a selection process has to be carried out separately for each location. On the other hand, this can also be considered to be an advantage for the pioneers of the field. The solutions they have created for a certain location cannot be copied directly by competitors. Therefore patenting may not be needed for all solutions, which means that solutions can be implemented faster and more time can be used for the actual solution development work.

4.2.7 Subsidy issues

Some algal operators are hoping for government incentives to help boost their development and to lower the gap between production costs and market prices. Other operators in the field, at the same time, indicate that the operations have to be market driven and operation has to be profitable without government subsidies. They also argue, that a common problem with government subsidy policies (worldwide) is that they may strongly guide the markets and they may also be changed every now and them, which creates other challenges, such as inconsistent and unpredictable markets. When considering the international operating environment and an emerging new industry, such as algal solutions, the differences between government subsidy policies may have a great impact on where the large international players build their production units.

5. Algae-based energy in India – roadmap

The many factors that affect the future of algae-based energy business in India create possibilities for SMEs, but also set limits for the schedule of business creation. This roadmap (Figure 4) is formulated as a vision for **Profitable algal energy business for Finnish SMEs**, which should be achievable within the next 15 years.

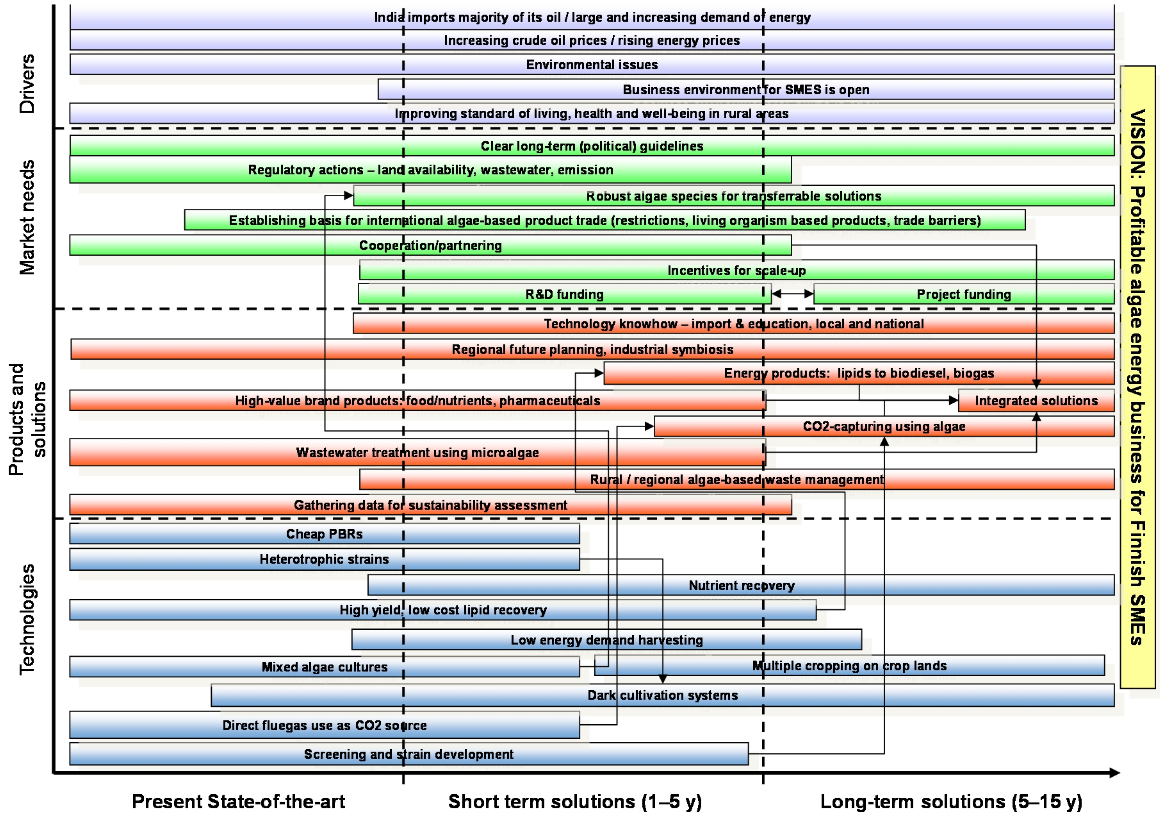

Figure 4. Algal energy roadmap in India – Opportunities for Finnish industries and SMEs.

5.1 Drivers

The overarching drivers for algal-based energy production in India include the same factors as in the rest of the world: fossil-fuel-based energy prices are increasing and more sustainable forms of energy are needed. Specific to India is India's dependence on imported oil and the increasing demand for transportation fuels and other energy products, which create a drive toward alternative energy sources that are sustainable. Moreover, in order to enhance the standard of living, more work places are needed especially in rural areas. In both the short and long term, the response to rapidly increasing demand and huge markets for energy in India will provide space for foreign actors also. Moreover, the many possible forms of algae-based energy systems also enable strong involvement of SMEs in the business.

5.2 Market needs

Regulations and guidelines are currently being planned at national and regional levels. R&D is being carried out in collaborations, including many different actors and public funding. However, both will need more encouragement and investment if rapid implementation of the solutions and technologies by companies is to occur. Moreover, since technological development is still mainly at the laboratory or pilot scale and many of the targeted energy products have huge markets, the first scale-up projects to demonstration and commercial scale will need public support. There is also a clear need for robust concepts that can be implemented in many locations with only slight adaptations.

5.3 Products and solutions

Many products and solutions complement each other and support the vision for algal energy. Solutions which pave the way for algal-based energy systems include regional planning that considers options for industrial symbiosis, data gathering that generates a systematic evaluation of different alternative energy systems, and enhancement of knowhow at local and national levels. For the medium and long term, clear market-driven solutions should be developed separately for wastewater treatment and general regional waste management, for CO_2 capture and for energy products. When these are demonstrated their integration will have a significantly higher chance of success, since the implementation risks will have been reduced. Depending on the production scale, an integrated system might also be the basis for business, but in this case the business risks will need significant support from local, regional and national stakeholders. One important solution, which complements the energy sector, is the production of high value products as by-products. This approach is already utilised in the oil industry, in which a major part of the income is generated through chemical and plastic by-products whereas the main volume of products is in the form of energy products. All these solutions require both technology and service providers, in addition to education and communication at many levels of the society.

5.4 Enabling technologies

The relatively lower economic performance of algal-based energy products compared to for example, bioethanol or biodiesel production from crops is to some extent a result of technological immaturity. Technological R&D currently focuses on identifying solutions, including photobioreactor (PBR) design and operation as an alternative for pond-based systems which require large areas of land , use of flue gas as source of CO_2 without lowering the CO_2 concentration and removal of other gas components, low energy harvesting methods, and development of strains for both mono and mixed cultures. These enabling technologies are not expected to be fully developed in the very near future but specific solutions are expected to be found in the medium and long term, especially in countries where substantial financial support is available. Specific technological solutions are expected, for example in development of strains that are more resistant to untreated flue gas and which therefore enable targeted CO_2 capture systems to be built. Moreover, species that can survive in various water and climate conditions should be identified. This will enable companies to develop business with lower costs during the development phase and a faster implementation phase. Another enabling technology which will benefit from strain development and selection is nutrient recovery. This has impacts on both the environmental performance and economics.

Specific targets for all technological development are low construction costs and low energy demand, but not all of the proposed solutions currently have sufficient business-driven motivation without government subsidies and support.

6. Conclusions and recommendations

A roadmap for small and medium size companies in an algal-based energy context in India has been developed, based on barriers and drivers identified by Indian stakeholders and analysed by experts. The roadmap is generic in the sense that many of the steps can be executed also by large companies. Several paths forward can be identified based on the roadmap: in general, development is needed on enabling technologies and mechanisms which support scale-up. These both lead to implementation of products and solutions and they create an environment for both large and smaller companies to make business.

The realisation of the roadmap pathways naturally depends on the business environment. Assuming, for example, that the price of oil is rather stable and technological breakthroughs take place slower than anticipated, then the main focus of algal-based energy systems could be on rural and integrated solutions. In rural areas algal-based solutions can be used for small-scale waste treatment and energy production. This could be, for instance, wastewater treatment to generate more biomass for a biogas plant or treatment of organic waste for fertilizer purposes. In remote locations, with limited access to electricity and where fossil fuel transportation costs are high, these could be competitive solutions. This development also has a positive social impact by increasing the quality of living and, probably, also by creating work in rural areas. In this field the development occurs with public support and production costs in simple systems are not very high, so there is definitely also room for small companies.

In integrated solutions, algae are used for multiple purposes and the business potential for SMEs is dependent on multiple factors. Technological solutions should be suitable for many purposes and climate conditions and the production site should be logistically well located. Economic feasibility is also increasing constantly because of technological developments concerning algal growth elsewhere. Local, regional and governmental support can also be used to enable this development process. Financial support is in most cases needed for developing the market uptake of technologies at the pre-commercial phase, as is the case with algae cultivation.

If on the other hand radical changes occur in the business environment, a wider application range for algal-based energy systems is possible. This would occur, for instance, if there is a significant increase in the price of oil or a worldwide environmental policy is agreed, or some very significant technological breakthrough occurs. Specific products or solutions in such a case include large scale lipid production for transportation fuel purpose, or fluegas CO_2 capture. These kinds of developments would completely change the current profitability and cost estimates to favour alternative energy sources, including among others algal-based energy systems. In such a scenario the most likely operators would be Indian and foreign large oil corporations that would have the capital needed for commercial scale production facilities and resources and funds for faster R&D. Moreover, there would be a lower actual need for government subsidies, either for initial investment of for the product itself. The opportunities for SMEs are also larger compared to the slower development scenario: not only large scale systems benefit from the change but also smaller scale, local waste management oriented systems benefit. Further, SMEs which provide e.g. technologies suitable for large scale systems, would have a larger market.

Opportunities for Finnish SMEs in the algal energy field of India are not different from SMEs from any other country. The operating environment in India is open and market entry for foreign companies is therefore technically easy. However, a local partner makes market entry faster and easier and it helps in creating a contact network and getting the necessary customer contacts. The roles for Finnish SMEs with the most potential would be in project management, project funding management, execution of specific (technological) parts of the project, or special component manufacturing. It is required to have a readily developed solution if implementation is in the focus of the SME. Clearly, this type of approach will need some more years in order to have mature overall system in which the solution fits, and it is logical to partner with other, Indian or other, developers to achieve this goal.

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References

Aradhey, A. 2013. India Biofuels Annual 2013. USDA Foreign Agricultural Service [cited 16.12.2013]. Available at: http://gain.fas.usda.gov/Recent%20GAIN%20Publications/Biofuels%20Annual_New%20Delhi_India_8-13-2013.pdf.

Arora, V. 2013. Energy Statistics 2013. Central Statistics Office, Ministry of Statistics and Programme Implementation, Government of India [cited 4.12.2013]. Available at: http://mospi.nic.in/mospi_new/upload/Energy_Statistics_2013.pdf.

Central Water Commission, Ministry of Water Resources. 2011. India: Country Paper on Water Security [cited 10.12.2013]. Available at: http://www.indiaenvironmentportal.org.in/files/file/Water%20Report%20-INDIA.pdf.

Chanakya, H., Mahapatra, D., Ravi, S., Chauhan, V. & Abitha, R. 2012. Sustainability of Large-Scale Algal Biofuel Production in India. Journal of the Indian Institute of Science, Vol. 92, No. 1 [cited 16.1.204]. Available at: http://journal.iisc.ernet.in/index.php/iisc/article/view/23/23.

Demirbas, M. 2011. Biofuels from Algae for Sustainable Development. Applied Energy, Vol. 88, Iss. 10, pp. 3473–3480. Available at Science Direct database of Elsevier: http://www.sciencedirect.com/science/article/pii/S0306261911000778.

FAOSTAT. 2011. Land use database [cited 12.12.2013]. Available at: http://faostat.fao.org/site/377/default.aspx#ancor.

Khan, S., Rashmi, Hussain, M., Prasad, S. & Banerjee, U. 2009. Prospects of Biodiesel Production from Microalgae in India. Renewable and Sustainable Energy Reviews, Vol. 13, Iss. 9, pp. 2361–2372. Available at Science Direct database of Elsevier: http://www.sciencedirect.com/science/article/pii/S1364032109000860.

Kaur, R., Wani, S., Singh A. & Lal, K. 2013. Wastewater production, treatment and use in India [cited 28.1.2013]. Available at: http://www.ais.unwater.org/ais/pluginfile.php/356/mod_page/content/111/CountryReport_India.pdf.

Mildbrandt, A. & Jarvis, E. 2010. Resource Evaluation and Site Selection for Microalgae Production in India. National Renewable Energy Laboratory [cited 9.12.2013]. Available at: http://www.nrel.gov/docs/fy10osti/48380.pdf.

Ministry of Environment and Forests, Government of India. 2010. Greenhouse Gas Emissions: 2007 [cited 3.12.2013]. Available at: http://moef.nic.in/downloads/public-information/Report_INCCA.pdf.

Ministry of New & Renewable Energy, Government of India. 2009. National Policy on Biofuels [cited 10.12.2013]. Available at: http://mnre.gov.in/file-manager/UserFiles/biofuel_policy.pdf.

Ministry of Statistics & Programme Implementation, Government of India. 2013. Key Indicators of Employment and Unemployment in India, 2011–12 [cited 28.12.2013]. Available at: http://pib.nic.in/newsite/erelease.aspx?relid=96641.

Ministry of Rural Development. 2010. Wasteland Atlas of India [cited16.12.2013]. Available at: http://www.dolr.nic.in/wasteland2010/wateland%20Introduction-%20forword%20.pdf.

Papola, T. & Sahu, P. 2012. Growth and Structure of Employment in India - Long-Term and Post-Reform Performance and the Emerging Challenge. Institute for Studies in Industrial Development [cited 2.12.2013]. Available at: http://isidev.nic.in/pdf/ICSSR_TSP_PPS.pdf.

Planning Commission, Government of India. 2013. Agriculture and Rural Development [cited 15.1.204]. Available at: http://planningcommission.gov.in/hackathon/index.php?sector=Agriculture_and_Rural_Development.

Population of India 2013. 2013. [cited 16.12.2013]. Available at: http://www.populationofindia.info/.

Priyadarshani, I., Sahu, D. & Rath, B. 2011. Microalgal Bioremediation: Current Practices and Perspectives. Journal of Biochemical Technology, Vol. 3, Iss. 3, pp. 299-304. [cited 20.1.2014]. Available at: http://www.jbiochemtech.com/index.php/jbt/article/viewFile/JBT3326/pdf_35.

The World Bank. 2012. India: Issues and Priorities for Agriculture [cited 2.1.2014]. Available at: http://www.worldbank.org/en/news/feature/2012/05/17/india-agriculture-issues-priorities.

UNEP Finance Initiative. 2009. Chief Liquidity Series Issue 1 Agribusiness [cited 16.1.2014]. Available at: http://www.unepfi.org/fileadmin/documents/chief_liquidity1_01.pdf.

von Braun, J., Gulati, A., Hazell, P., Rosegrant, M. & Ruel, M. 2005. Indian Agriculture and Rural Development [cited 16.12.2013]. Available at: http://www.ifpri.org/sites/default/files/publications/ib35.pdf.

Zafar, S. 2013. Biodiesel Program in India – An Analysis. Bioenergy Consult [cited 16.12.2013]. Available at: http://www.bioenergyconsult.com/tag/national-policy-on-biofuels/.

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Title	**Algal energy roadmap in India** **Opportunities for Finnish industries and SMEs**
Author(s)	Eemeli Hytönen, Ari Jussila & Sari Kuusikunnas
Abstract	Use of microalgae as a biofuel source has many advantages, as is acknowledged worldwide. Many countries are eager to offset carbon dioxide emission and develop indigenous and sustainable energy sources, especially countries which are dependent on imported energy. The relatively high growth rate and ability of microalgae to sequester carbon dioxide are main factors driving the development of future algal based biofuels. Microalgae also have potential to be a more sustainable source of energy, compared to other crops such as rapeseed or oil palm and lignocellulose. This results partly from the fact that algae can be cultivated on wasteland and the cultivation does not need fresh water but instead lower-quality water such as saline or wastewater can be used. This also leads to the possibility of wastewater bioremediation, since microalgae are able to utilize nitrogen and phosphorus from wastewater and absorb some heavy metals. Rising energy prices and increasing global energy demand are key driving forces for alternative energy solutions. Algal-based energy is one of the options being considered, but at the moment the production costs are significantly higher than the market price of energy. However, there are many ways to narrow this gap. Developing more efficient production technology is one way to achieve this goal. Integrated solutions, for example obtaining essential, expensive nutrients from wastewater, is another. Furthermore, if algae can be used to produce some high-value products or by-products as well, the operation could already be profitable. To support the development of algal energy, government subsidies are in place, however market-driven development of the industry is important. Currently microalgae are not cultivated at commercial scale for energy purposes only. There are however many companies and research institutes developing solutions to all of the main challenges. This report presents the findings of a roadmap work carried out in 2013 based on interviews with Indian experts and VTT expert workshops. The roadmap target is the potential role of Finnish SMEs in algae-based energy system in India.
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