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A perspective on algal biogas

- a report by IEA Bioenergy Task 37

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Overview

- Introduction
- Details on seaweed (world producion, products, composition)
- Anaerobic digestion of seaweed
- Details on microalgae (world producion, products, composition)
- Anaerobic digestion of microalgae
- Synergies between biogas plants and microalgae cultivation

IEA Bioenergy Task 37 report

A perspective on algal biogas

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SUMMARY

Algae are suggested as a biomass source with significant growth rates, which may be cultivated in the ocean (seaweed) or on marginal land (microalgae). Biogas is suggested as a beneficial route to sustainable energy; however the scientific literature on algal biogas is relatively sparse. This report comprises a review of the literature and provides a state of the art in algal biogas and is aimed at an audience of academics and energy policy makers. It was produced by IEA Bioenergy Task 37 which addresses the challenges related to the economic and environmental sustainability of biogas production and utilisation.

www.iea-biogas.net

What are algae?

- Seaweed (macroalgae)

visible by the eye,

can be various meters long

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- Microalgae

Small, mainly visible in the microscope

(e.g.*Chlorella*)

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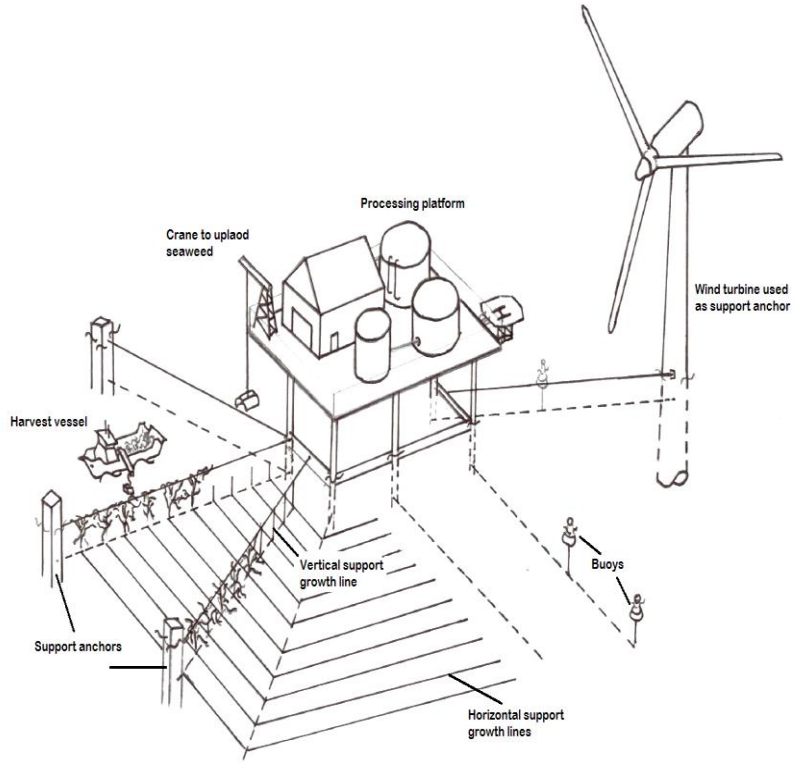
Seaweed (Macroalgae)

Seaweed: Food Products and market prices (Jacob et al, 2015)

Seaweed	Main Producers	Application and product	Price [€]
***Laminaria* sp.**	China, Japan and the Republic of Korea	kombu	2.8 kg^{-1}
***Undaria* sp.**		wakame	6.9 kg^{-1}
***Porphyra* sp.**		Nori	16.8 kg^{-1}

World production of seaweed is 26,000,000 t / yr (FAO, 2014)
→ approx. 5,000,000 t TS/ yr

Cultivation of seaweed

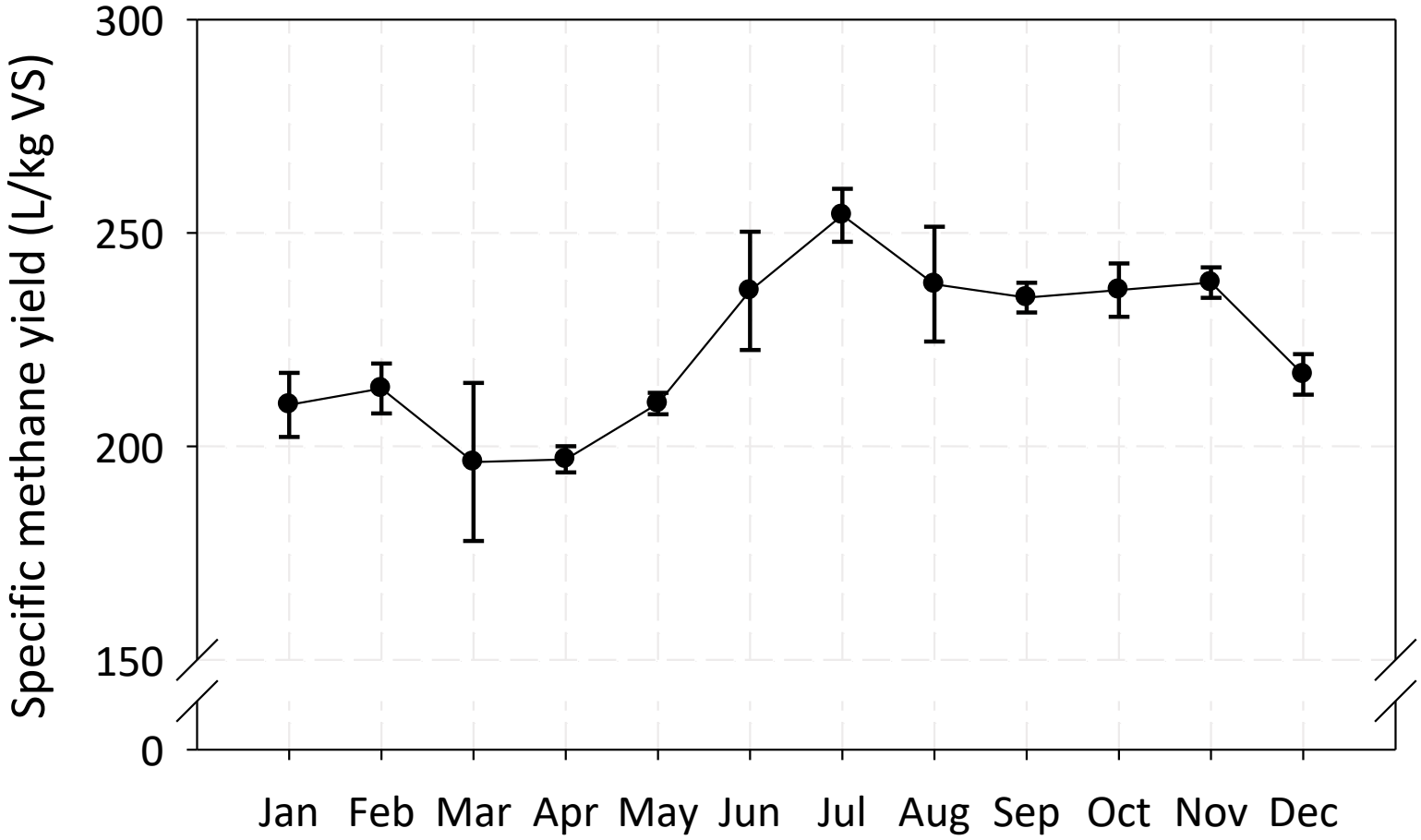


Anaerobic digestion of seaweed

Methane yields of seaweed

Seaweed	BMP Yield L CH4/kg VS	Reference
H. elongate	202-261	Allen et al., 2015, Jard et al., 2013
L. digitata	218-246	Allen et al., 2015; Vanegas and Bartlett, 2013; Allen et al., 2015
F. serratus	96	Allen et al., 2015
S. latissima	209-335	Allen et al., 2015; Vanegas and Bartlett, 2013; Vivekanand et al., 2011; Østgaard et al., 1993; Jard et al., 2013
A. nodosum	166	Allen et al., 2015
U. pinnatifida	242	Jard et al., 2013
S. polyschides	216-255	Vanegas and Bartlett, 2013; Jard et al., 2013
S. muticum	130	
P. palmata	279	Jard et al., 2013
G. verrucosa	144	Jard et al., 2013

Methane yields depend on harvest time



Annual variation in methane potential of *L.digitata* in the UK in 2008 (adapted from Adams et al., 2011)

Conclusions: AD of seaweed

- First digesters starting to use seaweed as feedstock at commercial scale
- Long-term anaerobic digestion may be problematic due to sand deposition in digesters, high sulphur content, high protein content and salinity
- Open questions:
  - Cultivation method
  - Optimal species
  - hectare yields
  - optimal harvest time / harvest method
  - suitability to ensiling

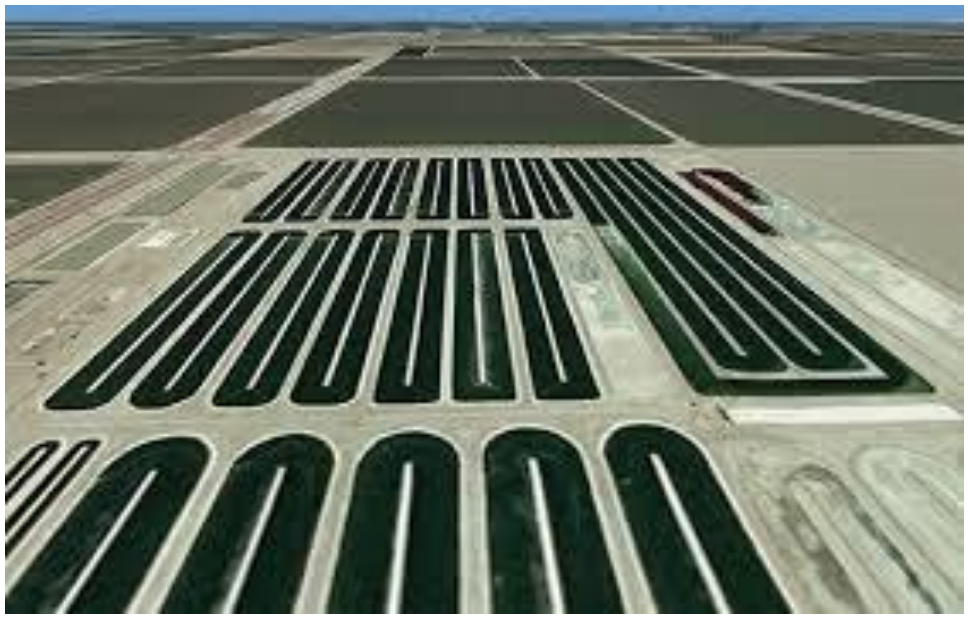
Microalgae

Microalgae: Products and Market prices (adapted after Pulz and Gross, 2004)

Micro-algae	Main Producers	Application and product	Price [€]
***Spirulina* sp.**	China, India, USA, Myanmar, Japan	Human nutrition Animal nutrition Cosmetics	36 kg^{-1}
***Chlorella* sp.**	Taiwan, Germany, Japan	Human nutrition Cosmetics	36 kg^{-1}
		Aquaculture	50 L^{-1}
Dunaliella salina	Australia, Israel, USA, Japan	Human nutrition Cosmetics ß-carotene	 215 - 2150 kg^{-1}
Aphanizomenon flos-aquae	USA	Human nutrition	
Haematococcus pluvialis	USA, India, Israel	Aquaculture	50 L^{-1}
		Astaxanthin	7150 kg^{-1}

World production of microalgae is 15,000 t TS/ yr (Benemann, 2013)

Cultivation systems



Open systems

Closed systems

Anaerobic digestion from microalgae

Biogas as conversion technology

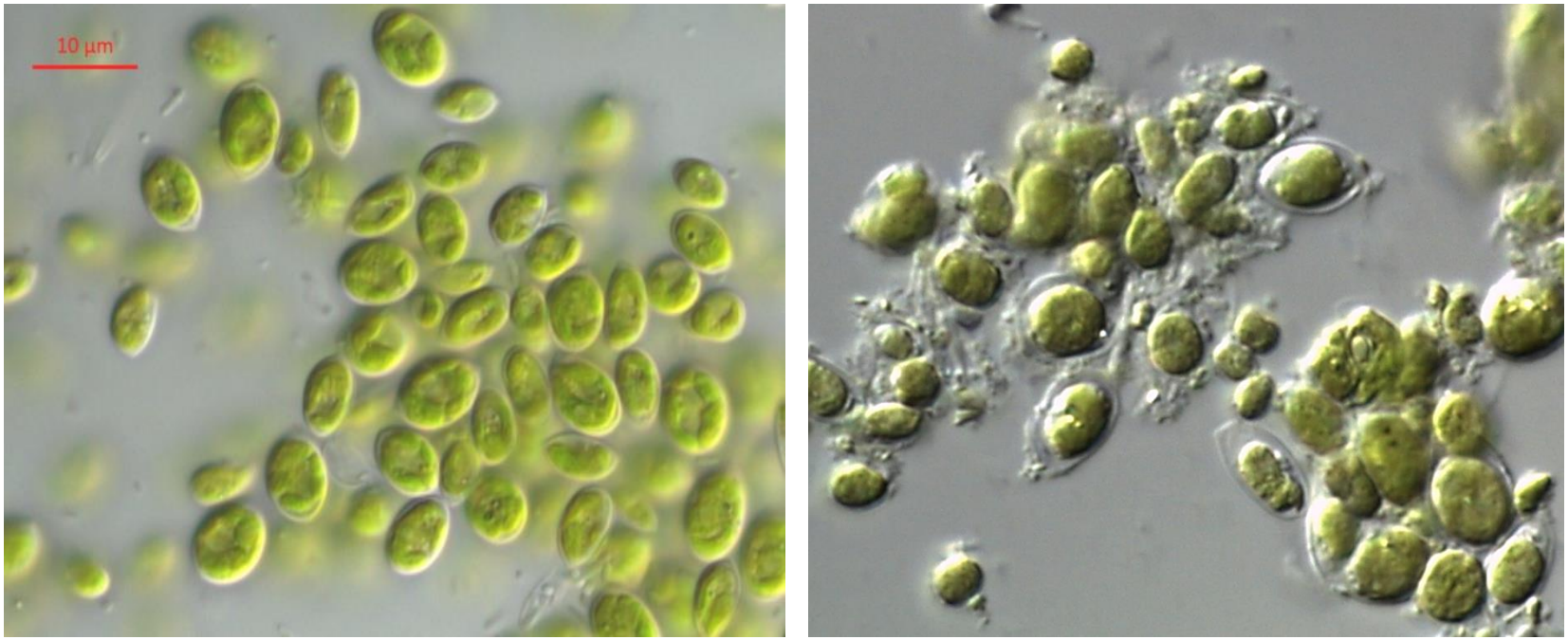
Advantages:

- No pure cultures necessary (cheaper production)
- No specific product needs to be produced (e.g. Triglycerides in biodiesel)
- Suitable as well for entire algal biomass or residue after extraction of high value product

Disadvantages:

- Some algae have thick cell walls (especially robust strains)
  → pretreatment necessary
- High protein content can lead to ammonia inhibition
  → dilution

Pretreatment of microalgae

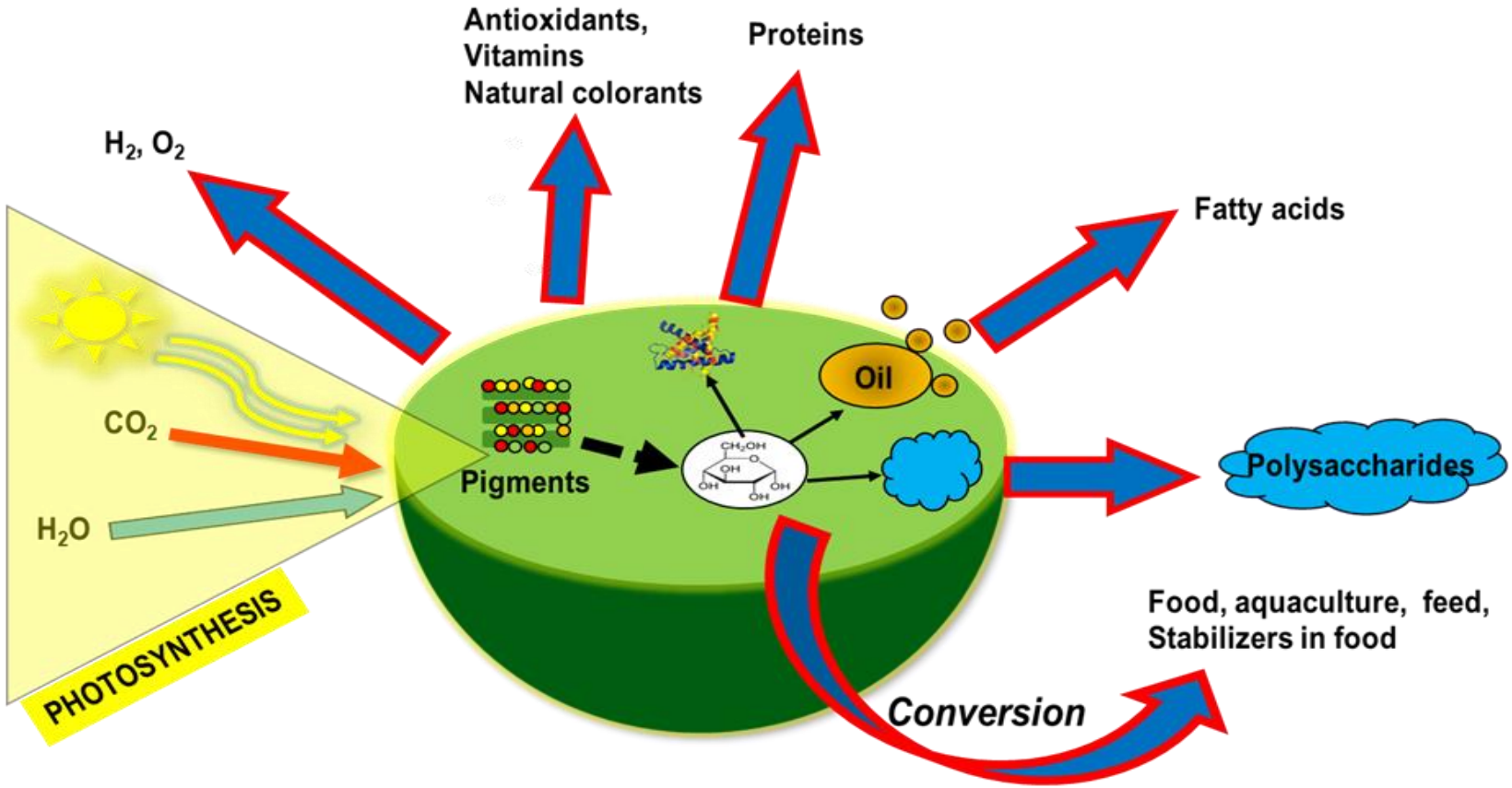


Chlorella vulgaris **before (left) and after (right) ultrasound pre-treatment**

Methane yields of microalgae

Species	CH_4 prod. [L/kg VS]	CH_4 content [%]	Literature
Arthrospira platensis	293	61	Mussgnug et al., 2010
Chlamydomonas reinhardtii	387	66	Mussgnug et al., 2010
Chlorella kessleri	218	65	Mussgnug et al., 2010
Chlorella vulgaris	310-350	68-75	Sanchez and Travieso, 1993
Dunaliella salina	323	64	Mussgnug et al., 2010
Dunaliela	420		Chen, 1987
Euglena gracilis	325	67	Mussgnug et al., 2010
Nanochloropsis spp.	312	80.5	Schmack, 2008
Scenedesmus obliquuus	178	62	Mussgnug et al., 2010
Spirulina	320-310		Chen, 1987
	424	76.3	Schmack, 2008

A more probable approach – The microalgae biorefinery



→ Residues of microalgae may be treated in a biogas plant

Synergies of microalgae production and biogas plants

Further synergies of microalgae and biogas

- Digestate utilisation

→ Digestate from biogas plants is suitable as nutrient media for algae (at least for some strains)

- Utilisation of CO_2

→ Flue gas from combustion of biogas has a comparable high CO_2-content

→ CO_2-rich offgas from biogas upgrading

- Utilisation of waste heat

Digestate as Nutrient Source

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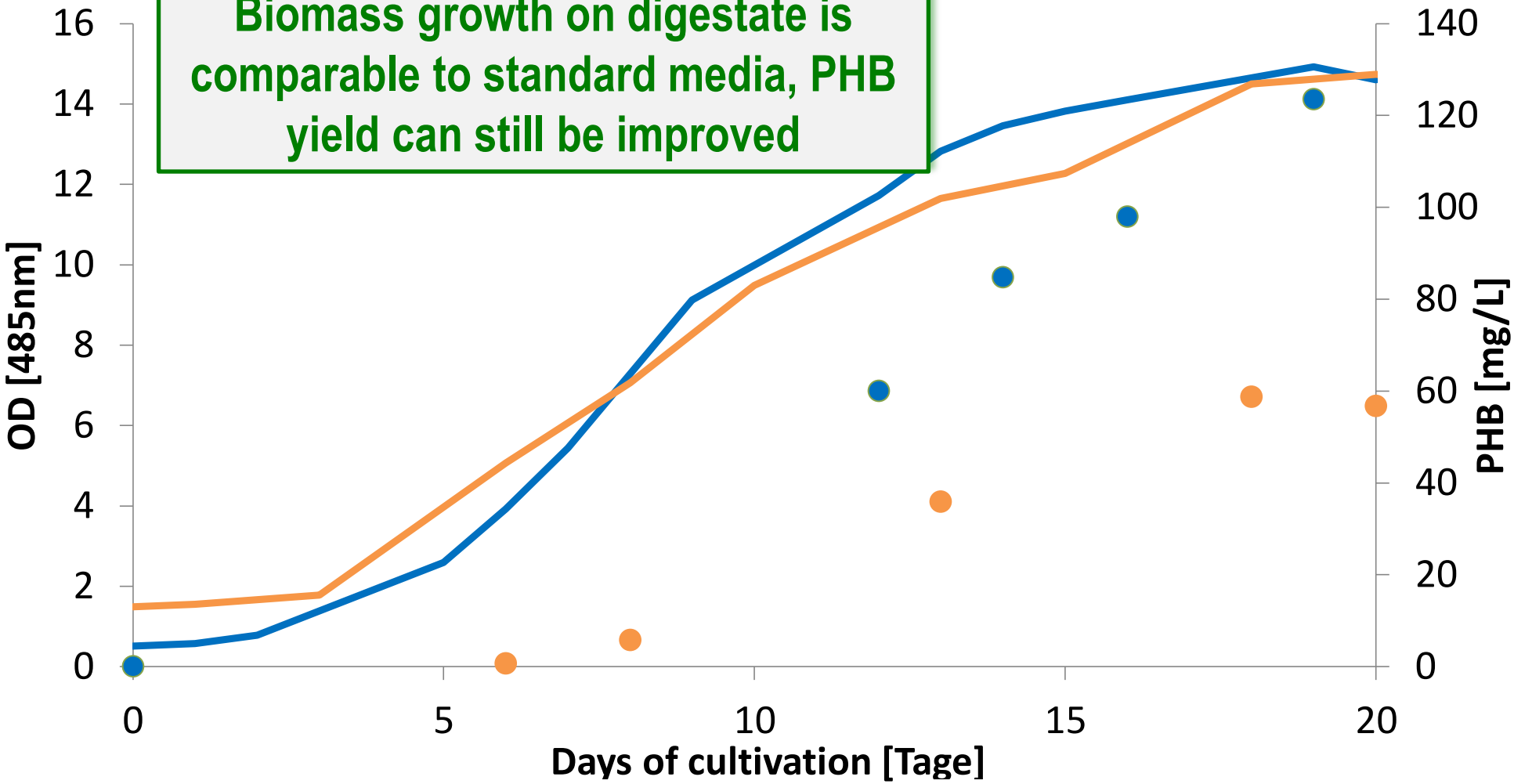
Growth comparison with standard media (*Synechocystis salina*)

Biomass growth on digestate is comparable to standard media, PHB yield can still be improved



Conclusions: AD of microalgae

- World production of microalgae biomass is much less than seaweed (almost 1,000 times)
- Microalgae can possess thick cell walls

→ Demand for pretreatment technologies

- Most probable approach: Microalgae biorefinery

→ Residues may go to anaerobic digestion

- Synergies between biogas plants and microalgae cultivation

→ Use CO_2 from biogas (e.g. after upgrading to biomethane)

→ Use nutrients from digestate as growth media

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