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Photofuel - Biocatalytic solar fuels for sustainable mobility in Europe

Deliverable D6.4

Financial Evaluation

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1 Introduction

This report summarizes the cost assessment for the Photofuel project. More specifically, it analyses the profitability of producing butanol with algae. It also describes all the process that would be needed for the growth of microalgae and all the equipment that it involves.

The cost assessment has been based on inputs from Photofuel members and from the techno-economic study on microalgal biomass production from the University of Florence.

The results present the profitability of this kind of facility for several productivity of algae. A "low productivity" (50 mg/l/d) and "high productivity" (600 mg/l/d) cases have been considered. The report also gives the production cost of biomass and butanol that makes the results comparable to literature.

The last section analyses possible scaling-up for the Photofuel biorefinery from a two hectares plant (base case analyzed all through the study) to two bigger sizes: 10 hectares and 100 hectares.

2 Process description

The process is the one developed by the Karlsruher Institut für Technologie (KIT) for the LCA-study and consists in 8 Unilayer Horizontal Tubular PhotoBioReactor (UHT-PBR), because it presents better areal productivities than the conventional tubular PBR (MHT-PBR) and provides significant advantages in terms of CAPEX and OPEX savings. Figure 1 shows a detailed process flow chart.

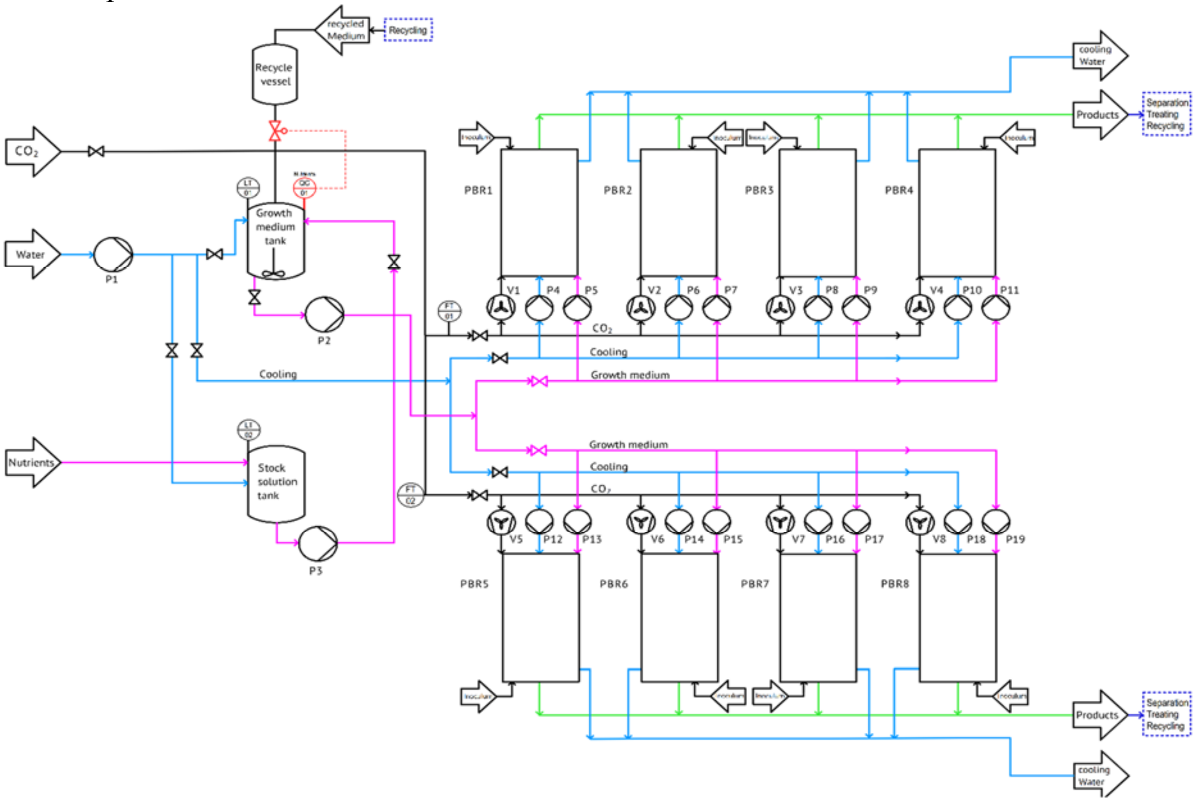


Figure 1 : Process Flow Chart

Each part and equipment of the process will be described in the following sections.

2.1 The photobioreactor

The process flow for each PBR cultivation system follows the same sequence:

1. Inoculation of a 1.3 m^3 Pre-Inoculum UHT-PBR (16 m^2 area) with the inoculum from 6x 20 L flasks (laboratory);
2. Inoculation of a 18.0 m^3 Pre-Production UHT-PBR (245 m^2 area) with the inoculum from the Pre-inoculum PBR;
3. Inoculation of a 97.5 m^3 Production UHT-PBR (2435 m^2 area) with the inoculum from the Pre-production PBR.

The characteristics of each reactor are detailed in the table 1 below:

Table 1: Photobioreactor characteristics

	Inoculum	Preproduction	Production
Number of tubes per module	4	16	96
Tubes length (m)	33	110	176
Tubes external diameter (cm)	6.5	6.5	6.5
Distance between each tube (cm)	8	8	8
Module volume (m3)	1.3	18	97.5
Total reactor surface (m2)	16	245	2435
Total volume (m3)	10.4	144	780
Total surface (hectare)	0.01	0.2	2

Each reactor has a volume of 97.5 m3, a 2 hectare plant consists of 8 units hence the total reaction volume of the photofuel facility is 780 m3.

2.2 Air and flue gas supply

The carbon dioxide necessary for the photosynthetic process is provided by air and gas bubbling. Each module is equipped with a 7.5 kW three lobe blower in order to supply flue gas to the PBRs. A main pipeline of decreasing diameter delivers the flue-gas to the modules.

2.3 Culture cooling and circulation

The cooling is handled by seawater (assumed to be available at close distance from the plant at an average temperature of 20 °C) which is filtered (60µm pore size) and then pumped through the heat exchanger and then back to the sea by means of two submersible pumps using a dedicated pipeline in polyethylene.

Heat transfer from culture to cooling water is obtained by circulating the culture through the heat exchanger by means of an open impeller 3.75 kW centrifugal pump.

The flow rate of the cooling seawater is regulated by the control system, which acts on the frequency inverter of the submersible pumps in function of the cooling needs and besides opens/closes the inlet valve of the modules.

2.4 Culture harvesting

The plant is equipped with two centrifugal separators the open impeller pumps described in the previous section are used to daily withdraw part of the culture from the PBR and feed one of the separators through a dedicated pipeline.

Wastewater treatment costs were not considered as we assumed that the exhausted medium contains negligible amounts of nutrients and that, after centrifugation, suspended solids and organic load in the exhausted medium are below the thresholds for discharge in the sea according to national and regional regulations.

2.5 Growth medium preparation

Nutrients (technical grade fertilizers containing nitrogen and phosphorus) are daily added to the cultures according to productivity and the nitrogen and phosphorus content of the biomass. A concentrated nutrient stock solution is prepared in two HDPE 2.5-m3 tanks and delivered to the growth medium tank (a 50-m3 galvanized steel tank lined with a PVC membrane for insulation) by means of a 0.75 kW centrifugal pump. Natural seawater is pumped by means of one of the submersible pumps described above to a filter (60-µm pore size) and then to the medium tank, where the growth medium is prepared and stored. One 5.5 kW centrifugal pump is then used to transfer the growth medium from the tank to a filter (1-µm pore size) and then to the modules through the dedicated pipeline.

2.6 Parameters control and data storage

An industrial PLC system continuously measures and regulates pH and temperature of the cultures by activating the different valves and by regulating the rotational speed of the submersible pumps, of the blowers and of the frequency-controlled circulation pumps.

Each module is also provided with a paddlewheel flow-meter for measuring cooling water consumption. Two thermal mass flow-meters, installed on the main flue-gas pipeline, measure total flue-gas consumption.

3 Assumptions

In order to establish the profitability of direct, solar fuel production, few technical hypotheses have been made:

- Construction period : one year starting in 2019
- Plant total operating time : 20 years
- Plant yearly operating time : 360 days
- Plant utilization rate in first year (2020): 90%
- The plant must be located in a country with enough solar radiation. The country that has been chosen is Portugal.

3.1 Methodology

The costs of the process were divided into capital (CAPEX) and annual operating costs (OPEX). Contingencies and decommissioning costs were not considered. The sum of OPEX and calculated total fixed capital costs per annum was divided by the annual biomass productivity to obtain the cost of 1 kg (dry weight) of biomass. A detailed description of the incurred capital and operating costs is reported below.

3.2 CAPEX Calculation

Total fixed capital is related to the erection of the industrial site itself. Also referred as “capital expenditures” (CAPEX), fixed capital constitutes the fraction of the capital investment which is depreciable.

In the next sections the costs “year1” represent the expenditures required in 2019 for the construction of the plant. The “total” costs represent the CAPEX needed afterwards since some equipment will have to be changed during the facility lifetime.

The sections 3.1 to 3.4 present the “direct costs” which are costs that can be completely attributed to the production of biomass.

3.2.1 Production modules

Each of the eight production modules is composed of polyethylene (PE) tubes, of air and flue gas sparger tubing and of some other minor equipment (Screws, nuts, bolts, etc.). Since PE needs to be changed every year, it is considered as OPEX. The costs of the reactors are detailed in the table 2.

Table 2 : Production modules cost decomposition

Equipment	Unit	Unit cost (€)	Quantity for one module	Cost year1 (€)	Lifespan (years)
PE Culture Chamber*					
Inoculum	m	0.2	132	211	1
Preproduction	m	0.2	1 760	2816	1
Production	m	0.2	16 896	27 034	1
Air/flue-gas sparger tubing					
Inoculum	m	0.4	132	422	5
Preproduction	m	0.4	1 760	5 632	5
Production	m	0.4	16 896	54 067	5
Screws, nuts, bolts, etc.					
Inoculum	-	-	-	22	20
Preproduction	-	-	-	334	20
Production	-	-	-	3 300	20
Cost production modules (year 1) (€)				**63 778**	
Total cost production modules (€)				**284 361**	

**considered as OPEX*

3.2.2 Machines and equipment

The section *Machines and equipment* is composed by 4 different items, all mentioned in the process description section: the pumps, the heat exchangers, the centrifugal separators and the filtration systems. Their costs are detailed in the table 3.

Table 3 : Machines and equipment cost

Equipment	Unit	Unit cost (€)	Quantity required	Cost year 1 (€)	Lifespan (years)
10 kW submersible pump	Pump	18 480	2	36 960	10
7.5 kW three-lobe blower	Blower	5 300	8	42 400	20
3.75 kW circulation pump	Pump	2 750	8	22 000	10
5.5 kW centrifugal pump	Pump	1 668	1	1 668	10
0.75 kW centrifugal pump	Pump	442	2	884	20
7.5 kW centrifugal separator	Separator	56 000	2	112 000	25
Heat exchanger	Exchanger	16 224	8	129 792	10
Filtration system for air/flue-gas	Filtration system	2 600	8	20 800	10
Filtration system + UV for seawater	Filtration system	10 000	1	10 000	10
Cost machines and equipment (year 1) (€)				**376 504**	
Total cost machines and equipment (€)				**489 032**	

3.2.3 Piping, fittings and valves

This section groups the cost of piping, fittings and valves which are required for the cooling, the culture circulation, the culture harvesting, the culture medium preparation and supply and for the dispatch of air and flue gas. Their costs are detailed in the table 4.

Table 4: Piping, fittings and valves cost

Equipment	Cost year 1 (€)	Lifespan (years)
Fitting and valves		
Cooling	19 164	20
Air/flue gas	72 431	20
Culture circulation	110 464	10
Culture harvesting	11 888	20
Culture medium preparation and supply	17 832	20
Piping		
Cooling	62 775	20
Air/flue gas	65 259	20
Culture harvesting	37 248	10
Culture circulation	2 794	20
Culture medium preparation and supply	3 522	20
Cost Piping, Fittings and valves (year1)		**403 376**
Total cost Piping, Fittings and valves (€)		**583 436**

3.2.4 Other direct costs

This section groups the equipment that cannot be integrated in one of the previous categories: the tanks, the electrical equipment and the laboratory. Their costs are detailed in table 5.

Table 5 : Other direct costs

Equipment	Cost year1 (€)	Lifespan (years)
Tanks		
Recycle Vessel	6 660	20
Growth Medium Tank	16 650	20
Stock Solution Tank	1 665	20
Butanol Tank	16 650	20
Cost tanks (year1)		**41 625**
Total cost tanks (€)		**41 625**
Electrical Equipment		
Gas and liquid flow-meters	29 328	10
Inverters	10 400	10
Electrical cabinets, wiring, PLC and control system	233 000	25
Cost Electrical equipment (year1)		**272 728**
Total cost Electrical equipment (€)		**321 156**

Laboratory	50 000	-
Cost Laboratory (year1)		**50 000**
Total cost laboratory (€)		**50 000**

3.2.5 Indirect costs

Indirect costs are costs that are not accountable to a cost object and not directly related to production. They are often defined as a share of the direct cost. For the photofuel facility, we defined four indirect costs: taxes & insurance, engineering & supervision, installation, and land.

Table 6 : Indirect cost

Indirect cost	Value	Cost year1 (€)
Engineering & Supervision	5% of total direct cost	60 400
Installation	10% of total direct cost	120 801
Taxes and Insurance	1% of total direct cost + Land	14 080
Land	-	200 000
	Total Indirect Cost (year1)	**395 282**
	Total Indirect cost (€)	**485 138**

3.2.6 Working capital

Working capital is defined as the funds, in addition to the total fixed capital, that a company must contribute to a project. Those funds must be adequate to bringing the plant into operation and meeting subsequent obligations. It is here defined as one month of operating cost which is equal to 33 180 €.

3.2.7 Summary

Table 7 summarizes all major capital costs discussed thus far, from the design and erection of the industrial site to plant startup. This table also includes the working capital.

Table 7 : Summary of CAPEX

Investment	Cost year 1 (€)	Total Cost (€)
Direct Cost	1 208 011	1 769 610
Indirect Cost	395 282	485 138
Increase in Working capital	33 830	33 830
Total CAPEX	**1 636 473**	**2 288 578**

Overall capital requirement for the project is estimated at **2 288 578 €** and 72% of the CAPEX is spent during the first year (1 636 473€)**.**

3.3 OPEX Calculation

This section details all ongoing costs required for the production of products. Also referred as operational expenditures (OPEX), these encompass costs associated with the plant operation, selling of products, and contribution to corporate functions (e.g., administration and R&D activities).

3.3.1 Labor

The plant have been designed so as to minimize manpower, thus several operations have been automatized. However, plant maintenance and algae cultivation still require a great deal of human skill and practice. Six employees with different roles and retributions are required to operate the facility. These are a plant supervisor responsible for work coordination, a biologist responsible for monitoring all aspects related to cultivation (culture health, formulation of the growth medium, determination of harvesting time, nutrient replenishment, etc.) and four workers in charge of growth medium preparation, harvesting, culture sampling and routine analyses, ordinary and extraordinary maintenance, and surveillance.

Table 8 : Labor repartition

Function	People required	Annual Salary (€)
Plant supervisor	1	52 000
Biologist	1	35 000
Worker	4	23 100
	Total (€/year)	**179 400**

3.3.2 Electricity

4 items need electricity: the blowers, the submersible pumps, the centrifugal pumps and the circulation pumps.

The blowers can work on two operating modes: during daytime (10 hours) the culture is bubbled at a flow rate sufficient to avoid sedimentation, ensure the desired light-dark cycle and remove the oxygen produced by photosynthesis. During the night (14 hours) the flow rate is decreased in order to limit the electrical consumption.

The circulation pumps also have two operating modes: a cooling period and a non-cooling period. When cooling is not necessary (e.g. in winter), the culture flow rates is reduce by acting on the pumps.

Based on IFPEN source, the price of power is assumed to be 0.175 €/kWh.

Table 9: Electric consumption

Equipment	Operation time (hours/year)	Hourly energy consumption (kWh)	Annual energy consumption (kWh/y)	Annual cost (€)
Blowers				
Day	3 600	30	108 000	18 900
Night	5 040	16.9	85 176	14 906
10 kW submersible pumps	2 520	15	37 800	6 615
7.5 kW three-lobe blower	3 600	9.5	34 200	5985
5.5 kW centrifugal pump	720	4.5	3 240	567
0.75 kW centrifugal pumps	720	0.94	677	118
3.75 kW circulation pumps				
Cooling Period	2 520	16	40 320	7 056
No Cooling Period	6 120	2	12 240	2 142
			Total (€/year)	**56 289**

3.3.3 Fertilizers and other consumables

Two kinds of fertilizers are used in the process: sodium nitrate ($NaNO_3$) and monosodium phosphate (NaH_2PO_4).

Other consumables include pH probes, temperature sensors and filter cartridges for air/flue-gas and seawater.

Table 10 : fertilizers and other consumables consumption

Utility	Unit	Unit cost	Quantity	Annual cost
$NaNO_3$	Tons	400	31	12 240
NaH_2PO_4	Tons	1500	2	3 000
Polyethylene	Meters	0.2	150 304	30061
Other consumables				6 980
			Total (€/year)	**52 281**

3.3.4 Indirect operating costs

Table 11 : Indirect operating costs

Indirect cost	Value	Total cost (€)
Overheads	10% of total direct operating cost	28 797
Maintenance	5% of total direct cost	60 401
Administration	10% of total direct operating cost	28 797
	Total Indirect operating Cost (€/y)	**117 994**

3.3.5 Summary

Table 12 summarizes all major operating costs discussed thus far, from the design.

Table 12 : Summary of OPEX

Direct Cost	287 970
Indirect Cost	117 995
Total OPEX (€/y)	**405 965**

Overall production cost requirement for the project is estimated at **405 965 €/year.**

3.4 Economic assumptions

3.4.1 Depreciation

Depreciation refers to the decrease in value of industrial assets with passage of time, primarily because of wear and tear. While not a true manufacturing cost, depreciation is considered to be a manufacturing expense for accounting purposes – it allows the recovery of the cost of an asset over a time period. In this study, depreciation is based on the straight-line method on the project economic life of 10 years.

3.4.2 Tax rate

As Portugal has been chosen for the project location, Portuguese income tax rate has been considered (21%).

3.4.3 Inflation

All the monetary flows calculated in the following tables are presented in nominal euros considering an inflation rate of 2.0% per year. In particular, all the investment costs, fixed and variable costs are escalated at 2.0% per year.

3.4.4 Wacc

The net cash flows during the lifetime of the project are discounted at the financial opportunity cost of capital to show project's worth. For this study, the Weighted Average Cost of Capital (WACC) is assumed to be 10%.

3.5 Production

For the study, a 1:1 biomass/butanol ratio is assumed.

Based on the inputs of Photofuel members, two productivity cases have been considered:

- A "Low Productivity" case: productivity of biomass is assumed to be 50 mg/l/d which, in the Photofuel conditions, represents 14 tons of butanol per annum.
- A "High Productivity" case: productivity of biomass is assumed to be 600 mg/l/d, which, in the Photofuel conditions, represents 170 tons of butanol per annum.

Based on IFPEN insights, the price of butanol has been set to 800 €/t.

4 Results

4.1 High productivity case

Figure 2 summarizes project's economic and financial evaluation of the high productivity case, highlighting the main profitability indicators.

Total investment cost is 2 288 578 € including working capital needs, pre-production expenditures, financial costs and inflation.

This project presents a net present value (NPV) of -4 521 028 € over its total lifetime. The revenues generated by the butanol sales (123 732€) are approximately three times lower than the operating costs of the facility (405 965 €) what makes the initial investment unrefundable.

In that scenario, most of the classic financial indicators (IRR, payback time…) are irrelevant because of the project non-profitability.

The production cost amounts 3.72 €/kg. This value is in line with other studies from literature and is even one of the most optimistic production cost value.

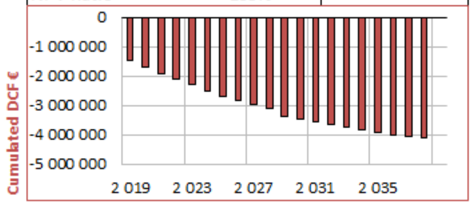
Photofuel Financial Evaluation

INVESTMENT	€
Direct Cost	1 769 610
Indirect Cost	485 138
Total overnight Cost	**2 254 747**
Increase in Working Capital	33 830
TOTAL Capital Requirement	**2 288 578**

Production cost	**3.72**

Financial Parameters

€	Total Capital
Discount Rate	10.0%
NPV after tax	-4 521 028
IRR after tax	**#N/A**
Payback	#N/A
Dynamic Payback	#N/A
NPV Ratio	-135%



Euro

Income Statement	2 020	2 021	2 022	2 023	2 024	2 025
SALES REVENUE	123 732	140 229	143 034	145 895	148 812	151 789
VARIABLE COSTS	99 667	112 956	115 215	117 520	119 870	122 267
VARIABLE MARGIN	24 064	27 273	27 818	28 375	28 942	29 521
Fixed Costs	480 303	486 370	492 558	498 870	505 309	511 876
OPERATIONAL MARG	- 456 239	- 459 097	- 464 740	- 470 496	- 476 366	- 482 354
GROSS PROFIT FRON	- 456 239	- 459 097	- 464 740	- 470 496	- 476 366	- 482 354
TAXABLE PROFIT	- 456 239	- 459 097	- 464 740	- 470 496	- 476 366	- 482 354
Income Tax	-	-	-	-	-	-
NET PROFIT	- **456 239**	- **459 097**	- **464 740**	- **470 496**	- **476 366**	- **482 354**

Figure 2 : Economic and financial evaluation – High productivity

4.2 Low productivity case

Figure 3 summarizes project's economic and financial evaluation of the low productivity case, highlighting the main profitability indicators.

This project presents a net present value (NPV) of – 5 709 625 € over its total lifetime. The revenue generated by the butanol sales (10 311€) are forty times lower that the operating cost of the facility (405 965 €) which makes the initial investment unrefundable.

In that scenario, most of the classic financial indicators (IRR, payback time…) are irrelevant because of the project non-profitability.

The production cost amounts 44.64 €/kg what let us thinks that the low productivity case could represent a pilot plant but cannot be built for commercial purposes.

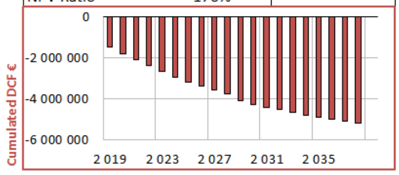
Photofuel Financial Evaluation

INVESTMENT	€
Direct Cost	1 769 610
Indirect Cost	485 138
Total overnight Cost	2 254 747
Increase in Working Capital	33 830
TOTAL Capital Requirement	2 288 578

Production cost	44.64

Financial Parameters

€	Total Capital
Discount Rate	10.0%
NPV after tax	-5 709 625
IRR after tax	#N/A
Payback	#N/A
Dynamic Payback	#N/A
NPV Ratio	-170%



Euro

Income Statement	2 020	2 021	2 022	2 023	2 024	2 025
SALES REVENUE	10 311	11 686	11 919	12 158	12 401	12 649
VARIABLE COSTS	99 667	112 956	115 215	117 520	119 870	122 267
VARIABLE MARGIN	- 89 356	- 101 270	- 103 296	- 105 362	- 107 469	- 109 618
Fixed Costs	480 303	486 370	492 558	498 870	505 309	511 876
OPERATIONAL MARGI	- 569 660	- 587 641	- 595 854	- 604 232	- 612 778	- 621 494
GROSS PROFIT FROI	- 569 660	- 587 641	- 595 854	- 604 232	- 612 778	- 621 494
TAXABLE PROFIT	- 569 660	- 587 641	- 595 854	- 604 232	- 612 778	- 621 494
Income Tax	-	-	-	-	-	-
NET PROFIT	**- 569 660**	**- 587 641**	**- 595 854**	**- 604 232**	**- 612 778**	**- 621 494**

Figure 3: Economic and financial evaluation – low productivity

5 Sensitivity analysis

Single factor sensitivity analysis is presented in a NPV diagram below. It shows that the sensitivity of the Net Present Value to an increase/decrease by 30% in key parameters - investment cost (Capex), operating costs (direct and indirect) and the butanol production (yield).

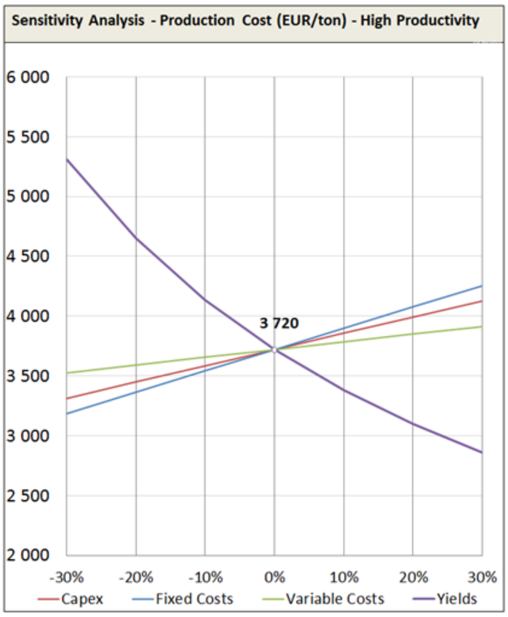


Figure 5: Sensitivity analysis for the High productivity case

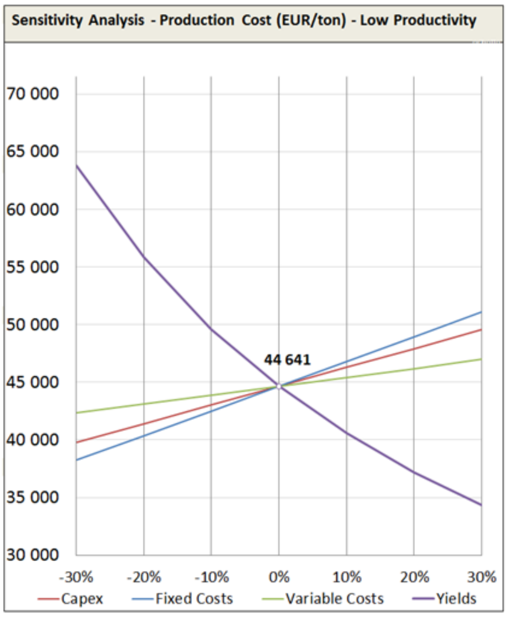


Figure 4: : Sensitivity analysis for the Low productivity case

In the high productivity case, production cost is very sensitive to the productivity of the algae. A decrease by 30% in the butanol production will increase the production cost from 3.72€/kg to 5.3€/kg (30% increase). An increase in butanol production by 30% will have a smaller impact (20% decrease).

The CAPEX and the OPEX variations have a much lower impact, an increase in 30% only increasing the production cost by a bit more than 10%.

Figure 5 and figure 4 show that the low productivity case follows the same trends than the high productivity case.

This sensitivity analysis confirms that productivity is absolutely key in the profitability of the Photofuel project. Having the most accurate production value for butanol is of major interest for assessing the viability of such structures.

6 Scale Up

Bigger facilities can induce economies of scale that would reduce the production cost and increase the profitability of the Photofuel biorefinery. Hence two other sizes of plant have been studied: a 10 hectares plant (5 times bigger) and a 100 hectares plant (50 times bigger). The scale-up factor considered for the CAPEX is 0.85.

Some other parameters have been changed:

- Since electricity is bought in much bigger quantities, a discount can be obtained. That's why the price of electricity is decreased from 0.175 €/kWh to 0.145 €/kWh (only for the 100 hectares plant).
- Similarly, the cost of fertilizers has been decreased by 30%.
- The need of manpower for the 10 hectares plant was estimated to be 1 plant supervisor, 2 biologists and 10 workers.
- The need of manpower for the 100 hectares plant was estimated to be 1 plant supervisor, 10 biologists and 40 workers.

Table 13 : Scale-up results

	2-Ha		10-Ha		100-Ha	
	Low Productivity	High Productivity	Low Productivity	High Productivity	Low Productivity	High Productivity
Investment Required (k€)	2 289	2 289	12 126	12 126	85 897	85 897
Opex (k€/year)	406	406	1 505	1 505	11 261	11 261

	2-Ha		10-Ha		100-Ha	
	Low Productivity	High Productivity	Low Productivity	High Productivity	Low Productivity	High Productivity
NPV (k€)	-5 710	-4 521	-23 895	-17 952	-169 160	-109 730
IRR (%)	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
Payback Time	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
Prodution Cost (€/kg)	44.64	3.72	37.85	3.15	27.03	2.25

The results we got for these two new sizes of plants are summarized in table 13

As expected, the production cost decreases with the size. For the high productivity case, the production cost decreases by 15% for the 10 hectares plant (3.15€/kg) and by 39% for the 100 hectares plant (2.25 €/kg). The 100 hectares plant is close to be profitable but would still need some improvements to get to a positive NPV. These statements are also valid for the low productivity case.

7 Case of pervaporation

7.1 Assumptions

All the technical and economic assumptions previously mentioned are still available in this case. High productivity is considered, as well as a 10 ha scale-up. However, the 7.5 kW centrifugal separator is replaced by a 2 stage pervaporation system, and equipment costs are detailed in Table 14.

Table 14 : Machines and equipment cost with pervaporation

Equipment	Unit	Unit cost (€)	Quantity required	Cost year 1 (€)	Lifespan (years)
10 kW submersible pump	Pump	18 480	2	36 960	10
7.5 kW three-lobe blower	Blower	5 300	8	42 400	20
3.75 kW circulation pump	Pump	2 750	8	22 000	10
5.5 kW centrifugal pump	Pump	1 668	1	1 668	10
0.75 kW centrifugal pump	Pump	442	2	884	20
Pervaporation system	Separator	4 349 100	1	4 349 100	25
Heat exchanger	Exchanger	16 224	8	129 792	10
Filtration system for air/flue-gas	Filtration system	2 600	8	20 800	10
Filtration system + UV for seawater	Filtration system	10 000	1	10 000	10
Cost machines and equipment (year 1) (€)				**4 613 604**	
Total cost machines and equipment (€)				**4 726 132**	

7.2 Results

Figure 4 summarizes project's economic and financial evaluation of the high productivity pervaporation case, highlighting the main profitability indicators.

Total investment cost is 7 293 304 € including working capital needs, pre-production expenditures, financial costs and inflation.

This project presents a net present value (NPV) of -19 891 481 € over its total lifetime. The revenues generated by the butanol sales (123 732 €) are approximately six times lower than the operating costs of the facility (760 955 €) what makes the initial massive investment unrefundable.

In that scenario, most of the classic financial indicators (IRR, payback time…) are irrelevant because of the project non-profitability, and in a much higher dimension than with the centrifugal separation.

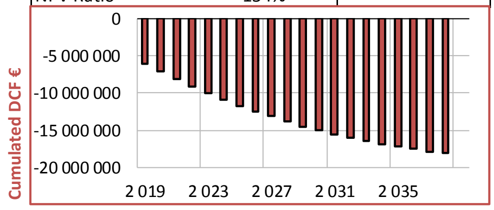
The production cost amounts 13.59 €/kg. This value is greater than many other studies from literature.

INVESTMENT	€
Direct Cost	**6 006 710**
Indirect Cost	1 163 074
Total overnight Cost	**7 169 783**
Increase in Working Capital	123 521
TOTAL Capital Requirement	**7 293 304**

Production cost	**13,59**

Financial Parameters

€	Total Capital	
Discount Rate	10,0%	
NPV after tax	**-19 891 481**	
IRR after tax	**#N/A**	
Payback	#N/A	
Dynamic Payback	#N/A	
NPV Ratio	-154%	



Euro

Income Statement	2 020	2 021	2 022	2 023	2 024	2 025
SALES REVENUE	123 732	140 229	143 034	145 895	148 812	151 789
VARIABLE COSTS	760 955	862 416	879 664	897 258	915 203	933 507
VARIABLE MARGIN	- 637 224	- 722 187	- 736 631	- 751 363	- 766 390	- 781 718
Fixed Costs	1 267 058	1 280 386	1 293 980	1 307 847	1 321 990	1 336 417
OPERATIONAL MARGI	- 1 904 282	- 2 002 573	- 2 030 611	- 2 059 210	- 2 088 381	- 2 118 135
GROSS PROFIT FROM	- 1 904 282	- 2 002 573	- 2 030 611	- 2 059 210	- 2 088 381	- 2 118 135
TAXABLE PROFIT	- 1 904 282	- 2 002 573	- 2 030 611	- 2 059 210	- 2 088 381	- 2 118 135
Income Tax	-	-	-	-	-	-
NET PROFIT	**- 1 904 282**	**- 2 002 573**	**- 2 030 611**	**- 2 059 210**	**- 2 088 381**	**- 2 118 135**

Figure 4 : Economic and financial evaluation – Pervaporation case

In a 10 ha scale-up, the results are still non-profitable with a pervaporation system. As expected, the production cost decreases with the size. For the high productivity case, the production cost decreases by 12% for the 10 hectares plant (11.93 €/kg). However, it is clearly not sufficient to be considered viable.

Table 15 : Scale-up results for pervaporation

	2-Ha	10-Ha
Investment Required (k€)	7293	33815
Opex (k€/year)	1482	6356
NPV (k€)	-19 891	-86 358
IRR (%)	#N/A	#N/A
Payback Time	#N/A	#N/A
Production Cost	**13,59**	**11,93**

8 Conclusion

The Photofuel cost assessment presents interesting results :

- The “high productivity” case has a production cost of biomass and butanol going from 3.72 €/kg (2 hectares) to 2.25 €/kg (100 hectares). This assessment is in line with major studies from literature and even propose some of the most optimistic values.
- The “low productivity” case has a production cost of biomass and butanol going from 44.64 €/kg (2 hectares) to 27.03 €/kg (100 hectares). These values show that this case cannot be viable for an industrial production. It also shows that the profitability of such a plant depends a lot on the productivity of the algae. It confirms that having the most precise value of productivity will be necessary to have the better cost assessment.
- The “high productivity” pervaporation case has a production cost of biomass and butanol going from 13.59 €/kg (2 hectares) to 11.93 €/kg (10 hectares). These values show that this case is not viable for an industrial production. Only a drastic reduction of pervaporation investment and operation costs could interestingly increase the project profitability.

It is important to keep in mind that, although this study is one of the most optimistic in terms of economic results, the plants described here are never profitable. The NPVs are very negative and the investments cannot be refund. However it proposes a new step towards profitably for algae biorefinery.

There are still some several upgrades that can be made in order to improve the profitability of the plant:

- Integrate photovoltaic power generation. It would increase the CAPEX but this would be balanced by the reduction of the OPEX.
- A more suitable location. The plant could be installed in a more suitable location where the sunlight is higher. The production of biomass should increase, but OPEX should increase simultaneously.
- Develop a thermo-tolerant strain that would require no cooling. It would decrease the power requirement and maybe the CAPEX if one of the two submersible pumps is no more necessary.

The next step for the economic analysis would be to assess the profitability of other Photofuel systems using more economic separation systems than the expensive pervaporation of butanol, such as Free Fatty Acids (FFA) or Octanol.