HELMHOLTZ Zentrum für Umweltforschung

BIOENERGY-
Chances and Pitfalls

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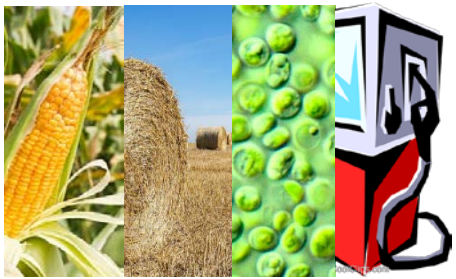
What is BIOENERGY?

- BIOENERGY is a form of energy that originates from biomass by converting it into electrical energy, heat, or fuel.
- This biomass can be regarded as biogenic fuel (or biofuel), i.e., fuels of biological-organic origin.
- In their chemical bonds, biofuels store solar radiation energy, which has been fixed by plants as primary producers through photosynthesis.
- This energy can be released again, usually through combustion.

Wikipedia 09/2021

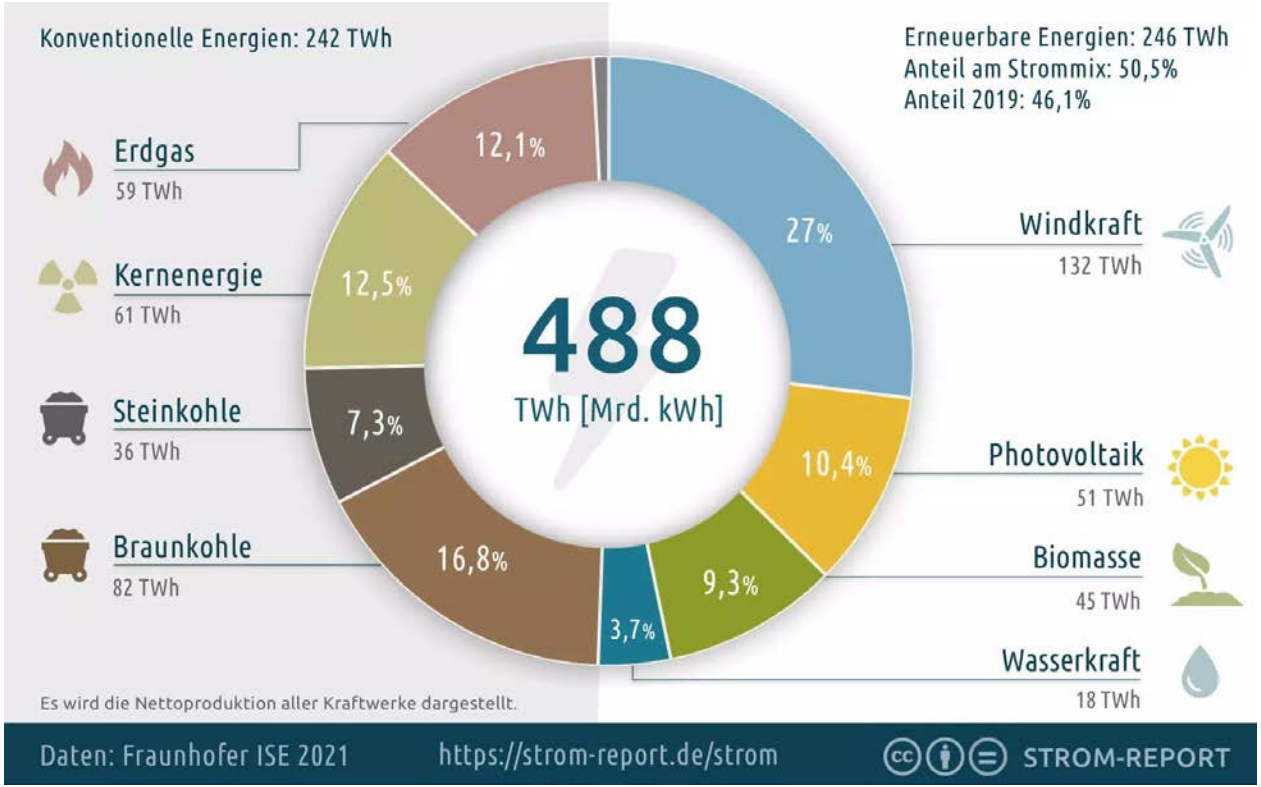
What is BIOENERGY?



	Bioenergie	
Heat production	*Fuels*	*Electricity*
Wood	Biomethane	Biogas (CH_4)
Biogas (CH_4)	Biodiesel	Biomass cogeneration plants
	Bioethanol	H_2
	Butanol, Methanol, H_2	

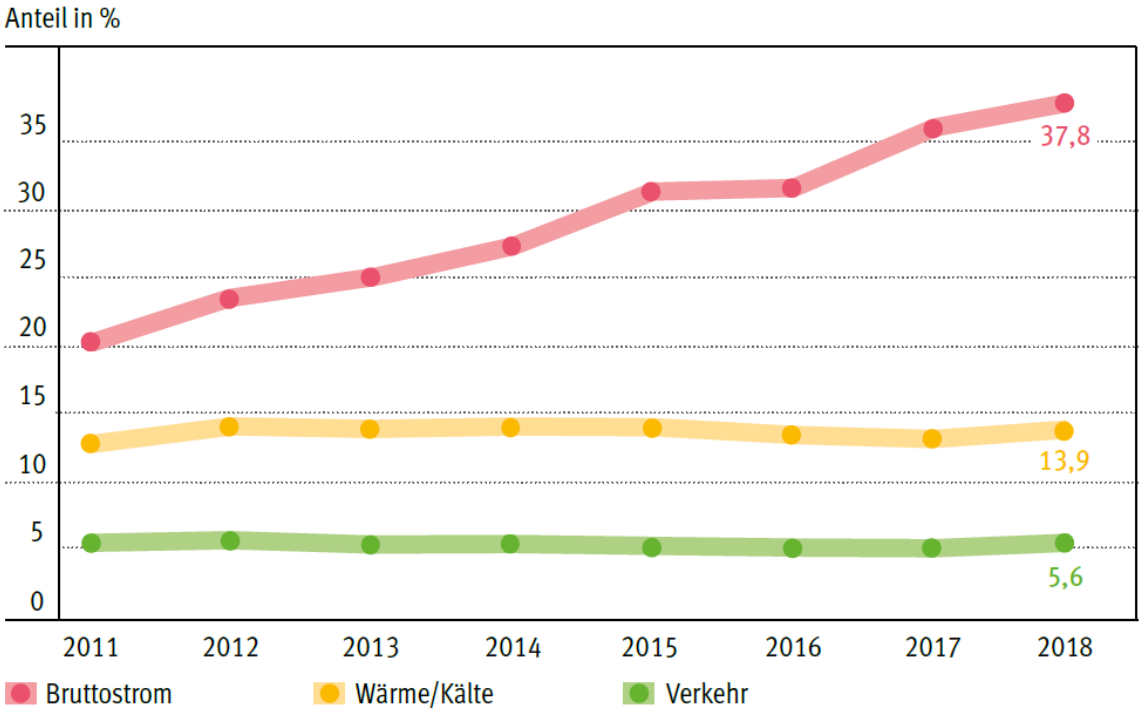
Where is Bioenergy established?

Energy mix in Germany 2020



Where is Bioenergy established?

Energy mix in Germany 2018

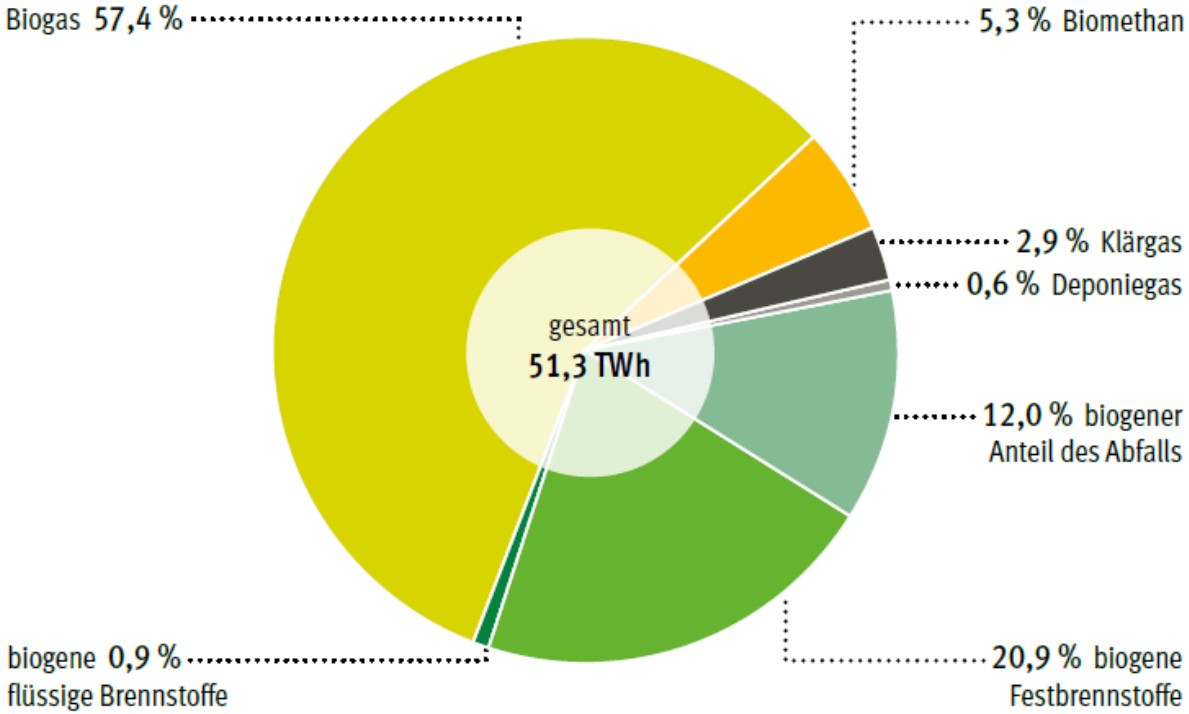


Quelle: BMWi, AGEE-Stat (Februar 2019)

Which energy sectors profit from renewable energy?

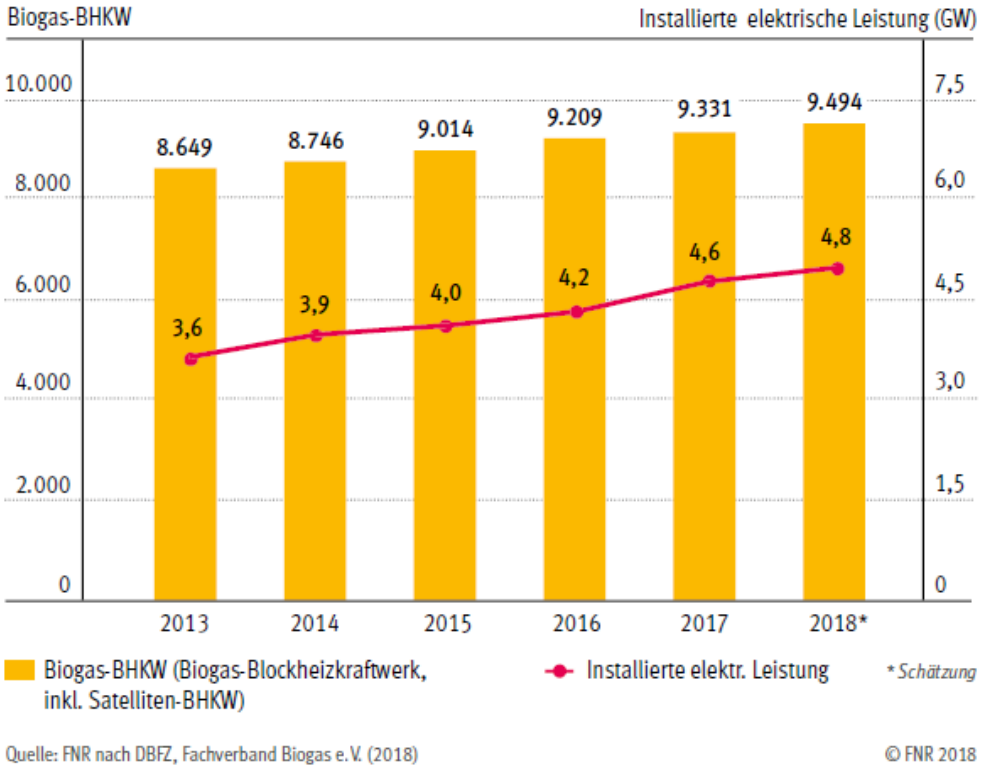
Where is Bioenergy established?

Energy mix in Germany 2018



Where is Bioenergy established?

Energy mix in Germany 2018

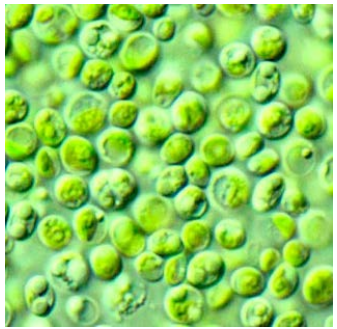


Limitations of BIOENERGY

Biomass availability

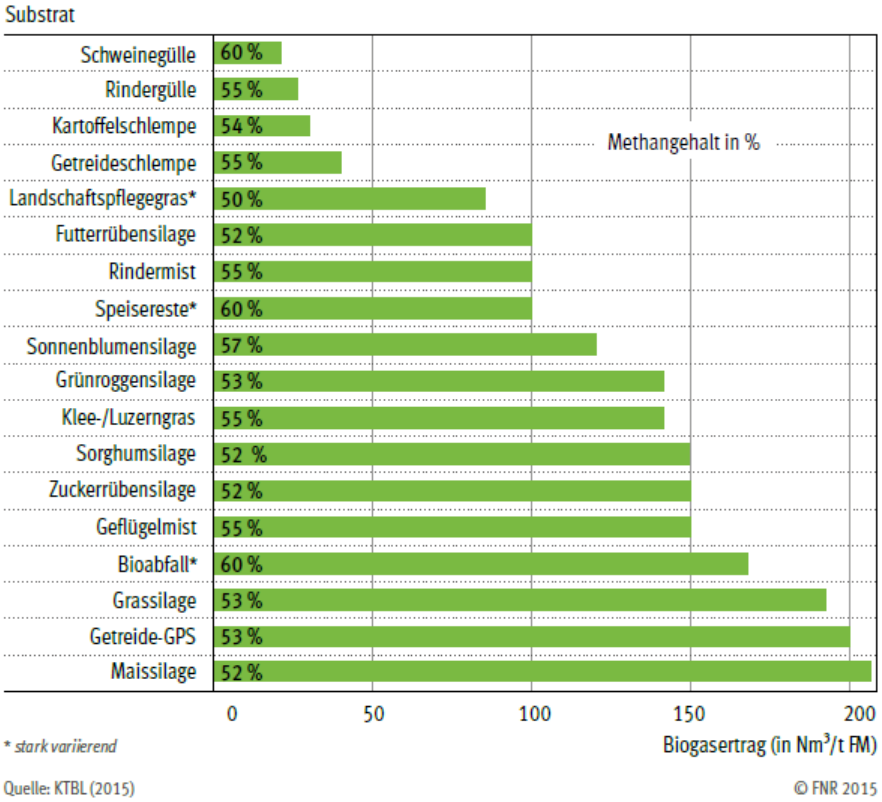
There are various biomasses to utilize

- wood
- agricultural raw materials
- algae
- organic residues (waste streams) from various sectors (food and feed or paper industry)



Limitations of BIOENERGY

Biomass quality

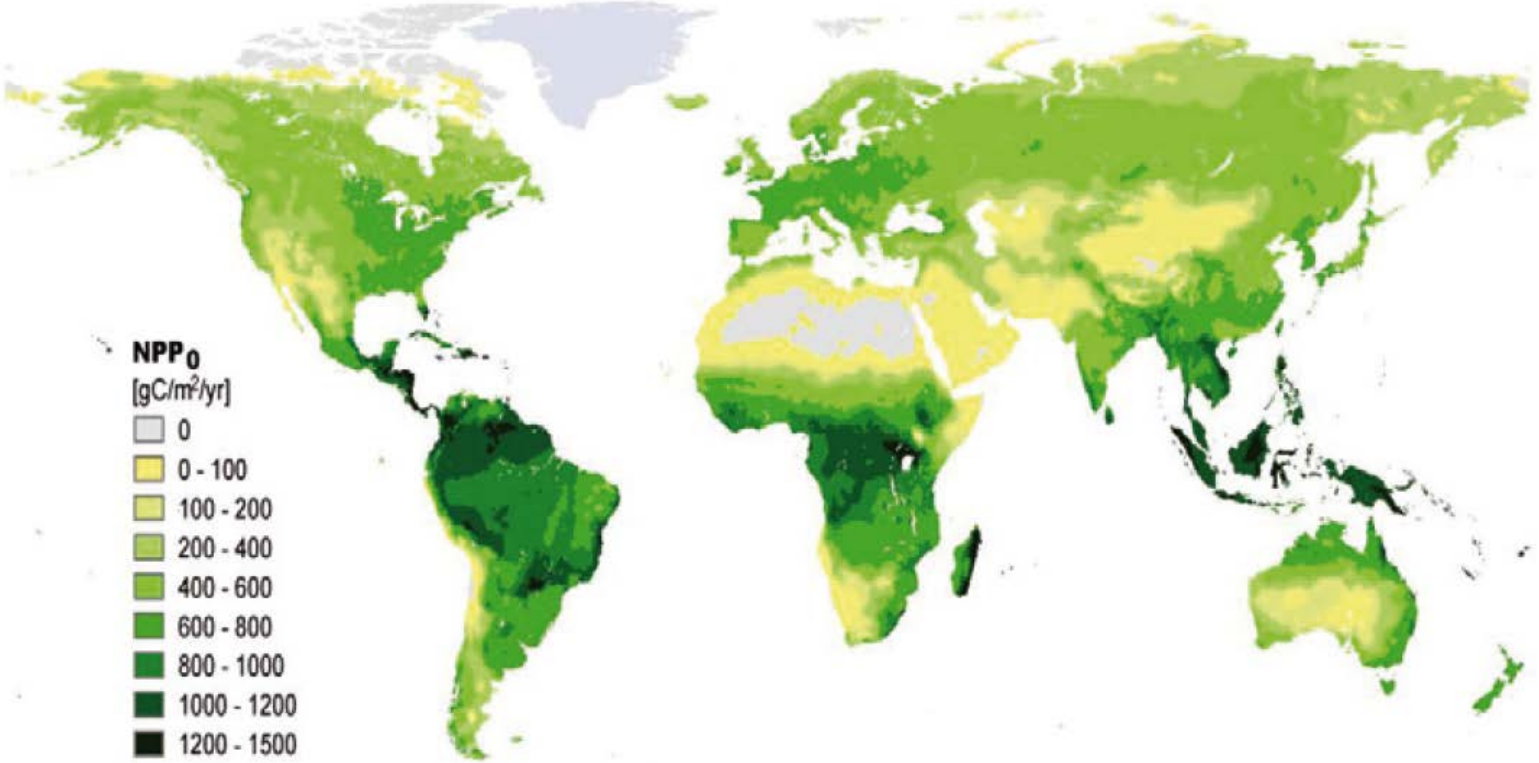


Depending on the origin of the biomass, energy yields vary significantly!

Limitations of BIOENERGY

Biomass availability

Net primary production (NPP) is the amount of plant biomass that grows in a given area within one year.



Leopoldina, 2012, Bioenergie Chancen und Grenzen

Limitations of BIOENERGY

Biomass availability

Net primary production (NPP) is the amount of terrestrial plant biomass that grows in a given area within one year.

Translated into numbers:

- total global surface area is 510 x 10^{12} m^2
- the terrestrial surface area is about 150 x 10^{12} m^2
  - 100 x 10^{12} m^2 is covered with vegetation
    - 41.6 x 10^{12} m^2 (28%) forests
    - 50 x 10^{12} m^2 (33%) agriculture
      - 15 x 10^{12} m^2 (10%) is cropland
      - 34 x 10^{12} m^2 (23%) is grassland and pasture
  - Rest is deserts, mountains, tundra, cities and other agriculturally unsuitable land

Leopoldina, 2012, Bioenergie Chancen und Grenzen

Limitations of BIOENERGY

Biomass availability – Germany (in Mio tC / a)

≈210, ≈160 over ground;
≈ 118 are harvested or grazed (≈70%)

<u>These 118 Mio t are distributed as follows:</u>

Food & Feed	≈ 53
Wood	≈ 14
Straw	≈ 20
Grazed	≈ 20
Other	≈ 11
NPP imported	**≈ 50**

- Intensive agriculture almost always leads to increased emissions of the greenhouse gases nitrous oxide (N_2O) and methane (CH_4)
- Due to land management, animal husbandry, and the use of fertilisers.
- Regardless of whether food, livestock feed, or energy crops are grown on the fields.

Leopoldina, 2012, Bioenergie Chancen und Grenzen

Limitations of BIOENERGY

Conversion efficiency (numbers cover 2006 to 2010)

	Solar Radiation		Bound in Biomass		
	Energy [EJ]	Power [TW]	Energy [EJ]	Power [TW]	Conversion efficiency
Solar Energy / NPP total	526651	16700	2200	70	0,42%
NPP overground			1300	41	
NPP useable			650	21	
Solar energy used for energy	1,3	0,36			
Global primary energy demand	500	16			

Leopoldina, 2012, Bioenergie Chancen und Grenzen

Limitations of BIOENERGY

Conversion efficiency

- **4.5%** of the irradiated light energy can theoretically be bound in biomass (theoretical maximum); **on average 0.4%** (!)
- If only the reactions up to glucose are considered, the theoretical maximum is **9 - 12%.**

- Only long-wave length light can be absorbed by the photocentres
- Much is lost as heat
- Only a fraction of the photosynthetically active surface is in an optimal environment (shading, too high light intensities, etc)
- In addition, energy consumption for biomass build-up, metabolism, reproduction, etc...

- In comparison: efficiency of commercial photovoltaic cells: **14-23%** => electrical energy (record currently 44.7% Frauenhofer ISE Berlin)

Barber, J. (2009) Chem Soc Rev 38:185; Frauenhofer ISE Berlin; Blankenship et al. (2011) Science 332:805

Limitations of BIOENERGY

Biomass availability – Conclusion

- Only if the fertilisation of crops is kept at a low level, if the conversion rate of biomass to biofuels is high, and if the need for fossil fuels in the conversion of biomass to biofuels is low, greenhouse gas emissions can be significantly reduced compared to those resulting from the burning of fossil fuels

- In the context of biomass production for bioenergy ecological and social implications needto be carefully evaluated

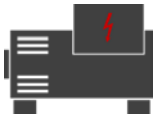
Novel Developments

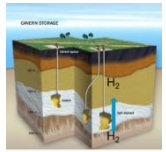
Next generation biorefineries – process integration

Electricity from waste via bioelectrochemistry

Dai *et al* (2021) *Front Chem Eng* 3 art. 652445

Rosa *et al.* (2017) *J Power Sources* 356:319





Gas storage

Biomethanation

Logroño *et al.* (2021) *Front Microbiol 12 , art. 619632*

Logroño *et al.* (2020) *Microorganisms 8 , art. 614*

Biogas production on demand

Mulat *et al.* (2016) *Appl Environ Microbiol* 82:438

Wastewater valorization

Becker *et al.* (2020) *Eng Life Sci* 20:90

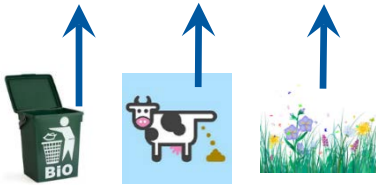
Aurich *et al.* (2017) *Org Proc Res Dev* 21:866

Moeller *et al.* (2017)*Energy Sustain. Soc* 7

Waste management

Weiner *et al.* (2017) *Environ Sci Technol* 51:1649

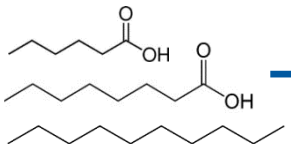
Pörschmann *et al.* (2017) *ACS Sustain Chem Engineer* 5:6420



Resilience and adaptation of AD microbiomes

Wintsche *et al.* (2016) *Frontiers Microbiol* 7:2034

Popp *et al.* (2017) *Appl Environ Microb* 83:e00438-17



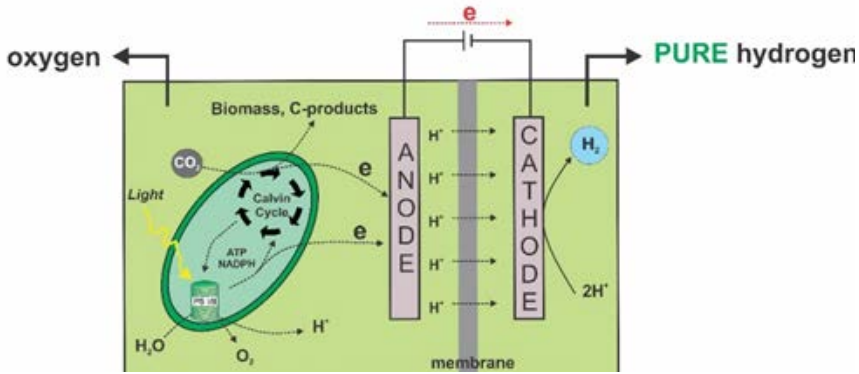
Alternative products: medium chain fatty acids (MCFA) → alkanes

Baleeiro *et al.* (2021) *Front Bioeng Biotechnol 9 ,* art. 725443

Urban *et al.* (2017) *Energy Environ Sci* 10:2231

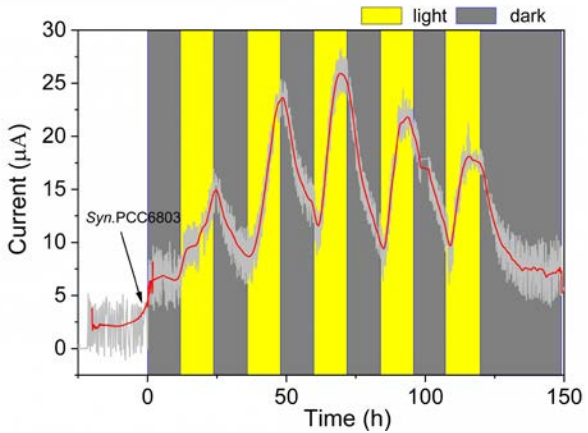
Novel Developments

Next generation biological fuel cells (BPVs)



Biophotovoltaics enables:

- Bio-based light to electricity / H_2 conversion
- Separation of O_2 and H_2 in a single device
- Splitting of water at 1/2 to 1/3 of the energy input of PEM or alkaline electrolysis



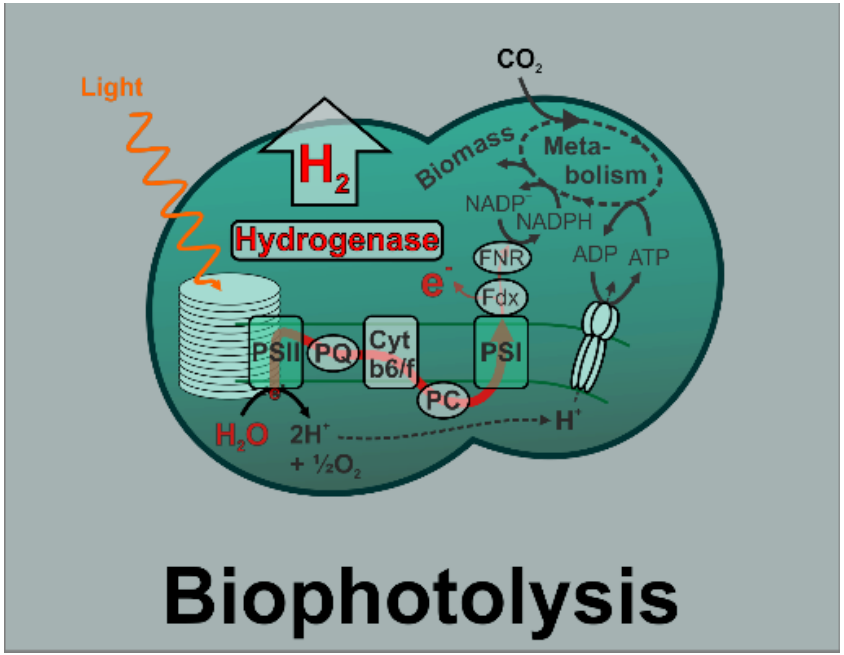
Courtesey of Dr. Jens O. Krömer and Dr. Bin Lai

Novel Developments

White Hydrogen (H_2 via bioartificial photosynthesis)

The concept of ‚white H_2' production is based on:

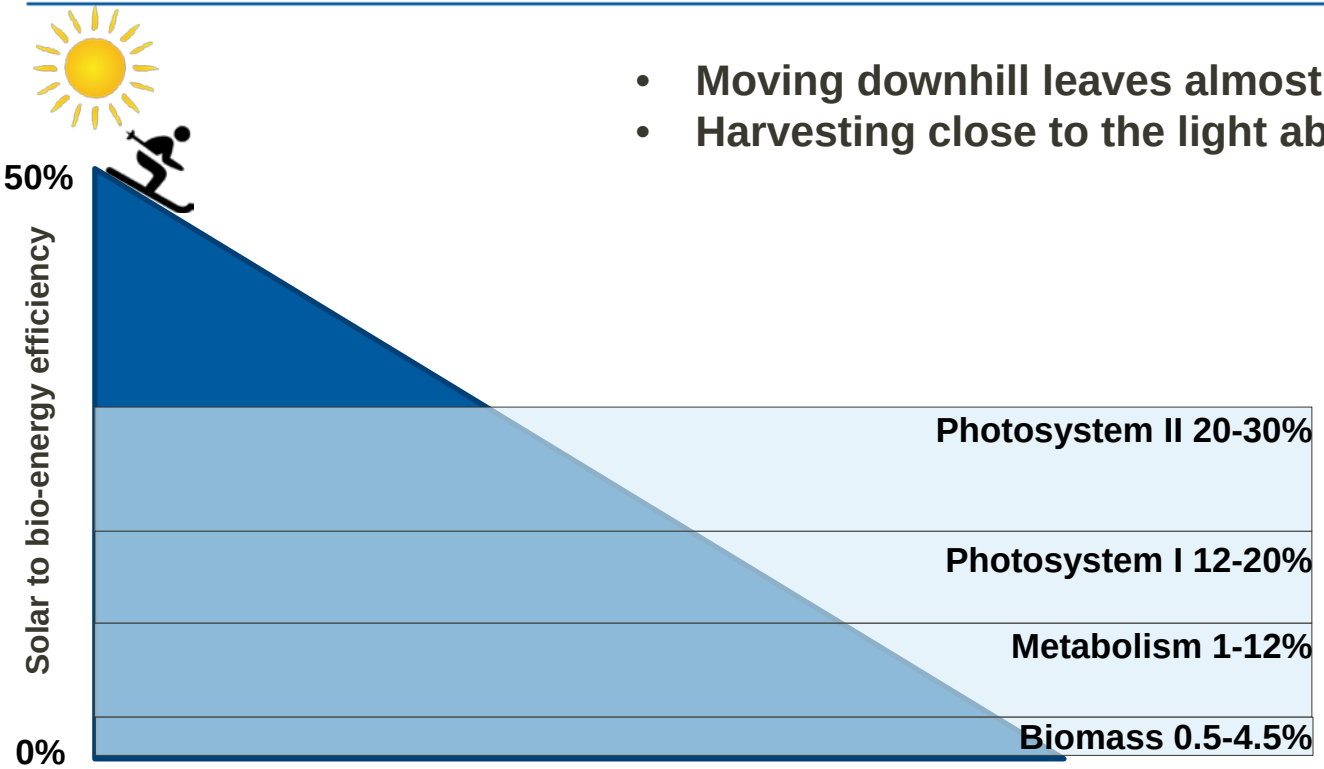
- photoautotrophic microbes,
- natural photosynthesis and its…
- water splitting reaction,
- H_2O and light as substrates.

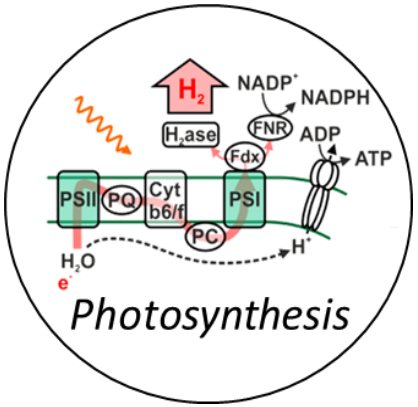


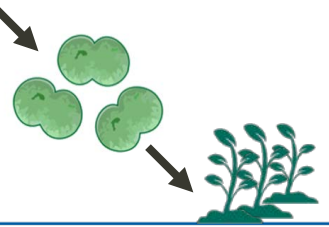
Novel Developments

White Hydrogen using Cyanobacteria as workhorse

- Moving downhill leaves almost NO useable energy
- Harvesting close to the light absorption reaction is key!







BIOENERGY – Final Conclusions & Outlook

- Biomass is a renewable carbon source BUT: **it is NOT available in unlimited quantities** and its production (and use) is **NOT sustainable and climate-friendly per se**.
- Bioenergy can make a significant contribution to the energy supply of the future by harnessing its full energy potential.
- To realise this potential, the efficiency of conversion pathways for bioenergy use is crucial. Processes must be **highly integrated into energy and material flows to avoid energy losses and the generation of waste**.
- A prerequisite for the use of biomass for energy production is the sustainable use of residues and the **material recycling of all material flows**.
- Solar cell factories have a huge potential and we are just starting to understand how to utilize it.

BIOENERGY – Chances and Pitfalls

Thank you for listening!