PUFAChain: The Value Chain from Microalgae to PUFA
The overall goal of the project PUFAChain is to develop a robust scientific and technological basis for substantiating strategic and technical decisions for the industrial development of high value products from algae. This shall contribute to develop this new and sustainable resource for market. The concept of the proposal is strictly oriented to the value chain of microalgae. Starting at the very end of the value chain the proposal picks up a distinct application of high market relevance. The main application targeted with this project is the use of high purified omega 3 fatty acids (DHA/EPA) as building blocks in modern oleo-chemistry to gain high value products for nutrition and pharmaceutical applications.

These applications will define specifications that propagate backwards along the various value-adding stages of the value chain. These stages include the downstream technologies of harvest, disruption, extraction and purification, the cultivation technology, and the biology at the beginning of the complete process. So, the aim of this project is to realise a specific exemplary value chain, develop the technical interfaces between the different value adding stages and investigate the still open research aspects at every single stage while simultaneously addressing the needs of the value chain as a whole. Finally, an integrated process, combining all technical steps, will be implemented for demonstration. A comprehensive and holistic sustainability approach will complement the scientific and commercial advances on each value-adding stage. A consortium of 6 companies and 3 research institutes will integrate state of the art science and technologies in order to assemble a complete process from algae production and harvesting to oil extraction and purification. Innovative technologies will be combined taking advantage of a complementary partnership with the best available expertise in this sector in Europe. These processes will be evaluated for their sustainability and scaled-up from lab to demonstrative prototype level.
Project Progress

Project Management:
The overall feedback of the midterm review was quite positive, even though some remarks regarding innovation potential and dissemination activities were made. These remarks will be addressed appropriately. The acquisition of partner Cremer OLEO by IOI Oleochemicals (see Newsflash) was successfully completed. This will however have no impact on the project implementation. The idea to install an external industrial advisory board was discussed, as some specific interest was expressed. The partners agreed that, in general, this could be advantageous for the project. Anyhow, it was further decided that each potential participation has to be discussed in detail and the underlying conditions need to be appropriate and accepted by all partners.

Research and Development:
11 strains of mesophilic microalgae have been grown under different light intensities, temperatures, and cultivation media in order to optimise the overall lipid content and profile. Two groups could be defined for summer and spring/autumn cultivation. In order to realise the proposed algae crop rotation principle (all-year industrial production), cryophilic strains for cold temperatures and low light intensities are still needed. The problem is the high AA to EPA ratio of these strains. After extensive tests, it appears that 4 strains from the Trebouxiophyceae are most suitable for industrial production. Upscaling experiments at pilot-scale for three of these cryophilic strains, in addition to 4 mesophilic strains, are currently in progress or soon to be started. Another important aspect of industrial production is the unambiguous identification of high-quality strains. Therefore genetic characterisation and species identification has been performed for all EPA/DHA-rich mesophilic strains. In the next months, this will also be done for the cryophilic strains. Expansion of the experimental unit to be able to cultivate more biomass for the extensive testing of microfiltration, extraction, and further processing has been started and will be fully operational soon.

*NATEX extraction plant for wet biomass.*

For downstream processing two pathways have been defined for the extraction of dried biomass with supercritical CO₂ and the extraction of wet biomass with liquid propane. In this reporting period, cell disruption and dried biomass extraction could be performed for one selected strain (the required amount of biomass for further strains was not available at the moment). It was possible to extract all oil available.

Dissemination Activities:
A poster has been presented at the 16th Scientific Conference of the Phycological Section of the German Botanical Society in Leipzig, Germany. Discussions with several European universities have been started to increase awareness of the benefits of microalgae for health and nutrition.
From the 19th to the 20th April 2016, a second project-internal sustainability workshop took place. As the first one, this workshop was again hosted by IFEU institute in Heidelberg, Germany. Before the actual workshop took place, the consortium took the opportunity of all representatives being present in order to hold a biannual General Assembly meeting to discuss latest progress and developments within PUFACChain. Main issues that were discusses, were the project progress, the feedback of the midterm review, the possibility to install an external industrial advisory board as well as ideas for future dissemination activities (see Project Progress).

After the biannual General Assembly was concluded, the sustainability workshop started. The objective of this workshop was the definition of interlinkages within the project value chain. Following the project progress, 5 algae strains (4 summer and 1 winter algae) with promising DHA and/or EPA yield have been selected for further investigation. For each of these 5 algae strains, the preferred/most suitable systems have been determined for inoculation and mass production. Candidates were green wall panels, various types of photobioreactors as well as raceway ponds. In addition, various growth scenarios for Southern/Central Europe (mono crop) and Northern/Central Europe (crop rotation) will be designed in order to identify the best solution for the selected algae strains. In order to properly investigate the interlinkages, the future value chain had to be broken down into specific steps: cultivation, harvesting, drying, disruption, extraction, enrichment, purification, separation. It was then discussed, which data is required for what step of the value chain, how this data can be acquired and who is the partner that can provide the data. While for cultivation and harvesting the criteria seem to be quite clear, drying, disruption and extraction appear to be more difficult and dependent on the individual algae strain. Therefore, a matrix with the algae strains and drying, disruption, extraction methods was set up and the partners discussed every possibility in detail in order to narrow down the most suitable solutions. These will be tested and verified in the course of the project. Afterwards, interlinkages for the reference products, e.g. heterotrophic algae, fish oil, flax... (defined on the 1st Workshop) were discussed. These will be considered by evaluating the sustainability of PUFACChain. For the economic assessment, scale of production facilities will be the most important issue for the near future to discuss. This will be done mainly with the industrial partners and moderated by DLO.
The Value Chain from Microalgae to PUFA

Background

The good and bad about AA and EPA/DHA in algal fatty acid formulations

One of the starting objectives of PUFACHain was to identify microalgae rich in omega-3-fatty acids (EPA/DHA), but with no or only little arachidonic acid (AA or ARA). The omega-6-fatty acid arachidonic acid generally was regarded as harmful in dietary preparations for the human being and thus, also became unwanted in our project’s final product.

However, following our project results and the observation that the presence of EPA seems to be closely linked to the presence of AA (so far, every analysed microalgal strain rich in EPA also showed AA in certain, though minor amounts) it was agreed that more thought had to be given to this matter.

A look into literature substantiated our project observations: According to Wen and Chen (2003), EPA and AA are very closely linked in their respective pathways. Depending on the concentrations of linoleic acid (LA) and alpha-linolenic acid (ALA) in the alga, oleic acid is first desaturated into LA and then either via gamma-linolenic acid (GLA) and a further desaturation step to AA and then to EPA, or the LA from the first desaturation step is first desaturated to ALA and then converted via alternative desaturation steps to EPA. This is because LA and ALA are competing for the delta-6-desaturase responsible for the first desaturation step.

Metabolic pathways from oleic acid to AA and/or EPA

Gurr (1985) states that plants (or algae) with a higher ALA content are more likely to synthesise EPA without AA in the respective pathway, while in case of a fatty acid pool with high amounts of LA often AA is synthesized as well in considerable amounts. So far it seems to be unclear if it is possible to influence the desaturation pathways, i.e. to guarantee or at least favour the formation of EPA instead of AA. It therefore needs to be further investigated if external triggers for example certain growth and harvest cycles could have an effect on this process.
Background

The good and bad about AA and EPA/DHA in algal fatty acid formulations

Even more important is the question: Would a certain AA content really be harmful for our desired final product(s)?

Arachidonic acid (C20:4) is present in the phospholipids of membranes of the body's cells and is abundant in the brain, muscles, and liver. It is mainly involved in cellular signalling, thus promoting repair and growth of skeletal muscle tissue. It is therefore for example widely used as a bodybuilding supplement. In addition, recent studies claim that AA is beneficial in the development of vision and brain in infants and small children. Baby formula including AA is already actively distributed by large global companies like DSM, Cargill Foods and Nestlé.

In contrast, AA is also alleged to cause inflammations and act as an immunosuppressant - thus directly having an antagonistic effect on the health benefits of omega-3-fatty acids, namely DHA and EPA. However, following various studies with very inconsistent results, the positive or negative effects of AA seem to be very much dependent from the way how AA is metabolised to eicosanoids (prostaglandins and leukotrienes) by the individual human body. Therefore it cannot be said that AA has only positive or negative effects. When looking at our initial question and several studies, it appears that a balanced diet of EPA and AA is most beneficial for the human body. The EPA/AA ratio should be high. But, in the same context also the ALA/LA ratio should be high. EPA has the same antagonistic effect on AA as ALA has on LA. So it is very hard if not impossible to state an upper limit for AA in human diets or food supplements as the overall dietary pattern of the individual needs to be taken into account.

In most fish oils rich in fatty acids, a certain ratio of AA relative to EPA can be found. It was therefore concluded that, as long as the EPA content is significantly higher than the AA content, the effects are overall beneficial, i.e. anti-inflammatory. These insights will also be taken into account in the further progress of PUFACHain.
Newsflash

France shows growing demand for algae

According to a study of Consultancy Alcimed, France is currently the 10th biggest algae supplier in the world with an annual production of 70,000 tons. Especially the Brittany region shows huge potential for algae cultivation. However, this compares to an annual import of 125,000 tons of algae (mainly Spirulina and Chlorella) to meet the national demands for food, feed, drinks, food supplements, and cosmetics. The majority of these algae are currently imported from Asian manufacturers. In order to be competitive in the future, more investments from and collaboration between innovative start-ups and big players as Roquette, Algosoce Technologies, Algolesko or Olmix will be crucial.

Sustainability as driver for growth and success?

Following a report by Harvard Business Review, companies investing in sustainability might be more innovative and successful in the long-term. This seems to be especially true for companies in the food industry. Even though sustainability is often mainly associated with higher production and supply costs, more and more companies start to notice that sustainable processes and products can lead to competitive advantages. In addition, as customers awareness towards sustainable products (including aspects as origin, fair trade, GMO, etc.) has significantly increased in recent years, companies should not miss to pay attention to sustainability. The same is true for omega-3-fatty acids. Following global health trends, the demand for oils and nutritional products rich in omega-3-fatty acids continuously increases. This of course drastically aggravates the situation for the two main sources of omega-3-fatty acids, fish and krill, that are more and more threatened by overfishing and extinction. Fortunately, growing customer awareness increases the wish for alternative sources of omega-3-fatty acids. Right from the start and throughout the entire project, PUFACChain has been dedicated to not only finding alternative solutions for omega-3-fatty acids but also bringing them closer to the market. This is supported by strong sustainability analysis.

Acquisition of Cremer OLEO by IOI Corporation Berhad

German oleochemical specialist and PUFACChain project partner Cremer OLEO GmbH has been acquired by the Malaysian IOI Corporation Berhad, one of the leading oleochemical producers in the world. The 89.4 million € deal includes the acquisition of the entire industrial business consisting of the production sites in Witten and Wittenberge and its associated business activities in Hamburg. By this acquisition, IOI hopes to strongly increase its presence in the Western and Eastern European markets. From now on, the company will operate under the name IOI OLEO GmbH.
Event Watch

10th Algae Biomass Summit

Date: 23rd - 26th October 2016  
Location: Phoenix, USA

From the 23rd to the 26th October 2016, the 10th annual Algae Biomass Summit will take place in Phoenix, USA. The Algae Biomass Summit is the largest algae conference in the world. This is where leading producers of algae products go to network with industry suppliers and technology providers, where project developers converse with utility executives, and where researchers and technology developers rub elbows with venture capitalists.

The summit includes the following sessions:
- Biology
- Engineering & Analysis
- Commercialization
- Industry Focus
- Peer-reviewed Posters

Main aspects of the "Biology" session are carbon utilization, improved productivity, polyculture biotechnology, outdoor cultivation and crop management, nutrient-based culturing, and synthetic biology. The field "Engineering & Analysis" includes topics such as sustainability, CO₂ and carbon utilization, downstream processing, cultivation innovations, and wastewater utilization. In the "Commercialisation" summit, the focus will be on algae cultivation technologies, system integration, reducing downstream processing costs, the Algae Industry Incubation Consortium Japan, and products from heterotrophic approaches. Finally, the are "Industry Focus" comprises topics such as macro algae, biotech regulation, IP and legal issues, strain development, algal biotechnology, and lessons learned.

For further information please visit: www.algaebiomasssummit.org
Consortium

GEORG-AUGUST-UNIVERSITY GOETTINGEN

The University of Goettingen is known for outstanding quality in several research areas and deeply anchored interdisciplinarity within natural and life sciences. The SAG, Culture Collection of Algae at the University, is among the three largest algal service culture collections in the world and a most comprehensive resource of micro algal cultures. It is supporting research in biotechnology and biodiversity through ex situ conservation of algae and expert knowledge on identifying and isolating. In addition to the characterization of and the provision of the partners with algae strains, the University of Goettingen also holds the role as overall project coordinator. These administrative tasks will be performed by the dedicated EU-Office of the University.

A4F Algae for Future

The Portuguese company A4F Algae for Future, S.A. is a spin-out from Necton S.A., dedicated to the development and delivering of bioengineering projects for the industrial production of microalgae. A4F develops microalgae production units in high-emitting industries for CO₂ mitigation. The Prototype Unit, implemented on a cement plant (SECIL) was the first set of tubular photobioreactor systems, from cell to biomass, on a scale that established "proof of concept". It has evolved into Algafarm – a 1 ha microalgae production unit as a joint project between SECIL and A4F – which is already commercialising Chlorella for the food and feed industries. A4F proposes an innovative approach through a gradual scale-up to maximize performance of each process. Within the project PUFACHAIN, A4F is coordinating two work packages and will be mainly responsible for the bioprocess engineering and the industrial scale.

MAHLE INNOWA

MAHLE InnoWa GmbH is a specialist in the development and application of membrane technologies in various application fields. Through the production of capillary membranes for micro and ultrafiltration that are built into module housing with filter areas ranging from 0.1 m² to 60 m², a variety of applications can be covered. This comprises e.g. a large selection of hollow fibre membranes with different dimensions and cut-offs, point-of-use and point-of-entry systems for water filtration, systems and modules for the crossflow-filtration of wine and fruit juice, as well as the possibility of customer specific filter system design. In PUFACHAIN MAHLE is responsible for a new integrated membrane based filtration and the reuse of process water.
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NATEX PROZESSTECHNOLOGIE

NATEX has gathered experience in supercritical fluid extraction technology for more than 25 years, predominantly in process development, plant design and the operation of CO2-extraction plants. Nowadays the company is well established as a specialist in supercritical fluid extraction technology and can offer its clients a "one stop shop" covering process development for new applications of CO2 processes, scale-up and design of industrial plants as well as manufacturing of main components, erection and start-up. NATEX will lead the work package involving the downstream processing and will investigate algae biomass in its liquid extraction and supercritical fluid technology.

IOI OLEO

IOI OLEO (formerly Cremer OLEO) is the German branch of IOI Oleochemicals Division of the globally active IOI Group. IOI Oleo produces raw materials based on vegetable origin like fatty acids, glycerol, and esters up to structured lipids. With a strong commitment to R&D the company provides its customers with state-of-the art tailor-made oleochemical solutions. The broad product range contains individual solutions for pharmaceutical excipients as well as oleochemical based active pharmaceutical ingredients for enteral and parenteral formulations. Apart from their role as scientific project coordinator, IOI OLEO is the lead of the working packages responsible for purification of crude algae oil as well as final product preparation.

FRAUNHOFER INSTITUTE FOR CELL THERAPY AND IMMUNOLOGY

The Fraunhofer Institute for Cell Therapy and Immunology with its Branch Bioanalytics and Bioprocesses (IZI-BB) offers solutions in the areas of biomedical engineering, biotechnology, environmental control systems and material testing, as well as industrial process automation for food, chemical and pharmaceutical industry. Its Extremophile Research & Biobank CCCryo group studies cold-adapted snow and permafrost algae. Aims of the group's applied research are the use of algal strains for production of high quality substances and development of product-optimised photobioreactors for high purity algal mass production and the extraction of high-value metabolites for health and cosmetics. Within the project, the Fraunhofer IZI-BB acts as provider of well characterised algal strains.
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INSTITUTE FOR ENERGY AND ENVIRONMENTAL RESEARCH

Founded in 1978, the ifeu – Institut für Energie- und Umweltforschung Heidelberg – GmbH is a private independent non-profit organisation for environmental research and consulting. IFEU has an extensive track record in areas such as waste management and packaging materials, transport & mobility, renewable energies and energy efficiency as well as food and bio-based systems. IFEU is especially renowned for its expertise (>20 years) in the field of life cycle assessment (LCA), environmental impact assessment (EIA), and integrated life cycle sustainability assessment (ILC-SA). At European level, IFEU is involved in a number of projects on bio-based products. In the project PUFACHain, IFEU will lead and perform in the work package focusing on the integrated assessment of sustainability.

STICHTING DIENST LANDBOUWKUNDIG ONDERZOEK

Wageningen University and Research Centre (Wageningen UR) is a collaboration between Wageningen University and the specialised former research institutes (Stichting Dienst Landbouwkundig Onderzoek - DLO) from the Dutch Ministry of Agriculture. This combination of knowledge and experience enables Wageningen UR to contribute actively to solving scientific, social and commercial problems in the field of life sciences and natural resources. DLO embodies strategic and fundamental research as well as applied research in which researchers are operating in close co-operation with farmers, companies and governments. The main tasks for DLO in the project concerns the assessment of the economics and social sustainability.

EURA CONSULT

EurA Consult has been established in 1999. As an innovation service provider the company advises more than 800 medium-sized companies in Germany, covering all industrial sectors. EurA Consult mainly focuses on consulting and assisting companies in national and European R&D projects. This comprises the entire innovation process, including the generation of promising ideas, the search for suitable partners, the establishment of the project consortium, the technical and administrative coordination of the project as well as the project controlling. Within the project PUFACHain, the company will act as assistance of the project coordinator and will furthermore be responsible for the dissemination activities.
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