Assessing the potential of photoelectrochemical carbon removal as negative emission technology

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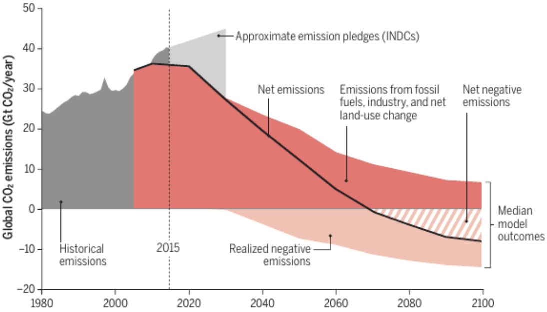
Negative emissions



- Anthropogenic emission rates are reduced too slowly

→ Almost all climate models assume negative emissions, where energy is invested to sequester atmospheric CO_2, starting from 2030

- Type of technology and costs still very speculative

[1] Anderson and Peters, *Science* **354** (2016). [2] Hansen et al., *Earth Syst. Dyn.* **8** (2017).

Technologies

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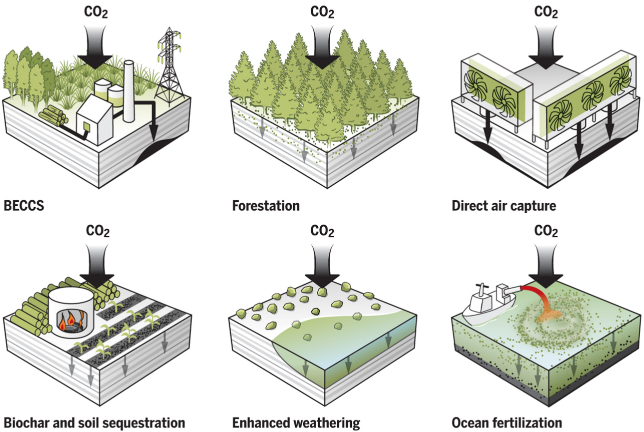

- Most considered technologies are based on natural photosynthesis
- Sequestration of CO_2 itself mainly relies on (safe) mineral trapping [2]

[1] J. Rosen, *Science* **359** (2018). [2] Smith et al., *Nat. Clim. Change* **6** (2016).

- Scalable!
- Long-term storage feasible
- *Energetic* efficiency ca. 2-3% [1]

→ **Large areas** [2,3]:

- 10 Mio. km^2 for dedicated crops

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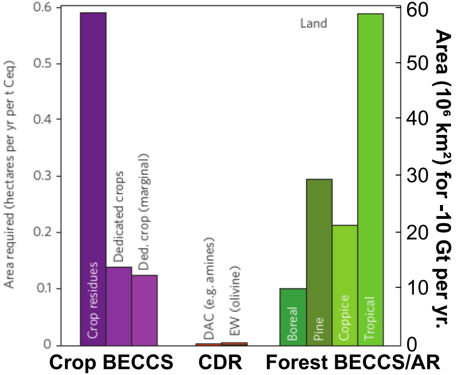

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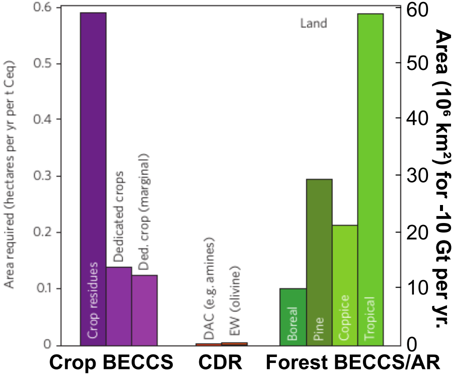

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Efficiency as the bottleneck!

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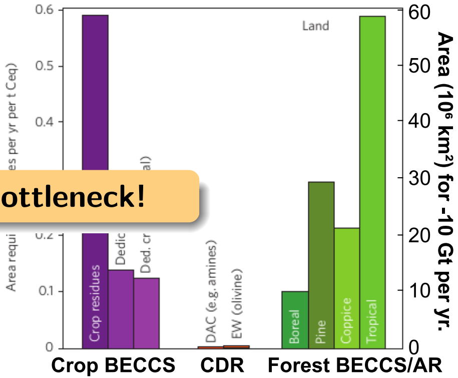

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Artificial Photosynthesis

- (Photo)electrochemical CO_2 reduction
- PV-coupled to dark electrolysis **or**
- Integrated systems

→ Challenges of PV & electrocatalysis

- For hydrogen, with 19% energetic efficiency about 10x more efficient than its natural counterpart [1]
- Negative-emissions-hydrogen [2]

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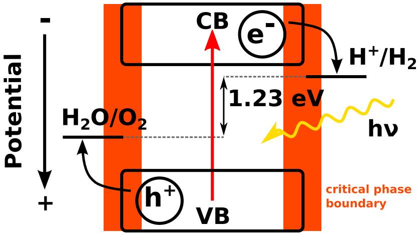

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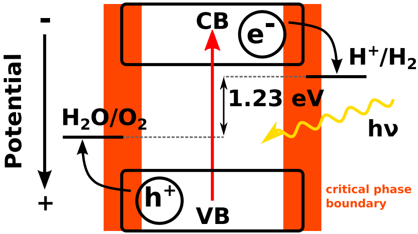

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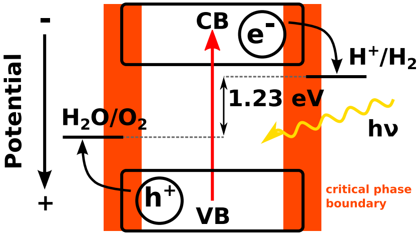

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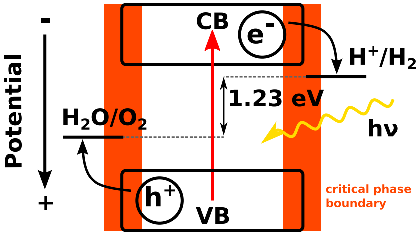

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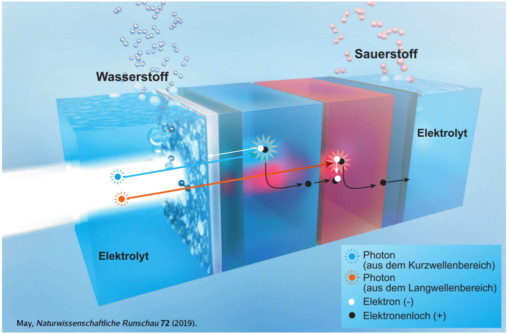
High efficiency



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- Suitable bandgap combinations, efficient catalysis
- Model using detailed balance, $\eta(j)$ from catalysis [2]

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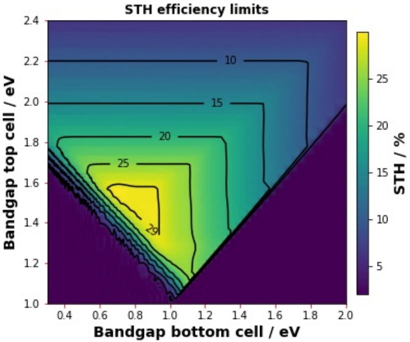

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  $\mathrm{STF} \sim \frac{j\Delta G}{P}$

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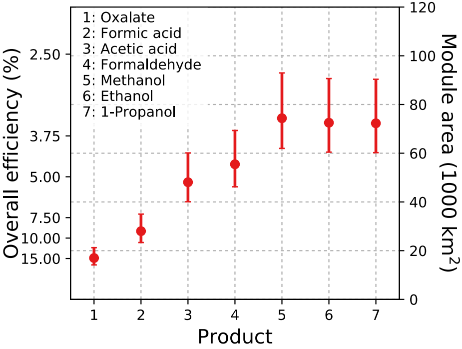
- Solar-to-carbon (STC) [2]:

  $\mathrm{STC} = \frac{\eta_F \eta_e j_e}{j_{ph}}$



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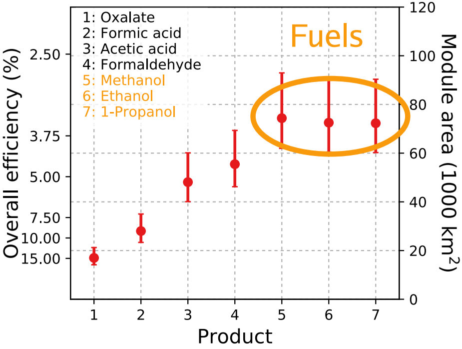

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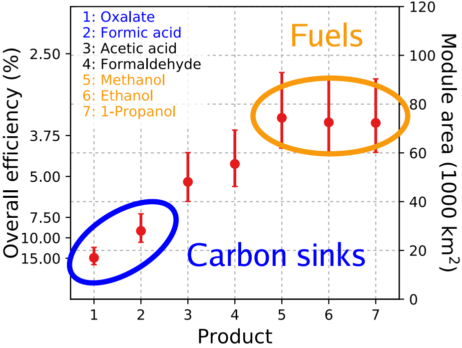

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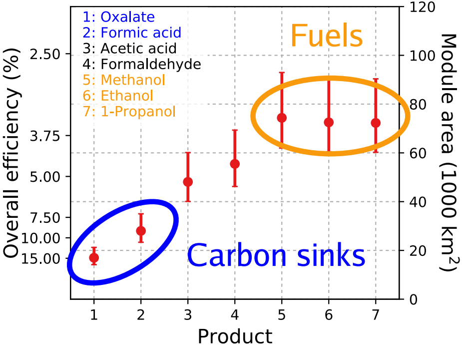

Limits about 10-20$\times$ of (achieved) nat. photosynthesis

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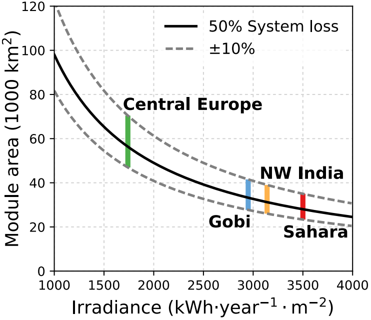
Required area



- Desert areas interesting due to high irradiance
- Water consumption (formate): ca. 5 km^3 as opposed to > 2000 km^3 for biomass [2]

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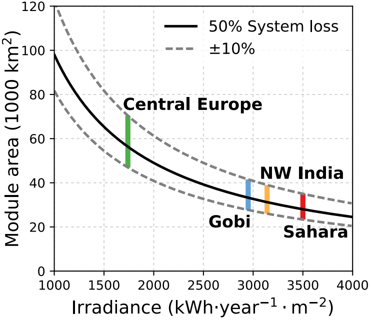

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Storage

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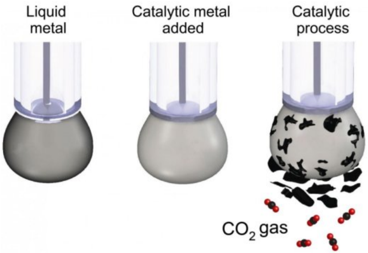
- Chemical post-processing, e.g. oxalate to organic minerals [1]
- Electrochemical production of solid carbon demonstrated [2]
- Organic construction materials?



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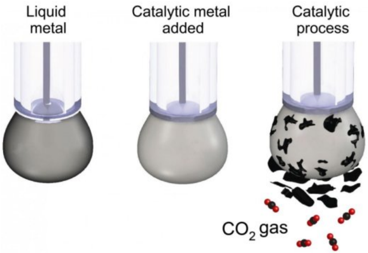

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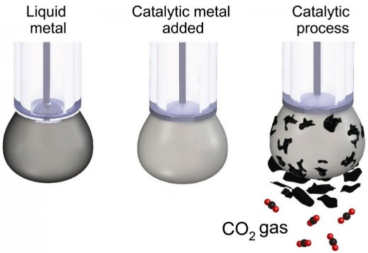

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Summary & Outlook

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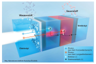

Artificial photosynthesis reduces land and water footprint, but will probably be expensive

→ **Solar-To-Carbon** efficiency as benchmark for evaluation

Wide range of liquid or solid products feasible ↔ storage

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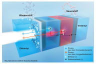

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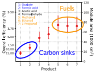

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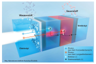

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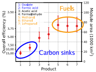

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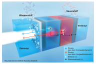

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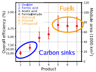

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Thanks for your attention!

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Leopoldina Nationale Akademie der Wissenschaften

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