

Algae production for energy and foddering

Attila Bai · Péter Jobbágy · Emília Durkó

Received: 6 April 2011 / Revised: 9 June 2011 / Accepted: 13 June 2011 / Published online: 1 July 2011
© Springer-Verlag 2011

Abstract This study not only presents the results of our own experiments in alga production, but also shows the expected economic results of the various uses of algae (animal feed, direct burning, pelleting, bio-diesel production), the technical characteristics of a new pelleting method based on literature, and also our own recommended alga production technology. In our opinion, the most promising alternative could be the production of alga species with high levels of oil content, which are suitable for utilization as by-products for animal feed and in the production of bio-diesel, as well as for use in waste water management and as a flue gas additive. Based on the data from our laboratory experiments, of the four species we analyzed, *Chlorella vulgaris* should be considered the most promising species for use in large-scale experiments. Taking expenses into account, our results demonstrate that the use of algae for burning technology purposes results in a significant loss under the current economic conditions; however, the utilization of algae for feeding and bio-diesel purposes—in spite of their innovative nature—is nearing the level needed for competitiveness. By using the alga production technology recommended by us and described in the present study in detail, with an investment of 545 to 727 thousand EUR/ha, this technology should be able to achieve approximately 0–29 thousand EUR/ha net income, depending on size. More favorable values emerge in the case of the 1-ha (larger) size, thanks to the significant savings on fixed costs (depreciation and personnel costs).

Keywords Algae · Bio-diesel · Animal feeding · Torrefied pellet · Sludge management · *Chlorella*

1 Introduction

Storage and handling of liquid manure on animal farms is compulsory, but these waste management activities are rather expensive tasks for such businesses. For the purification of waste water and various animal slurries, several experiments have recently been conducted by means of microalgae, which have demonstrated that microalgae are able to handle this problem at a high level of efficiency and in a profitable way [1–5]. In spite of this, the share of use of alga-based purification of waste water in practice is small, and the use of waste heat and flue gases (in case of cogeneration technology) are difficult problems to solve in the relatively few domestic agricultural biogas plants. This latter problem is the same for other types of power plants using renewable or fossil materials. Moreover, algae would theoretically be capable of replacing the total volume of oil, and they use materials for growth which are created as by-products in other technologies. These materials are otherwise mostly wasted (waste heat) or have explicitly harmful effects (carbon dioxide, nutrients in waste water). Among the currently applied technologies in Hungary, the use of open-pond technology could be troublesome because of the periodic (limited to the summer period) production and contamination (other species of algae can appear and proliferate), while the photobioreactor (PBR) technologies have high investment and operating costs.

Algae-based bio-diesel production in Hungary has yet to be applied. International tendencies show that the most promising alternative from environmental and economic

A. Bai (✉) · P. Jobbágy · E. Durkó
Faculty of Applied Economics and Rural Development
(UD-FAERD), Centre for Agricultural and Applied
Economic Sciences, University of Debrecen,
Debrecen, Hungary
e-mail: abai@agr.unideb.hu

viewpoints is the production of second-generation bio-fuel from algae species with high levels of oil content, which are suitable for utilization as by-products for animal feed and in the production of bio-diesel, as well as for use in waste water management and as a flue gas additive. In addition, algae production for feeding or burning purposes may also be considered (Fig. 1).

The seaweed meal is used mainly as a protein concentrate and is usually fed to livestock in the proportion of 20% of the total ration by weight by farmers in certain parts of the USA [7], so it could be a source of significant savings in foddering.

Among bio-fuels, the conventional bio-pellet market has gained a significant worldwide share over the last decade. Recently, over 12 million tons of wood pellets was used in the EU alone, and this trend is growing continuously, thanks to not only the effort to reduce greenhouse gas emissions, but also to the rising prices of oil and natural gas. The innovative new product for this purpose could be the torrefied pellet, which has several advantages over the conventional pellet [8, 9]:

- Moisture content is lower than that of wood pellets.
- Has a significantly higher calorific value than wood pellets.
- High bulk density, giving transport advantages.
- Energy density is nearly twice as much as that of bulk wood pellets.
- Torrefied pellets are hydrophobic and more stable in storage.
- Production and delivery costs are significantly lower than in the case of wood pellets.

Torrefaction is a thermo-chemical treatment without oxygen that incinerates biomass in the 200°C to 300°C range and low particle heating rates (<50 K/min) with a long residence time (>1 min). When co-fired with conven-

tional coal, no additional infrastructure such as separate storage or pulverization equipment is required, and it is virtually pollution free [10].

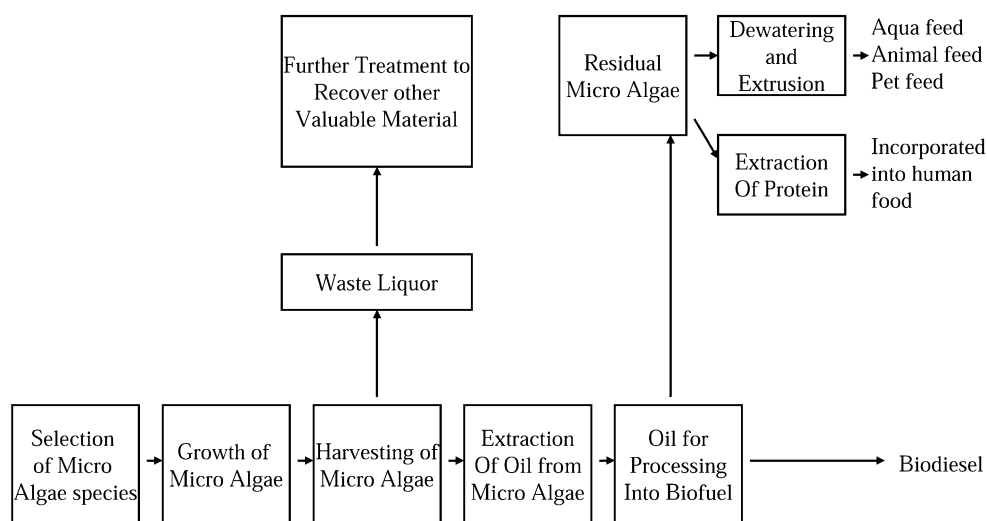
Production of torrefied pellet has mainly qualitative and logistical advantages compared to the conventional pellet. In addition, both the investment and the operating costs are lower than conventional pyrolysis. In the world today, there are eight pilot plants making torrefied pellet, so it may be therefore characterized as being truly innovative. Therefore, we decided to include this type of pellet in our calculation as a basis for comparison.

The purpose of our study is to show the results of our own alga production experiments, the expectable economic results of the various utilization forms (animal feed, combustion, pelleting, bio-diesel production), and also the technical characteristics of using the alga production technology recommended by us. Our goal was to establish a cost effective and environmentally friendly complex technology for pig sludge treatment and feeding primarily for those pig farmers who are open to applying new technologies.

2 Materials and methods

During 2009 and 2010, a series of four different laboratory and one outdoor experiments were performed, in order to develop an alga production technology which can be established and operated much more securely and over a longer growing season than the open-pond process, but which has much less capital investment needs than PBR technology. To this aim, the laboratory and outdoor experiments were carried out using four algae species (*Chlorella vulgaris*, *Scenedesmus quadricauda*, *Scenedesmus dimorphus*, *Spirulina platensis*). The reason why we selected these species was that we needed such a species which has

Fig. 1 Detailed process of energy from algae [6]



excellent characteristics in one of the main nutritive content (protein, lipid, carbohydrate) for our multi-purpose comparative analysis (between feeding, bio-diesel, burning).

Using our results, a complex economic assessment was also performed. Based on the results of our laboratory experiments, we found that whole liquid pig manure is completely unsuitable for algae production on a large scale. Rather, only diluted or filtered liquid pig manure may be used. Our results have shown that higher nutrient concentrations and additional CO₂ can result in higher yields, the protein content of the biomass considerably increased, the lipid content remained practically at the same level, while the carbohydrate content showed significant reduction. In the present study, two experiments were used as benchmark data.

The parameters of our indoor experiment 1 performed to compare the yields and nutritive values of the alga were as follows:

- 77 to 126 mg/100 ml of vaccine solution.
- Illumination, 4,500 lx, 18 h/day (Based on the researches of Ghezelbash et al., the maximum yield can be expected at this level of light intensity [11], and Seyfabadi et al. adjust illumination also on a similar scale (100 photons/m²/s ~5,000 lx) in their examinations [12]).
- Temperature, 24°C.
- Aeration, 100 l/h.
- 5-l (20 cm in diameter) pot.
- Diluted liquid manure, 25%, 10%, 5%, 1% solution. The original pig manure contained 12.5% organic matter, 4,880 mg/l nitrogen, 2,968 mg/l phosphorus, and 2,969 mg/l potassium, which is much thicker than the typical animal sludge (300 mg/l nitrogen, 100 mg/l phosphorus, 260 mg/l potassium, [13]). Application of dilution was necessary for study of the effect of transillumination.
- Carbon dioxide enrichment, ad libitum feeding and zero at all settings.
- Fertilizer solution diluted in four ways, two repetitions in each case.

To be able to make a comparison with the traditional plants and to demonstrate the yield-raising effects of CO₂, we also converted the previously presented yield results into tons per hectare per year values. We calculated with 30- and 50-cm water depths. The first value is ideal for mixing technology, while according to our literature-based hypothesis, the second value should be optimal for aeration technology. The obtained yield results apply to a 200-day-long growing season.

Having the previous experiment data, we wanted to determine whether the analyzed pilot species were capable of achieving the previous yield levels in a larger-size

experiment. For this reason, the experiments were performed using manure-free solutions which contained the appropriate nutrient elements. Parameters of experiment 2 compared to those of the previous experiment were as follows:

The same parameters:

- 77 to 126 mg/100 ml of vaccine solution.
- Illumination, 4,500 lx, 18 h/day.
- Temperature, 24°C.
- Indoor conditions.

Different parameters:

- 12-day-long measurement interval (June 28–July 10, 2010).
- 70-l-size tanks, 20-cm water depths.
- No fertilizer and carbon dioxide dosing, 500 ml of nutrient solution was added instead (two repetitions for each species).
- Moderate aeration, 50 l/h.

Based on the results of the laboratory tests, experiments with *C. vulgaris* were also performed at a larger scale and under outdoor circumstances. The objective was to achieve realistic yield and technological figures, which can be expected to occur when applying large-scale technologies. During the experiments, we also examined how the aeration and nutrient supply affected the yield, since these expenses can significantly influence the economics of production. The experimental parameters were all different from the circumstances of the previous laboratory experiments:

- Larger dose of vaccine than for the previous tests, 3.84 g/500 ml (*C. vulgaris*).
- 28-day measurement interval (from July 9 to August 6, 2010).
- A repetition for each variable (three levels of nutrients, two types of aeration, a total of 12 tanks).
- 1,000-l tanks, 500 l of water, 30-cm water depth.
- Natural illumination (14–15 h/day).
- Outdoor temperature (17–29°C daily average temperature; min. 14°C; max. 35°C; 28-day average, 24.5°C).
- No added manure and carbon dioxide; instead, we used 250-, 500-, and 1,000-ml nutrient solutions.
- Moderate aeration (50 l/h) or without aeration variants.

For the limited length of the present study, we could not introduce the results of all five experiments.

There are two kinds of approaches to determine the value of non-marketable products: the first is the method of deducting from the marketable end-product, and the second is the method based on the so-called replacement value [14]. With the help of the previous nutritive values, we also examined the changing of the yield figures in the case of the analyzed species and the methods of treatment and

utilization. To determine the feeding value, the following prices were used [15]:

- Protein, 0.64 EUR/kg (0.28 EUR/kg soybean meal price, 43% protein content)
- Vegetable oil, 0.92 EUR/kg (sunflower oil)
- Carbohydrate (starch), 66 EUR/kg (46 EUR/kg maize, 70% starch content)

The algae fuel values were calculated with the following basic data (Table 1). The theoretical calorific values of algae for the calculation of unit values are:

- Combustion heat of protein, 24 GJ/t
- Combustion heat of lipid, 39 GJ/t
- Combustion heat of carbohydrate, 17 GJ/t
- Average rate of heating value and calorific value, 0.9
- Calorific value of algae with 10% water content compared to that of 0%, 0.88

3 Results and discussion

Based on our previously presented laboratory experiment 1, we obtained the yield and nutritive values shown in Table 2, converted to tons per hectare values. The revenue mostly depends on the change of the oil yield without a radical restructuring of the price conditions, while the carbohydrate yield increases the revenues the least. The actual price ratios can be slightly modified by the substitute materials, but without any change in their order. This does not mean that the production of high oil content alga species would be the most promising in all circumstances, since profitability is influenced by the adaptability and the production cost of the various species.

With the help of the different nutritional values and their prices, we can determine the theoretical (ad valorem) price of 1 t of algae (Table 3), which is obviously the highest in the case of the algae with high oil content and depends largely on the method of utilization, as well.

When assessing competitiveness and using our proposed technology, which is introduced later, depending on the plant size, the prime cost can be estimated between 400 and 510 EUR/t in the case of *C. vulgaris*. Based on literature sources [18, 19], the technology cost of torrefied pellet production can be estimated between 36 and 55 EUR/t, while the total costs of extraction and esterification should

be 73 to 91 EUR/t [20]. Taking these costs into account, the results show that the use of algae in burning technology results in a significant loss under current economic conditions. However, the use of algae for feeding and bio-diesel purposes—in spite of their innovative nature—has nearly become competitive. If a sufficient number of livestock are locally available and the goal is to use minimum capital investment, then the algae should be used for feeding by all means. In principle, the nutritive value of the *Scenedesmus* species is the most valuable for both purposes; however, their production is the most risky. Except for this species, the available data suggest that the production of oil and bio-diesel would not be economical. However, if the market—either in the form of edible oil or in the form of bio-diesel—recognized the unique quality of algae oil at a higher price (minimum 0.65 to 0.73 EUR/l+VAT), these alternatives may already be quite attractive. Utilization for heating purposes can be primarily considered as a kind of loss elimination if the number of animals does not allow for the production of algae biomass to be used up entirely, and, optimally, the algae biomass could replace the on-site need for natural gas.

To choose the appropriate alga species, experiments had been carried out. The 1-day average yield results of the 5-l manure dilution breeding solutions (experiment 1) and those of the 70-l algae fertilizer solution (experiment 2) can be seen in Table 4.

Results for the three species did not differ greatly from the average of the previous experiments, but the yields of *C. vulgaris* exceeded the other three's results by 64%. This success is mainly thanks to the high adaptability of this species. The other species are considered less favorable, not only in terms of their yields, but also in terms of their susceptibility to contamination.

The data obtained made it clear that it is *C. vulgaris* which should be primarily applied in large-scale experiments if our goal is to produce larger and more consistent amounts of biomass. It should be noted, however, that if we are to produce vegetable oil, the use of the *Scenedesmus* species should be considered. In spite of their lower biomass yield, this species produced such amounts of lipid which exceeded the oil weight of the *Chlorella* species (Table 4, last column). When producing the *Scenedesmus* species, the main task should be to avoid contamination by other species, because the *Scenedesmus* species are less dominant, and the final result would therefore be a mixed

Table 1 Main economic characteristics of the substituted products of algae for heat energy [16]

Substituted product	Unit price 1	Unit price 2	Calorific value
Natural gas	14.97 EUR/GJ	0.51 EUR/m ³	34 MJ/m ³
Coal	8.28 EUR/GJ	0.15 EUR/kg	18 MJ/kg
Wood pellet	10.39 EUR/GJ	0.22 EUR/kg	21 MJ/kg

Table 2 The yield of test alga species, quantity, and quality (tons per hectare) [17]

Species, treatment	Average yield (t/ha) ^a		Protein %	Lipid %	Carbohydrate %
	30-cm depth	50-cm depth			
<i>Chlorella vulgaris</i>	76	127	19.9	20.2	59.9
<i>Chlorella vulgaris</i> + CO ₂	151	252	32.3	22.2	45.5
<i>Scenedesmus quadricauda</i>	81	134	10.9	36.9	52.2
<i>Scenedesmus quadricauda</i> + CO ₂	166	277	25.7	35.8	38.5
<i>Scenedesmus dimorphus</i>	53	89	8.7	50.1	41.2
<i>Scenedesmus dimorphus</i> + CO ₂	118	197	20.2	50.9	28.9
<i>Spirulina platensis</i>	44	74	26.6	9.1	64.3
<i>Spirulina platensis</i> + CO ₂	86	144	35.8	10.2	54

The maximum value of that category is italicized

^a 200-day growing period, in 1% dry matter solution

and less valuable culture instead of a *Scenedesmus* culture. Because of the risk of contamination and other uncertainties of plant production in open field conditions, our outdoor experiments were performed with *C. vulgaris*. Based on the results of these outdoor experiments, the following conclusions can be made:

- Nutrition supply has a significant yield-increasing effect up to the optimum point, while the aeration level brings only moderate and uncertain growth.
- Temperature changes during the measurement period (17–29°C) practically did not affect the reproduction of the algae, so no yield reduction can be expected during the summer months.
- In the case of the 12-day-long period, the application of a medium-level nutrition supply with no aeration can be recommended. This will bring a higher yield in alga production until the 14th or 15th day, compared to the variants with much higher expenditures (aeration, more intensive fertilization).
- Larger systems have better adaptability and a capability to neutralize temperature fluctuations and other harmful effects. As a result, the annual average yield in all but one case of our measurements varied between 202 and 311 t/ha. The 230-t/ha yield level in our economic

calculations can be considered a typical and safely reachable value.

3.1 The proposed technology for alga production

After the experiments clearly demonstrated that alga yield and the effectiveness of other inputs were very much influenced by luminescence, light must then be guaranteed as one of the major factors influencing the treatment of liquid pig manure. In our opinion, light should be provided by sedimentation and filtration, and not with dilution, due to the enormous need for water and environmental concerns, as well as a significant increase in the size of the technology. We propose a three-stage filtration system with a 1-day-long retention time in each settling vessel whose capacity is slightly higher than the daily amount of sludge in the pig farm of the case study. By adding some nutrients to those remaining in the filtrate, the proper nutrient supply of algae could be guaranteed. The defecated and filtered material with high dry and organic content can be most practically utilized as a kind of organic fertilizer for direct nutrient supply, but this is suitable for even anaerobic fermentation processes. One part of the filtrate used for alga production (the liquid phase) can be returned to the pig

Table 3 Ad valorem price for the test species of algae with different methods of utilization (euros per ton)

Species	Feeding	Burning			Algae oil methyl-ester and feed
		Natural gas	Wood pellet	Coal	
<i>Chlorella vulgaris</i>	440	273	189	153	491
<i>Chlorella vulgaris</i> + CO ₂	498	291	200	160	556
<i>Scenedesmus quadricauda</i>	502	309	215	171	596
<i>Scenedesmus quadricauda</i> + CO ₂	553	320	222	178	647
<i>Scenedesmus dimorphus</i>	571	342	236	189	702
<i>Scenedesmus dimorphus</i> + CO ₂	622	356	247	196	753
<i>Spirulina platensis</i>	400	251	175	138	425
<i>Spirulina platensis</i> + CO ₂	444	262	182	145	469

The maximum value of that category is italicized

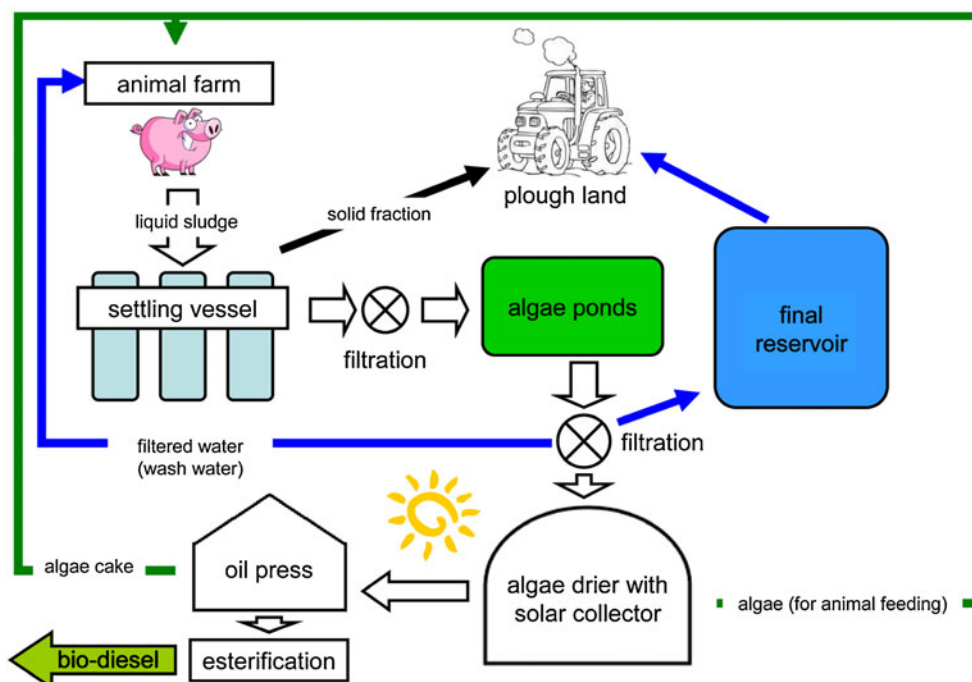
Table 4 The daily average yields during the laboratory experiments (grams per cubic centimeter) [17]

Species	2010 fertilizer solution				2009	2010	Difference	2010
	25%	10%	5%	1%	Average	Solution	%	Lipid
<i>Chlorella vulgaris</i>	134	209	164	127	158	260	64	47
<i>Scenedesmus quadricauda</i>	140	236	209	134	180	164	−9	48
<i>Scenedesmus dimorphus</i>	116	206	159	89	143	153	8	51
<i>Spirulina platensis</i>	92	167	142	74	119	101	−15	15

The oil yield was calculated by the 2010 oil yield multiplied by the average oil content of the 2009 experiments at 50-cm water depth. Unlike Table 2, we did not measure the effect of CO₂ because the direct goal of this experiment was to determine the most promising algae species for the outdoor (case study in pig farm) experiments where CO₂ was unavailable for us

farm technology; another part goes to the reservoir. The examined *C. vulgaris* produced on liquid manure is recommended to be utilized as animal feed. Further examinations are required to determine the maximum proportion of the algae mixed into the feeds of different groups of animals. However, we cannot exclude the possibility that—in the case of sharp oil price rises—after the extraction of oil from the algae, only the remaining biomass (with less lipid content) would be used for feeding. We adapted our tests to the Monergo Ltd. pig farm (size of alga pond, 0.216 ha), which participated in our experimental project, but we designed the test for the 1-ha size, as well. The flowchart of our proposed technology can be studied in Fig. 2. It can be mentioned that Sevrin-Reyssac developed a system operating by similar principles in the 1990s; however, he integrated zooplankton ponds and fishponds with algae ponds [21].

The pig manure from the animal farm goes through triple sedimentation. The material remains in a settling tank for 1 day and is introduced to the alga ponds after an additional 3 days. The sludge with low dry matter content is re-cleaned with a wine filter before introduction. The size of the ponds with a water depth of 50 cm (which does not block transillumination) allows the processing of the entire amount of sludge which accumulates on the pig farm. The ponds are oval-shaped, each equipped with a ventilator of proper capacity, which primarily starts and maintains mixing. We want to extend the vegetation period and to avoid contamination by foreign matter and algae species into the ponds by using a plastic foil system built over the ponds, which is partially opened in summer. The filtration of the alga content in the ponds—similar to the filling process—takes 2 days, using special filtration equipment. Subsequently, the algae with high water content would be placed into a drier, which

Fig. 2 The flowchart of planned cultivation

would dry the harvested algae to the optimal dry matter content, preferably with the help of solar energy and a ventilator. Then, the water released from the ponds and purified of algae is returned to the farm buildings in a pipeline and will replace the wash water. The remaining liquid fraction is transferred into the final reservoir and can be used on plow land, similar to the solid fraction stored in the sedimentation tanks. The dried algae (depending on algae species, animal stock, and the algae processing capacity) are either directly used to feed the livestock or, after the extraction of the oil content, are utilized as cooking oil or, after esterification, as a next-generation bio-diesel. The residue (algae cake) is re-utilized as animal feed. The expected economic indicators of the technology are introduced in Table 5.

Considering the economic conditions in 2010 and the most probable cost/revenue trends, the operating of the alga plantation (0.216 ha) is likely to reach a break-even point in the tested pig farm. However, if we calculate with a 1-ha

plantation, there are significant savings in relation with two cost items (depreciation and personnel costs). Since these two cost items are determining in the cost structure, the different size would mean a difference of almost 29,100 EUR/ha. Additionally, there is a great difference in terms of profitability. As it is an experimental technology, the break-even point without subsidies cannot be considered as a very bad result, since it ensures a return on invested assets within the calculated lifetime. The annual cash surplus of 14,200 EUR in the case of a smaller size (or 76,000 EUR is available in 1 ha size) will contribute significantly to stabilizing the financial position of the investor.

The investment needs and the operation costs are many times more than the cost of conventional crops, but this can be a problem only during the establishment phase, because (1) the actual expenses are only half of the costs and (2) these can keep returning, as the harvesting of the alga lakes occurs every second day.

Table 5 The expected economic indicators of the algae plant

	Unit	0.216 ha	Percent	1 ha	Percent
Production cost					
Algae vaccine	EUR/a	727	2.8	3,367	3.6
Fertilizer (supplementary)		2,924	11.2	13,535	14.6
Personnel costs		5,804	22.2	17,411	18.8
Electricity		1,873	7.2	8,669	9.3
For production		1,091	4.2	5,051	5.4
For harvesting/storage		782	3	3,618	3.9
Amortization		13,600	51.9	45,331	48.9
In production		6,658	25.4	22,193	23.9
In harvesting/storage		6,942	26.5	23,138	25
Other costs		1,247	4.8	4,415	4.8
Total cost		26,175	100	92,731	100
For production		18,451	70.5	65,975	71.1
For harvesting/storage		7,724	29.5	26,760	28.9
Prime cost	EUR/t	527		404	
Specific cost per 1 m ³ of sludge	EUR/m ³	1,869		1,429	
Investment cost	EUR	162,211	100	540,673	100
For production		78,589	48	261,945	48
For harvesting/storage		83,622	52	278,727	52
Revenues/savings					
Algae yield	t/a	404		404	
Ad valorem price	EUR/t	20,051		92,836	
Yield value	EUR/a	2,440	75	11,295	75
Feed cost saving		4,175	9	19,327	9
Wash water saving		26,665	16	123,458	16
Total revenues/Savings		491	100	30,727	100
Net income		404		404	
Cash flow balance (without tax)		20,051		92,836	
Profitability by costs	%	−2		33	
Profitability by fixed assets (ROE)		0		6	

Source: own calculations based on own experimental data and 2010 Hungarian economic conditions. Considered main characteristics in case study (0.216 ha). Costs: algae ponds, 8×280-m² surface with 50-cm depth suitable for disposal of 70-m³/day filtered liquid pig sludge; 200 days vegetation period yearly; 1.8 t algae vaccine; 2,379 kg nitrogen and 2,518 kg phosphorus fertilizer per year (17 rotations); one full-time worker; 7.5 kW electric capacity with differential utilization (20–100%); amortization period, 2–33% depending on type of fixed assets; incomes, 50-t/year saving in feeding in value (replacement values detailed in Sect. 2.1); additional cost saving in the case of substitution of soya bean used in the pig farm in the case study (18EURc/kg protein); 2,800-m³/year savings in cleaning water in the pig farm

The dominant share of the operational costs is production costs, but in case of investment cost, the production and the harvesting/storage require about the same amount of financial sources. Further processing of the algae would significantly change the cost and investment structure, as well.

4 Conclusions

Based on the alga experiments we conducted during 2009 and 2010, the following was determined:

In our opinion, the most promising alternative among the various alga production technologies could be the production of alga species with high levels of oil content, which are suitable for utilization as by-products for animal feed and for producing bio-diesel, as well as waste water management and as a flue gas additive.

According to the results of our experiments, *C. vulgaris* should be recommended for large-scale technology. The yield results of this alga species surpassed the results of other species by 64% in large-scale circumstances. This result is mainly owing to the high adaptability of this species. The other species showed much less favorable results, not only in terms of their yields, but also the extent of contamination. For all these reasons, the field experiments had been carried out with this alga species, and our recommended technology is based on this species.

Taking the costs into account, our results show that the use of algae for burning purposes can be considered as a loss-minimizing possibility under current economic conditions, if the number of animals does not allow the use of the entire amount of the produced alga biomass and, preferably, if natural gas could be replaced by it. However, the use of algae for animal feeding and bio-diesel—despite its innovative nature—is nearly competitive.

The alga production technology recommended by us and presented in detail in this study is capable of generating 0–29,000 EUR/ha net income with an investment of 545,500 to 727,300 EUR/ha, depending on size. The case study (0.216 ha) results show that an annual cash flow surplus of 14,200 EUR (or 76,000 EUR in the case of 1-ha size) will contribute significantly to stabilizing the financial position of the investor. The prime cost of dry alga biomass is estimated at 400 to 510 EUR/t.

The investment and operation costs are many times more than the cost of conventional crops, but this can be a problem only during the establishment phase, because (1) the actual expenses are only half of the costs, and (2) these can keep returning, as the harvesting of the alga lakes occurs every second day. Our results may be of interest primarily for those pig farmers who would like to combine the waste management of their plants and the reduction of

feed costs with energy production, assuming they are open to applying new technologies.

References

1. Wilkie AC, Mulbry WW (2002) Recovery of dairy manure nutrients by benthic freshwater algae. *Bioresour Technol* 84 (1):81–91. doi:10.1016/S0960-8524(02)00003-2
2. Kim J, Lingaraju BP, Rheume R, Lee JY, Siddiqui KF (2010) Removal of ammonia from wastewater effluent by *Chlorella vulgaris*. *Tsinghua Science and Technology* 15(4):391–396. doi:10.1016/S1007-0214(10)70078-X
3. Lim SL, Chu WL, Phang SM (2010) Use of *Chlorella vulgaris* for bioremediation of textile wastewater. *Bioresour Technol* 101 (19):7314–7322. doi:10.1016/j.biortech.2010.04.092
4. González LE, Cañizares RO, Baena S (1997) Efficiency of ammonia and phosphorus removal from a Columbian agro-industrial wastewater by the microalgae *Chlorella vulgaris* and *Scenedesmus dimorphus*. *Bioresour Technol* 60(3):259–262. doi:10.1016/S0960-8524(97)00029-1
5. Mulbry W, Kondrad S, Pizarro C, Kebede-Westhead E (2008) Treatment of dairy manure effluent using freshwater algae: algal productivity and recovery of manure nutrients using pilot-scale algal turf scrubbers. *Bioresour Technol* 99(17):8137–8142. doi:10.1016/j.biortech.2008.03.073
6. Narsi S (2011) Oilgae comprehensive report. A detailed guide for algae biofuels. www.oilgae.com/ref/report/report.html. Accessed 8 June 2011
7. Sambamurthy AVSS (2005) A textbook of algae. I K International, New Delhi
8. Bergman P C A, Kiel J H A (2005) Torrefaction for biomass upgrading, ECN report, ECN-RX-05-180 doi:www.ieabcc.nl/meetings/task32_Berlin_ws_system_perspectives/03_Kiel.pdf. Accessed 8 June 2011
9. Prins MJ, Ptasiński KJ, Janssen J (2006) More efficient biomass gasification via torrefaction. *Energy ECOS 2004—17th International Conference on Efficiency, Costs, Optimization, Simulation, and Environmental Impact of Energy on Process Systems* 31 (15): 3458–3470 doi:10.1016/j.energy.2006.03.008
10. Peng JH, Bi HT, Sokhansanj S, Lim JC, Melin S (2010) An economical and market analysis of Canadian wood pellets. *Int J Green Energ* 7(2):128–142. doi:10.1080/15435071003673518
11. Ghezlbash F, Farboodnia T, Heidari R, Agh N (2008) Biochemical effects of different salinities and luminance on green microalgae *Tetraselmis chuii*. *Research Journal of Biological Sciences* 3 (2):217–221. doi:10.3923/rjbsci.2008.217.221
12. Seyfabadi J, Ramezani Z, Khoeyi ZA (2010) Protein, fatty acid and pigment content of *Chlorella vulgaris* under different light regimes. *J Appl Phycol*. doi:10.1007/s10811-010-9569-8
13. Nábrádi A (2002) Fertilization management. In Bai (ed) Use of biomass. Szaktudás, Budapest, pp. 30–37
14. Nábrádi A (2007) The economic value of grassland products. *APSTRACT* 1(1):19–28. doi:ageconsearch.umn.edu/bitstream/43572/2/a2.pdf
15. Molnár Zs, Pájtli P, Keresztessy MK (2009) Cereals and industrial plants. Agriculture market report. https://www.aki.gov.hu/download/gabona_07_17_pdf/483. Accessed 8 June 2011
16. Barka E, Bartha T, Halmai O, Szabó T, Vigassy Cs (2010) Annual Report. Hungarian Energy Office. http://www.eh.gov.hu/gcpdocs/201012/tajekoztato_2009_web.pdf. Accessed 8 June 2011
17. Stündl L, Bársony P, Herpergel Z, Fehér M (2010) in Bai A (Ed) Complex economic analysis of our algae experiments including a case study. Final study of the project titled “Development of algae production in animal sludge for energy and feeding. Economic

- modelling” (ATEBIOEN, 2009–2010). Baross Gábor Research Program. Debrecen, pp. 1–73
18. Kiel J H A, Verhoeff F, Gerhauser H, Meuleman B (2008) BO₂-technology for biomass upgrading into solid fuel-pilot-scale testing and market implementation. Energy Research Centre of the Netherlands (ECN). <http://www.ecn.nl/docs/library/report/2008/m08036.pdf>BO₂
 19. Németh A (2009) Economic and technological review of biomass conversion technologies and economic feasibility analysis of torrefied pellet production in Hungary. MSc thesis, Wageningen University
 20. Narsi S (2010) The algae energy industry. Opportunities and prospects. Oilgae Digest. www.oilgae.com/ref/report/digest/digest.html#k_t_aways. Accessed 8 June 2011
 21. Sevrin-Reyssac J (1998) Biotreatment of swine manure by production of aquatic valuable biomasses. *Agr Ecosyst Environ* 68(3):177–186. doi:[10.1016/S0167-8809\(97\)00070-4](https://doi.org/10.1016/S0167-8809(97)00070-4)