SWOT ANALYSES

of 20 cultivation systems for algae production for energy purposes in the NW European region

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EnAlgae
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Investing in Opportunities
This project has received European Regional Development Funding through INTERREG IV B.
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Introduction and methodology

To identify the different drivers and obstacles for sustainable exploitation of algae for energy production within NW Europe, there was a need to identify the most promising cultivation systems for production of algae for energy purposes in the region.

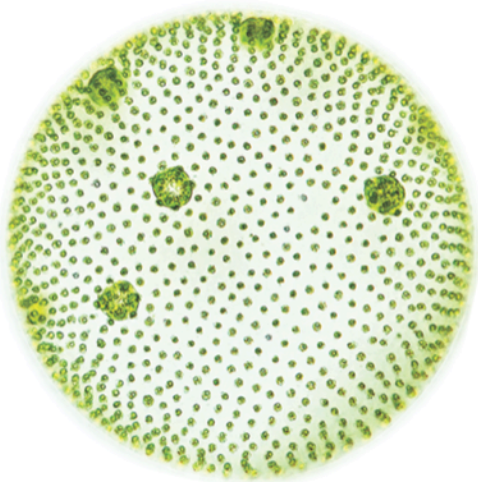
Through discussion with EnAlgae project partners, 20 promising algae cultivation systems and concepts, 16 for micro and 4 for macroalgae were identified, Each concept was assessed through a SWOT analysis. This report presents the results of the SWOT analyse.

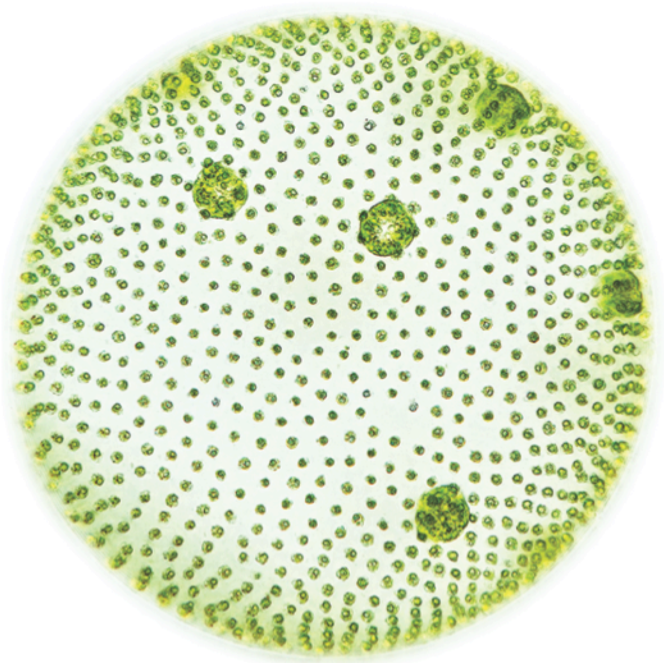
The SWOT analysis provides a snapshot of current state of the scoped technologies and the innovation system surrounding these technologies in NW Europe. It also analyzed future changes that could stimulate or raise barriers in the application of these cultivation systems.

The objective of this study was to identify the 4 most promising algae cultivation systems and concepts that could play an important role in reducing the carbon footprint of the energy sector in the region. The 4 selected algae cultivation system were then studied further using Technological Innovation System (TIS) analysis.

SIXTEEN SWOT ANALYSES

of energetic microalgae cultivation
in NW Europe..





… in open raceway ponds

Strengths

- **Salt water is available in Ireland, UK, Netherlands, France, Belgium, Germany. Fresh water is available in all 8 countries of NW Europe.**
- Use of salt water in combination to extremophile algal strains reduces contamination by nutrient competitors and algae predators[9].
- **Raceway ponds are available in pilot and commercial scale in the Netherlands (also one EnAlgae pilot), in Belgium[8] and in France.**
- **Use of polar algal strains could improve heating pond costs[2].**
- Capital costs decrease by increasing scales[1].

Weaknesses

- **LCA shows very high heat losses (low energy efficiency) for energetic algae production in open ponds. The higher the latitude the higher the losses[9].**
- Climate prescribes heating and lightning (e.g. LED lights) requirements for high productivities of algae, especially in the winter. Lighting and especially heating costs increase by geographical latitude[1].
- **Salt water is not available in Switzerland and Luxemburg.**
- **Fresh water use has economic and environmental implications.**
- Mineral nutrients are a substantial cost[1]
- **Cost of land is substantial part of investment in countries with land shortage like Luxembourg, Netherlands, Belgium, and Switzerland.**
- Algae most likely comes as a mixed culture with bacteria so it may need purification downstream that adds an extra cost.

Opportunities

- Export of biotechnology knowledge to other countries with warmer climates and higher available surface area for energetic algae cultivation[2].
- **Investments towards projects upscaling raceway pond technologies for other market products e.g. food/feed, will benefit energetic algae cultivation projects via technology transfer.**
- Algae from open ponds can be used except for energy products also for production of fertiliser, soil amendment, platform and fine chemicals.

Threats

- **Alternative biofuel production technologies are more cost effective than energetic algae and as such more attractive for investors[1].**

*Strengths & Weaknesses Performance Matrix: **Importance high**; Importance medium; Importance low*

*Opportunities & Threats Performance Matrix: **Probability/Impact high**; Probability/Impact medium; Probability/Impact low*

… in open raceway ponds using anaerobic digestate

Strengths

- Digestate will be transported over the fence by neighbouring AD industry (e.g. industrial symbiosis).
- **Extremophile algal strains reduces contamination by nutrient competitors and algae predators [9].**
- **Raceway ponds are available in pilot and commercial scale in the Netherlands and Belgium[8].**
- Capital costs decrease by increasing scales[1].
- **Use of polar algal strains could improve heating pond costs[2].**

Weaknesses

- **LCA shows very high heat losses (low energy efficiency) for energetic algae production in open ponds. The higher the latitude the higher the losses[9].**
- Climate prescribes heating and lightning (e.g. LED lights) requirements for high productivities of algae, especially in winter. Lighting and especially heating costs increase by geographical latitude[1].
- **Cost of land is substantial for investing in countries like Luxembourg, Netherlands, Belgium, and Switzerland.**
- Digestate may be contaminated by unwanted microorganisms like bacteria, so algae may need purification that adds an extra cost.

Opportunities

- **Liquid digestate from e.g. dairy manure contains all nutrients (N, P, micronutrients) algae cultivation needs and at zero cost [10].**
- **AD technology is a very popular technology spread all over NW Europe[1].**
- Export of biotechnology knowledge to other countries with warmer climates and higher available surface area for energetic algae cultivation[2].
- In addition to energy products, algae from open ponds can be for production of fertiliser, soil amendment, platform and fine chemicals.
- **Investments towards projects upscaling raceway pond technologies for other market products e.g. food/feed, will benefit energetic algae cultivation projects via technology transfer.**

Threats

- **Digestate quality must have some standards (composition, pH, colour etc.)**
- Digestate may be need to be cleaned or treated before used for algae cultivation (e.g. pH, ammonia etc.).
- **Alternative biofuel production technologies are more cost effective than energetic algae and as such more attractive for investors[1].**
- **Digestate price may rise due to market competition (currently no market price).**
- Depending on the end market, purification of products from contaminants may add an additional cost.

Strengths & Weaknesses Performance Matrix: ***Importance high****; Importance medium; Importance low*

Opportunities & Threats Performance Matrix: ***Probability/Impact high****; Probability/Impact medium; Probability/Impact low*

… in open ponds with industrial/ fossil CO_2 (Carbon Capture and Use, CCU)

Strengths

- Heat and CO_2 will be transported over the fence by neighbouring industry (e.g. industrial symbiosis).
- **Salt water is available in Ireland, UK, Netherlands, France, Belgium, Germany. Fresh water is available in all 8 countries of NW Europe.**
- Use of salt water in combination to extremophile algal strains reduces contamination by nutrient competitors and algae predators[9].
- **Raceway ponds with fossil/renewable CO_2 are available in pilot and commercial scale in the Netherlands (also one EnAlgae pilot) and Germany.**
- **Use of polar algal strains could improve heating pond costs[2].**
- Capital costs decrease by increasing scales[1].

Weaknesses

- **Climate prescribes heating and lightning (e.g. LED lights) requirements for high productivities of algae, especially in the winter. Lighting and especially heating costs increase by geographical latitude[1].**
- **LCA shows very high heat losses (low energy efficiency) for energetic algae production in open ponds. The higher the latitude the higher the losses.**
- CO_2-rich flue gas may need dilution and pretreatment before use (cost increase).
- **Salt water is not available in Switzerland and Luxemburg. Fresh water use has economic and environmental implications.**
- Mineral nutrients are a substantial cost[1]; use of minerals from wastewater would lower costs
- **Cost of land is substantial for investing in countries like Luxembourg, Netherlands, Belgium, and Switzerland.**
- Algae may be mixed with bacteria so it may need purification that adds an extra cost.

Opportunities

- **CO_2-rich flue gases have zero to date.**
- Flue gas bioremediation can be in the future eligible for government support schemes[9].
- Export of biotechnology knowledge to other countries with warmer climates and higher available surface area for energetic algae cultivation[2].
- **All NW European countries are industrially thriving and produce large amounts of CO_2 as industrial by-product (Biogas, alcohol fermentation, cement production, steel making, fossil fuel combustion).**
- Algae from open ponds can be used except for energy products also for production of fertiliser, soil amendment, platform and fine chemicals.
- **Investments towards projects upscaling raceway pond technologies for other market products e.g. food/feed, will benefit energetic algae cultivation projects via technology transfer.**

Threats

- **Alternative biofuel production technologies are more cost effective than energetic algae and as such more attractive for investors[1].**
- Algal biomass produced by CO_2 flue-gases may not be compliant to food markets (co-product to biofuels).

Strengths & Weaknesses Performance Matrix: ***Importance high****; Importance medium; Importance low*

Opportunities & Threats Performance Matrix: ***Probability/Impact high****; Probability/Impact medium; Probability/Impact low*

… in close ponds

Strengths

- **Raceway ponds are available in pilot and commercial scale in the Netherlands, in Belgium[8] and in France.**
- Capital costs decrease by increasing scales[1].
- **Use of polar algal strains could improve heating pond costs[2].**
- **Salt water is available in Ireland, UK, Netherlands, France, Belgium, Germany. Fresh water is available in all 8 countries of NW Europe.**

Weaknesses

- **LCA shows very high heat losses (low energy efficiency) for energetic algae production in close ponds (ey lower than with open ponds). The higher the latitude the higher the losses[9].**
- Climate prescribes heating and lightning (e.g. LED lights) requirements for high productivities of algae, especially in the winter. Lighting and especially heating costs increase by geographical latitude[1].
- **Salt water is not available in Switzerland and Luxemburg. Fresh water use has economic and environmental implications.**
- Mineral nutrients are a substantial cost[1].
- **Cost of land is substantial for investing in countries like Luxembourg, Netherlands, Belgium, and Switzerland**

Opportunities

- Export of biotechnology knowledge to other countries with warmer climates and higher available surface area for energetic algae cultivation[2].
- It is likely that there will be a medium value market for food or food additives (Chlorella, Dunalliela, Chlamydomonas)[1], that coupled with a integrated biorefinery could produce biofuels also (thermochemical, fermentation[3]).
- Algae from close ponds can be used except for energy products also for production of food/feed, fertiliser, soil amendment, platform and fine chemicals.
- **Investments towards projects upscaling raceway pond technologies for other market products e.g. food/feed, will benefit energetic algae cultivation projects via technology transfer.**

Threats

- **Alternative biofuel production technologies are more cost effective than energetic algae and as such more attractive for investors[1].**
- Depending on the end market, purification of products from contaminants may add an additional cost.

*Strengths & Weaknesses Performance Matrix: **Importance high**; Importance medium; Importance low*

*Opportunities & Threats Performance Matrix: **Probability/Impact high**; Probability/Impact medium; Probability/Impact low*

… in close raceway ponds with anaerobic digestate

Strengths

- Digestate will be transported over the fence by neighbouring AD industry (e.g. industrial symbiosis).
- **Extremophile algal strains reduces contamination by nutrient competitors and algae predators.**
- **Use of polar algal strains could improve heating pond costs**[2].
- **Raceway ponds are available in pilot and commercial scale in the Netherlands (also one EnAlgae pilot) and Belgium**[8]**.**
- Capital costs decrease by increasing scales[1].
- **Liquid digestate from e.g. dairy manure contains all nutrients (N, P, micronutrients, micro) algae cultivation needs**

Weaknesses

- **LCA shows very high heat losses (low energy efficiency) for energetic algae production in close ponds. The higher the latitude the higher the losses**[1]**.**
- Climate prescribes heating and lightning (e.g. LED lights) requirements for high productivities of algae, especially in the winter. Lighting and especially heating costs increase by geographical latitude[1].
- **Cost of land is substantial for investing in countries like Luxembourg, Netherlands, Belgium, and Switzerland.**
- Digestate may be contaminated by unwanted microorganisms like bacteria, so algae may need purification that adds an extra cost.

Opportunities

- **Liquid digestate is available a zero gate price.**
- **AD technology is very popular technology spread all over NW Europe.**
- Export of biotechnology knowledge to other countries with warmer climates and higher available surface area for energetic algae cultivation[2].
- **Investments towards projects upscaling raceway pond technologies for other market products e.g. food/feed, will benefit energetic algae cultivation projects via technology transfer.**

Threats

- **Digestate quality must have some standards (composition, pH, colour etc.)**
- Digestate may be need to be cleaned or treated before used for algae cultivation (e.g. pH, ammonia etc.).
- **Alternative biofuel production technologies are more cost effective than energetic algae and as such more attractive for investors**[1].
- Depending on the end market, purification of products from contaminants may add an additional cost.
- **Digestate price may rise due to market competition (currently no market price).**

Strengths & Weaknesses Performance Matrix: ***Importance high****; Importance medium; Importance low*

Opportunities & Threats Performance Matrix: ***Probability/Impact high****; Probability/Impact medium; Probability/Impact low*

… in Photobioreactors (PBRs)

Strengths

- **PBR and flat panel technologies are available in pilot and commercial scale in the UK, Germany, Belgium, France and the Netherlands[8].**
- Land footprint is relatively low and algae yields high (compared to other algae cultivation technologies)
- **Salt water is available in Ireland, UK, Netherlands, France, Belgium, Germany. Fresh water is available in all 8 countries of NW Europe.**
- Contamination from predators or competitors is low, so yields are higher than ponds and also downstream product purification is not needed [9].
- **Use of polar natural could improve heating pond costs[2]**
- **Capital costs decrease at higher scales.**

Weaknesses

- **High capital and electricity costs especially in low scale.**
- Heat and CO_2 will be produced on site, by e.g. biomass boilers.
- Climate prescribes heating and lightning (e.g. LED lights) requirements of algae cultivation reactors for higher productivities especially in the winter. Lighting and heating costs increase by geographical latitude.
- **Salt water is not available in Switzerland and Luxemburg**
- Fresh water use has economic and environmental implications

Opportunities

- **Onsite renewable heat production may be eligible for government financial support.**
- It is likely that there will be a medium value market for food or food additives (Chlorella, Dunalliela, Chlamydomonas)[1,] that coupled with a integrated biorefinery could alsoproduce biofuels (thermochemical, fermentation[3]).
- **Investments towards projects upscaling PBR technologies for other market products e.g. food/feed, will benefit energetic algae cultivation projects via technology transfer.**

Threats

- **Alternative biofuel production technologies are more cost effective than energetic algae and as such more attractive for investors[1].**

Strengths & Weaknesses Performance Matrix: ***Importance high****; Importance medium; Importance low*

Opportunities & Threats Performance Matrix: ***Probability/Impact high****; Probability/Impact medium; Probability/Impact low*

… in Photobioreactors with industrial/ fossil CO_2 (Carbon Capture and Use, CCU)

Strengths

- Heat and CO_2 will be transported over the fence by neighbouring industry (e.g. industrial symbiosis).
- **PBR and flat panel technologies are available in pilot and commercial scale in the UK, Germany, Belgium, France and the Netherlands[8]. PML in the UK, an EnAlgae pilot, has a PBR pilot in operation using CO_2 flue gases from Boots PLC.**
- Land footprint is relatively low and algae yields higher than other algae pond cultivation[1].
- **Salt water is available in Ireland, UK, Netherlands, France, Belgium, Germany. Fresh water is available in all 8 countries of NW Europe.**
- Contamination from predators or competitors is low, so yields are higher than ponds and also downstream product purification is not needed[9].
- **Capital costs decrease at higher scales.**

Weaknesses

- **High capital and energy costs especially in low scale.**
- **Climate prescribes heating and lightning (LED lights) requirements of algae cultivation reactors for higher productivities especially in the winter. Lighting and heating costs increase by geographical latitude.**
- Fresh water use has economic and environmental implications
- **Salt water is not available in Switzerland and Luxemburg**

Opportunities

- **CO_2-rich flue gases has no production cost**
- Flue gas bioremediation may be in the future eligible for government support schemes
- **All NW European countries are industrial centres and produce large amounts of CO_2 as industrial by-product (Biogas, alcohol fermentation, cement production, steel making, fossil fuel combustion).**
- **Investments towards projects upscaling PBR technologies for other market products e.g. food/feed, will benefit energetic algae cultivation projects via technology transfer.**

Threats

- **Competitive biofuel technologies are more cost effective than CO_2 flue-gas algae and as such more attractive for investors.**
- CO_2-rich flue gas may need dilution and pretreatment before use (cost increase).
- Algal biomass produced by CO_2 flue-gases may not be compliant to food markets (co-product to biofuels).

*Strengths & Weaknesses Performance Matrix: **Importance high**; Importance medium; Importance low*

*Opportunities & Threats Performance Matrix: **Probability/Impact high**; Probability/Impact medium; Probability/Impact low*

… in Photobioreactors with anaerobic digestate and industrial/ fossil CO_2 (Carbon Capture and Use, CCU)

Strengths

- Digestate, heat and CO_2 will be transported over the fence by neighbouring industry (e.g. industrial symbiosis).
- **PBR and flat panel technologies are available in pilot and commercial scale in the UK, Germany, Belgium, France and the Netherlands[8]. PML in the UK, an EnAlgae pilot, has a PBR pilot in operation using CO_2 flue gases from Boots PLC.**
- Land footprint is relatively low and algae yields higher than other algae pond cultivation[1].
- Contamination from predators or competitors is low, so yields are higher than ponds and also downstream product purification is not needed[9].
- **Extremophile algal strains could increase biomass productivity.**
- **Capital costs decrease at higher scales.**
- **Liquid digestate from e.g. dairy manure contains all nutrients (N, P, micronutrients, micro) algae cultivation needs**

Weaknesses

- **High capital and energy costs especially in low scale.**
- **Climate prescribes heating and lightning (LED lights) requirements of algae cultivation reactors for higher productivities especially in the winter. Lighting and heating costs increase by geographical latitude.**
- Digestate may be contaminated by unwanted microorganisms like bacteria, so algae may need purification that adds an extra cost.

Opportunities

- **Liquid digestate and industrial/fossil CO_2 is available a zero gate price.**
- **AD technology is very popular technology spread all over NW Europe.**
- **All NW European countries are industrially thriving and produce large amounts of CO_2 as industrial by-product (Biogas, alcohol fermentation, cement production, steel making, fossil fuel combustion).**
- Flue gas and wastewater bioremediation may be in the future eligible for government support schemes
- **Investments towards projects upscaling PBR technologies for other market products e.g. food/feed, will benefit energetic algae cultivation projects via technology transfer.**

Threats

- **Quality of the CO_2 stream and the digestate must have some standards (composition, pH, colour etc.)**
- CO_2 stream or the digestate may be need to be cleaned or treated before used for algae cultivation (e.g. pH, ammonia, heavy metals etc.).
- **Competitive biofuel technologies are more cost effective than CO_2 flue-gas algae and as such more attractive for investors.**
- Algal biomass may not be compliant to food markets (co-product to biofuels).

Strengths & Weaknesses Performance Matrix: ***Importance high****; Importance medium; Importance low*

Opportunities & Threats Performance Matrix: ***Probability/Impact high****; Probability/Impact medium; Probability/Impact low*

… in Photobioreactors with GM strains

Strengths

- **PBR and flat panel technologies are available in pilot and commercial scale in the UK, Germany, Belgium, France and the Netherlands[8].**
- Land footprint is relatively low and algae yields high (compared to other algae cultivation technologies).
- **Salt water is available in Ireland, UK, Netherlands, France, Belgium, Germany. Fresh water is available in all 8 countries of NW Europe.**
- Contamination from predators or competitors is low, so yields are higher than ponds and also downstream product purification is not needed[9].
- **Use of GM strain could improve growth characteristics and product portfolios[4].**
- **Capital costs decrease at higher scales.**

Weaknesses

- **High capital and electricity costs especially in low scale[1].**
- Heat and CO_2 will be produced on site, by e.g. biomass boilers[4].
- **The regulatory and permit system is currently very bureaucratic-heavy for GMMs, GMOs and their products even under containment[5].**
- Climate prescribes heating and lightning (e.g. LED lights) requirements of algae cultivation reactors for higher productivities especially in the winter. Lighting and heating costs increase by geographical latitude.
- **GM processing is costly because effluents released to the environment must be GM-free.**
- **Salt water is not available in Switzerland and Luxemburg.**
- Fresh water use has economic[1] and environmental implications.

Opportunities

- **Onsite renewable heat production may have be eligible for government financial support.**
- Export of biotechnology knowledge
- **National governments have the power to approve/ban cultivation of EU-approved GMO varieties on their grounds.**
- **Investments towards projects upscaling PBR technologies for other market products e.g. food/feed, will benefit energetic algae cultivation projects via technology transfer.**

Threats

- **Alternative biofuel production technologies are more cost effective than energetic algae and as such more attractive for investors[1].**
- Use of GM products for food and feed has a very bureaucratic-heavy procedure to grant approval, so market are more limited than with non-GM algae[5].

*Strengths & Weaknesses Performance Matrix: **Importance high**; Importance medium; Importance low*

*Opportunities & Threats Performance Matrix: **Probability/Impact high**; Probability/Impact medium; Probability/Impact low*

… in Photobioreactors with aquaculture wastewater (RAS) and GM algae

Strengths

- Wastewater will be transported over the fence by neighbouring aquaculture industry (e.g. industrial symbiosis).
- **PBR and flat panel technologies are available in pilot and commercial scale in the UK, Germany, Belgium, and the Netherlands[8]. HTW Saar in Germany has a Recirculation Aquaculture System (RAS) connected to a PBR.**
- Land footprint is relatively low and algae yields higher than other algae pond cultivation[1].
- Contamination from predators or competitors is low, so yields are higher than ponds and also downstream product purification is not needed[9].
- **Use of GM strain could improve growth characteristics and product portfolios[4].**
- **Capital costs decrease at higher scales.**
- **RAS contains all nutrients (N, P, micronutrients, micro) algae cultivation needs**

Weaknesses

- **High capital and energy costs especially in low scale.**
- **The regulatory and permit system is currently very bureaucratic-heavy for GMMs, GMOs and their products even under containment[5].**
- **Climate prescribes heating and lightning (LED lights) requirements of algae cultivation reactors for higher productivities especially in the winter. Lighting and heating costs increase by geographical latitude.**
- **GM processing is costly because materials released to the environment (RAS) must be GM-free.**
- Wastewater from RAS may be contaminated by algae predators and competitors so it needs pretreatment and purification before entering the PBR that adds an extra cost.

Opportunities

- **RAS wastewater and industrial/fossil CO_2 is available a zero or negative gate price[9].**
- **Inland aquaculture ponds are very popular spread all over NW Europe.**
- RAS bioremediation may be in the future eligible for government support schemes
- RAS wastewater does not need to be cleaned chemically before used for algae cultivation (e.g. pH, ammonia, heavy metals etc.).
- **National governments have the power to approve/ban cultivation of EU-approved GMO varieties on their grounds.**
- **Investments towards projects upscaling PBR technologies for other market products e.g. food/feed, will benefit energetic algae cultivation projects via technology transfer.**

Threats

- **RAS wastewater must have some standards (composition, pH, colour etc.)**
- **Competitive biofuel technologies are more cost effective than CO_2 flue-gas algae and as such more attractive for investors.**
- **Use of GM products for food and feed has a very bureaucratic-heavy procedure to grant approval, so market are more limited than with non-GM algae[5].**

Strengths & Weaknesses Performance Matrix: ***Importance high****; Importance medium; Importance low*

Opportunities & Threats Performance Matrix: ***Probability/Impact high****; Probability/Impact medium; Probability/Impact low*

… in Photobioreactors with industrial/ fossil CO_2 (Carbon Capture and Use, CCU) and GM algae strains

Strengths

- Heat and CO_2 will be transported over the fence by neighbouring industry (e.g. industrial symbiosis).
- **PBR and flat panel technologies are available in pilot and commercial scale in the UK, Germany, Belgium, France and the Netherlands[8]. PML in the UK, an EnAlgae pilot, has a PBR pilot in operation using CO_2 flue gases from Boots PLC.**
- Land footprint is relatively low and algae yields higher than other algae pond cultivation.
- **Salt water is available in Ireland, UK, Netherlands, France, Belgium, Germany. Fresh water is available in all 8 countries of NW Europe.**
- Contamination from predators or competitors is low, so yields are higher than ponds and also downstream product purification is not needed [9].
- **Use of GM strain could improve growth characteristics and product portfolios[4].**
- **Capital costs decrease at higher scales.**

Weaknesses

- **The regulatory and permit system is currently very bureaucratic-heavy for GMMs, GMOs and their products even under containment.**
- Location of the algae cultivation plant must be co-located with CO_2/heat producing unit (e.g. industrial symbiosis).
- **High capital and energy costs especially in low scale.**
- Fresh water use has economic and environmental implications
- **Salt water is not available in Switzerland and Luxemburg**
- **Climate prescribes heating and lightning (LED lights) requirements of algae cultivation reactors for higher productivities especially in the winter. Lighting and heating costs increase by geographical latitude.**
- **GM processing is costly because materials released to the environment must be GM-free.**

Opportunities

- **CO_2-rich flue gases has zero price[9].**
- Export of biotechnology knowledge.
- Flue gas bioremediation can be in the future eligible for government support schemes
- **All NW European countries are industrial centres and produce large amounts of CO_2 as industrial by-product (Biogas, alcohol fermentation, cement production, steel making, fossil fuel combustion).**
- **Investments towards projects upscaling PBR technologies for other market products e.g. food/feed, will benefit energetic algae cultivation projects via technology transfer.**

Threats

- **Competitive biofuel technologies are more cost effective than CO_2 flue-gas algae and as such more attractive for investors.**
- Algal biomass produced by CO_2 flue-gases and/or GM algae may not be compliant to food/feed markets (co-product to biofuels)[5].

Strengths & Weaknesses Performance Matrix: ***Importance high***; *Importance medium; Importance low*

Opportunities & Threats Performance Matrix: ***Probability/Impact high***; *Probability/Impact medium; Probability/Impact low*

… in High Rate Algal Ponds (HRAP) with municipal wastewater

Strengths

- **HRAP has lower construction and operating costs than activated sludge systems.**
- HRAP can be integrated with active sludge technologies or replace them.
- Capital costs decrease by increasing scales[1].
- **Extremophile algal strains reduces contamination by nutrient competitors and algae predators.**
- **Use of polar algal strains could improve algal productivity**.

Weaknesses

- **The technology has not been demonstrated in NW Europe (only in New Zealand that has similar climate to the UK)**
- HRAP have a larger land footprint than activated sludge systems.
- Algae will be contaminated by bacteria so it may need purification that adds an extra cost.
- **Cost of land is substantial for investing in countries like Luxembourg, Netherlands, Belgium, and Switzerland**.

Opportunities

- Algae from HRAP can be used for production of fertiliser, soil amendment, platform and fine chemicals, and fuels.
- **Inland aquaculture ponds are very popular spread all over NW Europe.**
- **Municipal wastewater prices is negative.**
- Export of biotechnology knowledge to other countries with warmer climates and higher available surface area for energetic algae cultivation[2].
- **Investments towards projects upscaling PBR technologies for other market products e.g. food/feed, will benefit energetic algae cultivation projects via technology transfer.**

Threats

- **Alternative biofuel production technologies are more cost effective than energetic algae and as such more attractive for investors[1]**.
- Sewage tertiary treatment step may still be needed downstream.
- Depending on the end market, purification of products from contaminants may add an additional cost.

Strengths & Weaknesses Performance Matrix: ***Importance high****; Importance medium; Importance low*

Opportunities & Threats Performance Matrix: ***Probability/Impact high****; Probability/Impact medium; Probability/Impact low*

… in Photobioreactors with Recirculation Aquaculture System (RAS)

Strengths

- Wastewater will be transported over the fence by neighbouring aquaculture industry (e.g. industrial symbiosis).
- **PBR and flat panel technologies are available in pilot and commercial scale in the UK, Germany, Belgium, and the Netherlands[8]. HTW Saar in Germany has a Recirculation Aquaculture System (RAS).**
- Land footprint is relatively low and algae yields higher than other algae pond cultivation[1].
- Contamination from predators or competitors is low, so yields are higher than ponds and also downstream product purification is not needed[9].
- **Extremophile algal strains could increase biomass productivity.**
- **Capital costs decrease at higher scales.**
- **RAS contains all nutrients (N, P, micronutrients, micro) algae cultivation needs**

Weaknesses

- **High capital and energy costs especially in low scale.**
- **Climate prescribes heating and lightning (LED lights) requirements of algae cultivation reactors for higher productivities especially in the winter. Lighting and heating costs increase by geographical latitude.**
- Wastewater from RAS may be contaminated by algae predators and competitors so it needs purification before entering the PBR that adds an extra cost.

Opportunities

- **Wastewater and industrial/fossil CO_2 is available with zero gate price[9].**
- **Inland aquaculture ponds are very popular spread all over NW Europe.**
- RAS bioremediation may be in the future eligible for government support schemes
- RAS wastewater does not need to be cleaned chemically before used for algae cultivation (e.g. pH, ammonia, heavy metals etc.).
- **Investments towards projects upscaling PBR technologies for other market products e.g. food/feed, will benefit energetic algae cultivation projects via technology transfer.**

Threats

- **RAS wastewater must have some standards (composition, pH, colour etc.)**
- **Competitive biofuel technologies are more cost effective than algae and as such more attractive for investors.**
- Algal biomass may not be compliant to food markets (co-product to biofuels.

Strengths & Weaknesses Performance Matrix: ***Importance high****; Importance medium; Importance low*

Opportunities & Threats Performance Matrix: ***Probability/Impact high****; Probability/Impact medium; Probability/Impact low*

… in dark fermentation reactors with heterotrophic algae

Strengths

- **Algae dark fermentation activities exist in pilot and commercial scale in the UK and in US so knowledge in production, handling, processing and marketing is in place**
- Land footprint is relatively low and algae yields high (compared to other algae cultivation technologies)
- **Productivity is significantly higher than autotrophic algae production.**
- Salt water is available in Ireland, UK, Netherlands, France, Belgium, Germany. Fresh water is available in all 8 countries of NW Europe.
- **Generic fermentation reactor technologies are already matured at all scales.**
- Capital costs decrease at higher scales.

Weaknesses

- **High capital and electricity costs especially in low scale.**
- Sugars feed add a significant operational cost.
- **Salt water is not available in Switzerland and Luxemburg**
- Fresh water use has economic and environmental implications

Opportunities

- **Investments towards projects upscaling dark algal fermentation technologies for other market products e.g. food/feed, will benefit energetic algae cultivation projects via technology transfer.**
- Price of sugars may increase due to competition from different markets.

Threats

- **Alternative biofuel production technologies are more cost effective than energetic algae and as such more attractive for investors[1].**

*Strengths & Weaknesses Performance Matrix: **Importance high**; Importance medium; Importance low*

*Opportunities & Threats Performance Matrix: **Probability/Impact high**; Probability/Impact medium; Probability/Impact low*

… in dark fermentation reactors with GM heterotrophic algae

Strengths

- **Algae dark fermentation activities exist in pilot and commercial scale in the UK and in US so knowledge in production, handling, processing and marketing is in place**
- Land footprint is relatively low and algae yields high (compared to other algae cultivation technologies)
- **Productivity is significantly higher than autotrophic algae production.**
- Salt water is available in Ireland, UK, Netherlands, France, Belgium, Germany. Fresh water is available in all 8 countries of NW Europe.
- **Generic fermentation reactor technologies are already mature at all scales.**
- Capital costs decrease at higher scales.
- **Use of GM strain could improve growth characteristics and product portfolios[4].**

Weaknesses

- **High capital and electricity costs especially in low scale.**
- Sugars feed add a significant operational cost.
- **Salt water is not available in Switzerland and Luxemburg**
- Fresh water use has economic and environmental implications
- **The regulatory and permit system is currently very bureaucratic-heavy for GMOs and their products even under containment[5].**
- **GM processing is costly because effluents released to the environment must be GM-free.**

Opportunities

- **National governments have the power to approve/ban cultivation of EU-approved GMO varieties on their grounds.**
- **Investments towards projects upscaling dark algal fermentation technologies for other market products e.g. food/feed, will benefit energetic algae cultivation projects via technology transfer.**
- Price of sugars may increase due to competition from different markets

Threats

- **Alternative biofuel production technologies are more cost effective than energetic algae and as such more attractive for investors[1].**
- Use of GM products for food and feed has a very bureaucratic-heavy procedure to grant approval, so market are more limited than with non-GM algae[5].

Strengths & Weaknesses Performance Matrix: ***Importance high****; Importance medium; Importance low*

Opportunities & Threats Performance Matrix: ***Probability/Impact high****; Probability/Impact medium; Probability/Impact low*

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Four SWOT analyses of seaweed cultivation for energy production in NW Europe

… on marine long lines/frame

Strengths

- **Salt water coastlines are available in UK, France, Ireland, Germany, Netherlands, and Belgium, and ranked by length in this order (estimation).**
- **Several long line facilities are operating on a commercial scale in the UK, Ireland, and NW France, but also in Denmark, NW Spain, and Norway.[7]**
- Capital costs decrease by increasing scales[9].
- No competition with arable land.
- **The scale of Seaweed cultivation site is expanding in NW Europe.[8]**
- Globally 24m MT of Wet seaweed was produced in 2013, with the majority being cultivated[6]

Weaknesses

- **Salt water is not available in Switzerland and Luxemburg**
- **Distance from the shore increases logistics costs, and decreases competitiveness of seaweed product[2].**
- Fertilisers might be needed for increasing product yield, which increases operational costs of production.
- **Hatchery facilities are required (ashore/near shore) for gametophyte and/or zoospore cultures and transplanting seaweed onto rope/frame/cloth, which increases cost of capital investment.**
- Seaweed hatchery, transplanting, matrix transportation, and finally seaweed harvesting are still under development and demonstration phase[1].
- Special licencing permits for seaweed farming need to be issued.
- **Technologies for handling and storage of seaweed biomass is in the development phase.**

Opportunities

- **Production of biogas from seaweed has been tested and used by many AD plants in France, Germany and the UK.[cite]**
- Seaweed from long lines can be used not only for energy production but also for production of food and feed, nutraceuticals, fertiliser, soil amendment, platform and fine chemicals, cosmeceuticals, pharmaceuticals.
- Possibility of growing large scale seaweed farms integrated in off-shore windmill farms, coupling maintenance, reducing navigation hazard.
- Possibility of reducing costs of seaweed hatchery systems by incorporating seaweed into other aquaculture hatchery facilities.

Threats

- **Alternative biofuel production technologies are more cost effective than energetic algae and as such more attractive for investors[1].**
- Public perception over degradation of landscape beauty and maritime safety caused by seaweed longlines is ambiguous.
- If there is not enough seaweed, the downstream processing plants will have to use alternative biomass suppliers when seaweed harvesting year ends.

Strengths & Weaknesses Performance Matrix: ***Importance high****; Importance medium; Importance low*

Opportunities & Threats Performance Matrix: ***Probability/Impact high****; Probability/Impact medium; Probability/Impact low*

… harvesting in the wild

Strengths

- **Salt water is available in Ireland, UK, Netherlands, France, Belgium, Germany.**
- **Several companies operate on a commercial scale in the UK, Ireland, and NW France, but also in Denmark, NW Spain, and Norway[7].**
- Availability of wild seaweed could be higher near water-front tourist resorts. Seaweed blooms and drifts represent a large source of waste biomass
- **Minimal capital investment for seaweed harvesting, if hand-harvesting is used, moderate capital investment for mechanical harvesting**
- Globally 24m MT of Wet seaweed was produced in 2013, with the majority being cultivated[6].

Weaknesses

- **Salt water is not available in Switzerland and Luxemburg.**
- **Harvesting distance from the shore increases logistics costs, and decreases competitiveness of seaweed product[2].**
- Harvesting is more complicated, e.g. diving, hand-harvesting.
- Wild harvesting has limited small scale capacity.
- **Permits for wild harvesting need to be issued.**
- Seaweed blooms and drift are seasonal and potentially harmful to harvesters.
- Amount of seaweed required for EU energy generation is unlikely to be naturally available
- Amount of biomass available for harvesting vary from year to year.

Opportunities

- Wild seaweed can be used except for energy production also more likely production of food and feed, nutraceuticals, fertiliser, soil amendment, platform and fine chemicals, cosmeceuticals, pharmaceuticals.
- **Production of biogas from seaweed has been tested and used by many AD plants in Germany and the UK [cite]**

Threats

- **Benthic and turf harvesting of wild seaweed may have ecosystem implications.**
- If there is not enough seaweed, the downstream processing plants will have to use alternative biomass suppliers when seaweed harvesting year ends.
- **Alternative biofuel production technologies are more cost effective than energetic algae and as such more attractive for investors**[1].

*Strengths & Weaknesses Performance Matrix: **Importance high**; Importance medium; Importance low*

*Opportunities & Threats Performance Matrix: **Probability/Impact high**; Probability/Impact medium; Probability/Impact low*

… on marine long-lines/frame as an Integrated Multi-trophic Aquaculture (IMTA) concept

Strengths

- **Salt water aquaculture is available in Ireland, UK, Netherlands, France, Belgium, Germany. Fresh water aquaculture is available in all 8 countries of NW Europe.**
- Capital costs decrease by increasing scales[1].
- Seaweed IMTA can be combined e.g. with ashore and near-shore salmon, trout, oysters, mussels and halibut farms and mitigate ecosystem damage (scavenge nitrogen, phosphorus, fix waste).
- Loch Duart and Loch Fyne in the UK and Hjarnoe Havbrug in Denmark are using IMTA concept in their fish farms. IMTA is used also in Canada, Chile, and Portugal[10].

Weaknesses

- **Salt water IMTA cannot be placed in Switzerland and Luxemburg.**
- Special licencing permits for IMTA seaweed farming need to be issued.
- **Distance from the shore increases logistics costs, and decreases competitiveness of seaweed[2].**
- The ecological benefits of IMTA are still in development stage
- Seaweed nurseries, transplanting, matrix transportation, and finally seaweed harvesting are still under development and demonstration[1].
- **Hatchery facilities are required (ashore/near shore) for gametophyte cultures and transplanting seaweed onto rope/ frame/cloth, which increases cost of production.**

Opportunities

- Seaweed from IMTA can be used for energy products, also for production of feed, nutraceuticals, fertiliser, soil amendment, platform and fine chemicals, cosmeceuticals, pharmaceuticals.
- **Legislation will mandate aquaculture farmers to create IMTA farms for tackling their aquaculture waste and tackle environmental impacts of their business activities[3].**
- **Production of biogas from seaweed has been tested and used by many AD plants in Germany and the UK**

Threats

- **Wastewater must have some standards (composition, pH, colour etc.)**
- The nitrogen/nutrient credit market does not exist in NW Europe, but exists in the US (Connectict)[3].
- **Alternative biofuel production technologies are more cost effective than energetic algae and as such more attractive for investors[1].**
- Algal biomass may not be compliant to food markets (co-product to biofuels.
- If there is not enough seaweed, the downstream processing plants will have to use alternative biomass suppliers when seaweed harvesting year ends.

Strengths & Weaknesses Performance Matrix: ***Importance high****; Importance medium; Importance low*

Opportunities & Threats Performance Matrix: ***Probability/Impact high****; Probability/Impact medium; Probability/Impact low*

… in inland tank as an Integrated Multi-trophic Aquaculture (IMTA) concept

Strengths

- Seaweed IMTA can be combined e.g. with ashore salmon, trout, and halibut farms and mitigate ecosystem damage (scavenge nitrogen, phosphorus fix waste).
- Aquaculture wastewater will be transported over the fence by neighbouring aquaculture industry (industrial symbiosis) or be co-located in the farm.
- **Salt water aquaculture is available in Ireland, UK, Netherlands, France, Belgium, Germany. Fresh water aquaculture is available in all 8 countries of NW Europe.**
- Environmental impact expected to be minimal

Weaknesses

- The scale of inland tanks is not applicable for biofuel production.
- **The technology has not been demonstrated in NW Europe.**
- **Salt water IMTA cannot be placed in Switzerland and Luxemburg.**
- **Cost of land is substantial part of investment in countries with land shortage like Luxembourg, Netherlands, Belgium, and Switzerland.**
- **Nursing facilities are required ashore for growing and transplanting seaweed babes on rope/frame/cloth, which increases cost of production.**
- High throughput seaweed nurseries, transplanting, matrix transportation, and finally seaweed harvesting are still under development and demonstration[1].

Opportunities

- Aquaculture wastewater is available a zero gate price[10].
- **The legislation in the future will mandate aquaculture farms to build strategies to mitigate the environmental impacts of their business activities, via e.g. Building IMTA farms.[3]**
- Seaweed from IMTA can be used for energy products, also for production of feed, nutraceuticals, fertiliser, soil amendment, platform and fine chemicals, cosmeceuticals, pharmaceuticals.
- Seaweed produced on nutrients from other aquaculture can be considered organic, therefore attracting higher price/different market.

Threats

- **Wastewater must have some standards (composition, pH, colour etc.)**
- **Alternative biofuel production technologies are more cost effective than energetic algae and as such more attractive for investors[1].**
- The nitrogen/nutrient credit market exists in the the US (Connecticut)[3].
- Algal biomass may not be compliant to food markets (co-product to biofuels.
- If there is not enough seaweed, the downstream processing plants will have to use alternative biomass suppliers when seaweed harvesting year ends.

*Strengths & Weaknesses Performance Matrix: **Importance high**; Importance medium; Importance low*

*Opportunities & Threats Performance Matrix: **Probability/Impact high**; Probability/Impact medium; Probability/Impact low*

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