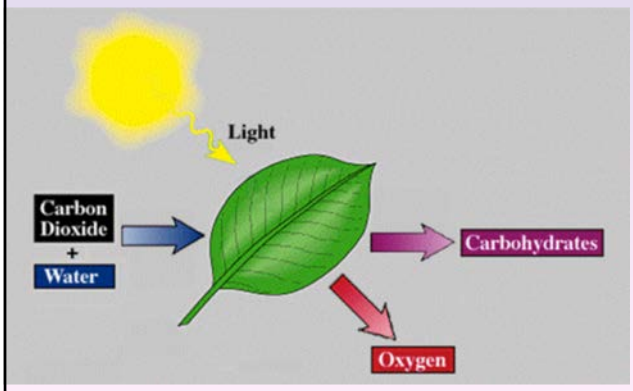
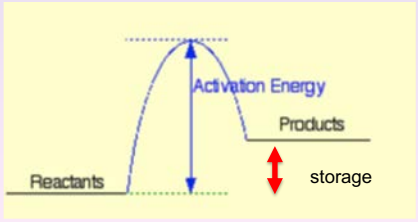
What

Natural photosynthesis…





…Storing energy in chemical bonds

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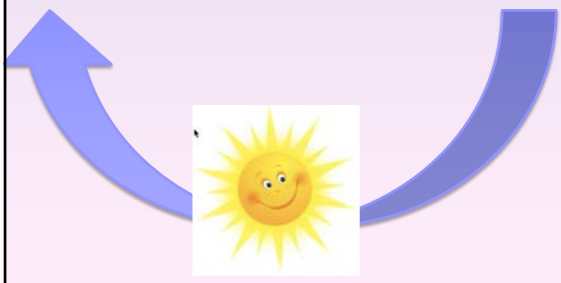
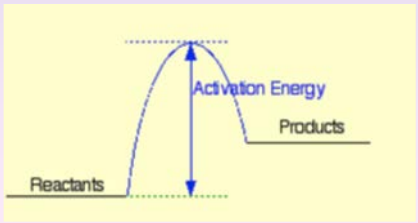
What

Artificial photosynthesis…

Fuel + O_2 ⟹ XCO_2 + H_2O plus energy





…Storing energy in chemical bonds

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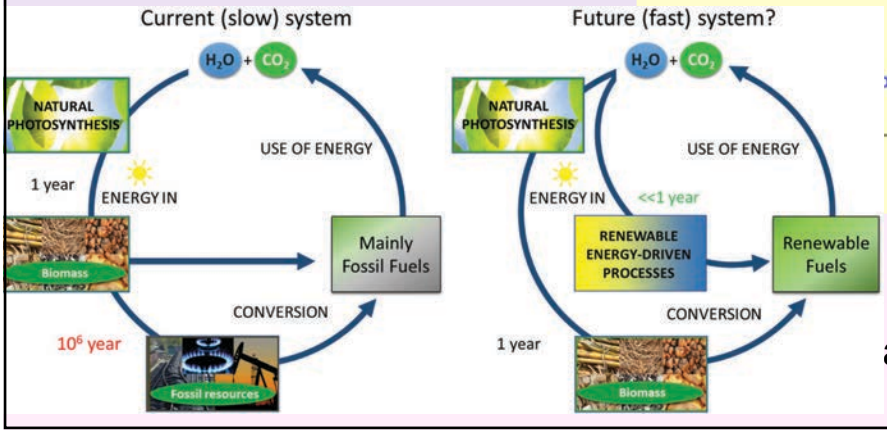

Products

al bonds

Why

2018: New law for climate (Klimaatwet)

5% CO_2 emission in 2050

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Why

2018: New law for climate (Klimaatwet)

5% CO_2 emission in 2050

Why

CO_2-neutral energy

Why

Issue 1: CO_2-neutral energy= intermittent

Cope with
day/night fluctuation
Summer/winter

1 may 2018

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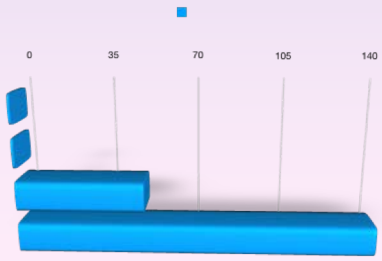
Storage of energy is important

Energy density per Kg

Compressed air (300 atm)	~ 0.5 MJ kg-1
battery	~ 0.1-0.5 MJ kg-1
Liquid fuels	~ 50 MJ kg-1
H_2 (700 atm)	~ 140 MJ kg-1



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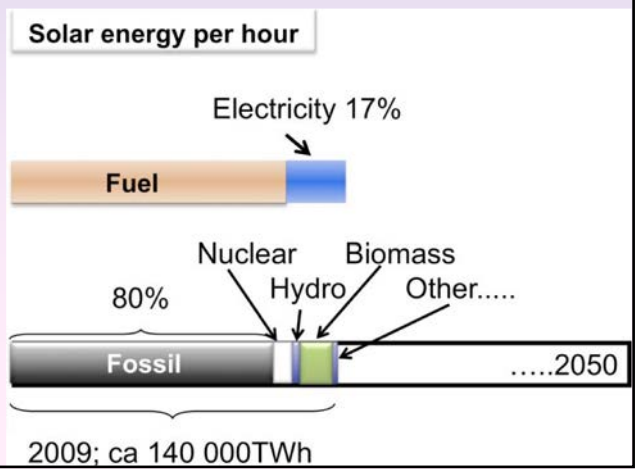
Why

Issue 2: We still need fuel for heavy applications

Current use →



140 x10^{12} Tesla batteries

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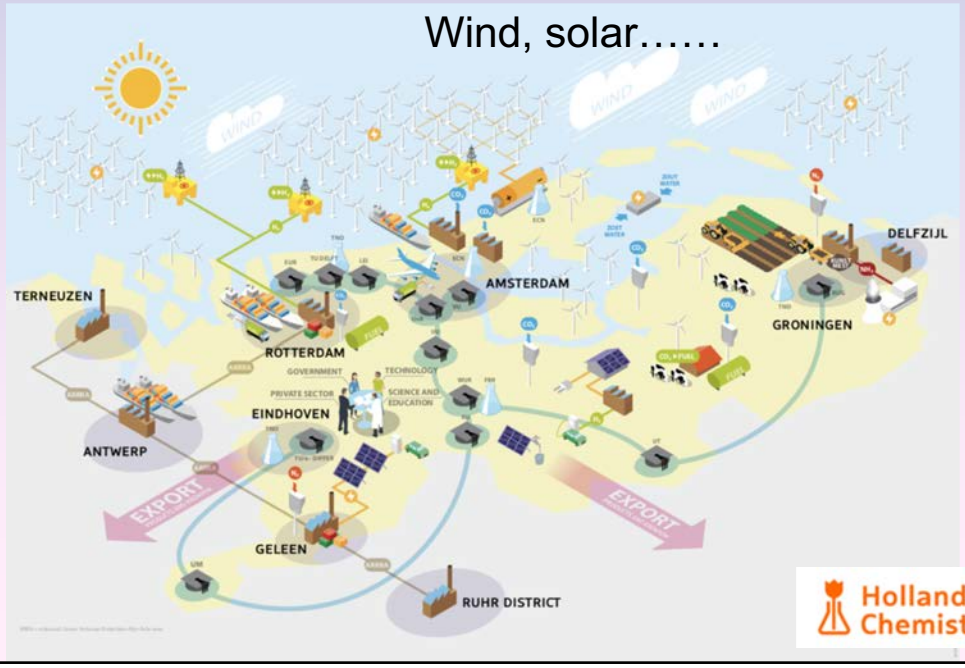
Future

Why

Wind, solar……



Holland Chemistry

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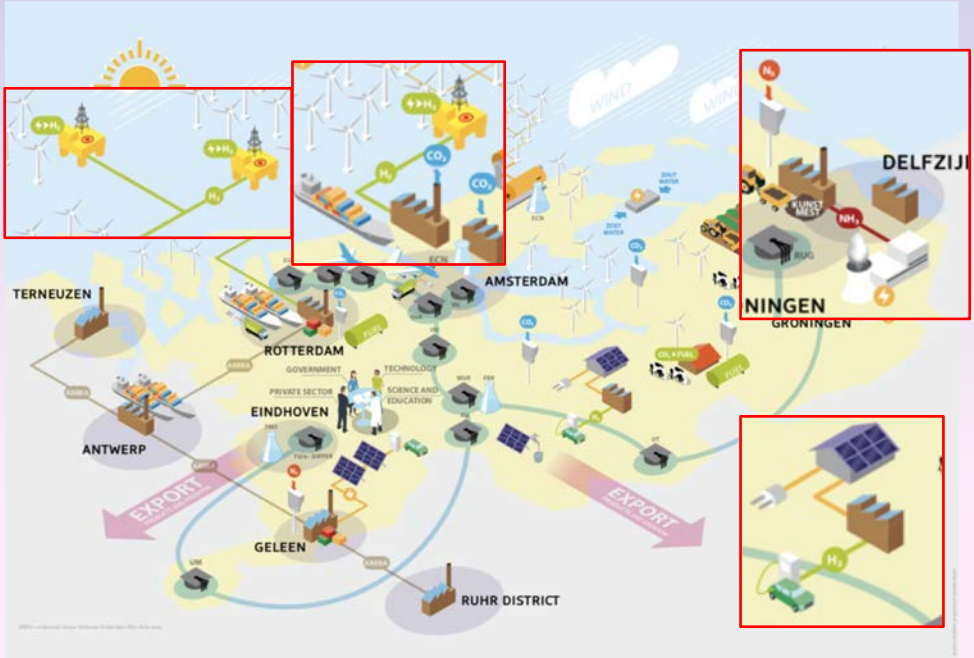
Wind, solar……chemistry



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Wind, solar……chemistry

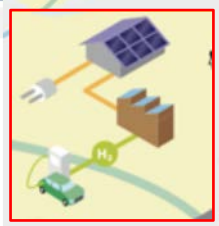
Port of Rotterdam

HOME > NEWS

ENERGY TRANSITION NEWS 21 March 2019

Kick-off for designing a gigawatt electrolysis plant

In order to provide the Dutch industry with sustainable hydrogen much needs to be done. Sustainable hydrogen can be generated by means of water electrolysis, utilizing electricity from wind and sun. Bringing that to an industrial level requires a thousandfold scale-up of existing technology. This is in fact the aim of the 'Gigawatt Electrolysis Factory' project that recently kicked-off at the Institute for Sustainable Process Technology.



NEWS RELEASE 17-JAN-2020

Thousand-ton scale demonstration of solar fuel synthesis starts operation in Lanzhou, China

CHINESE ACADEMY OF SCIENCES HEADQUARTERS

SHARE PRINT E-MAIL

The world's first demonstration project for direct solar fuel synthesis started operation in Lanzhou, China on Jan. 17, 2020. The project represents that China now takes the first step in the world for industrial production of liquid fuels from solar energy.

Overall, the project converts carbon dioxide, water and solar energy into transportable liquid fuels such as methanol by taking advantages of three technological units: solar photovoltaics to generate electricity; electrolyzer to split water producing hydrogen; and CO2 hydrogenation to produce methanol in the end.

IMAGE: EQUIPMENT FOR CO2 HYDROGENATION TO PRODUCE METHANOL. view more ›

CREDIT: DICP

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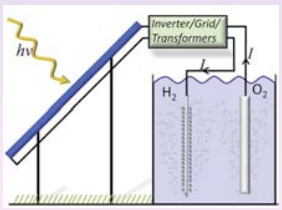
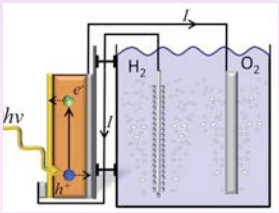
How

Most simple $2H_2O \longrightarrow O_2 + 2H_2$

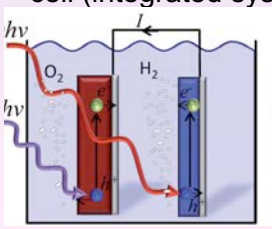
PV + electrolysis
(two system approach)



- PV + electrolysis
  (integrated system)



- Photoelectrochemical
  cell (integrated system)



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Solar Fuel

- PV-Electrolysis

Around 10-15% efficiency
Scalable!

Triple junction PV + Electrolysis

- PV-Electrolysis

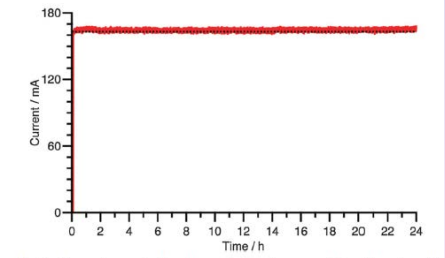
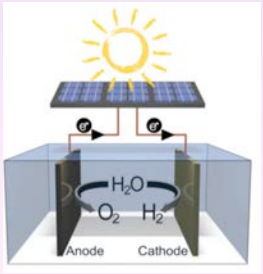


Fig. 3 Current generated by the modular system combining the solar cell and a water splitting cell. Utilising a GaInP/GaAs/Ge multi-junction solar cell and Ni electrodes in 1 M NaOH at room temperature. Stable current over 24 h testing of light driven water electrolysis corresponds to an SFE = 22.4%. Dashed black line indicates the solar cell short-circuit current while the red curve shows the water splitting current.

Spiccia et al. 2015

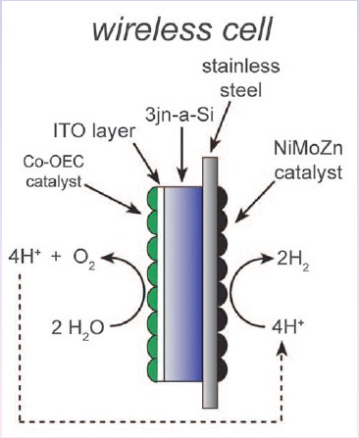
- 22% STH efficiency
- Expensive triple junction PV
- Concentrated light
- Cheap Ni-catalysts

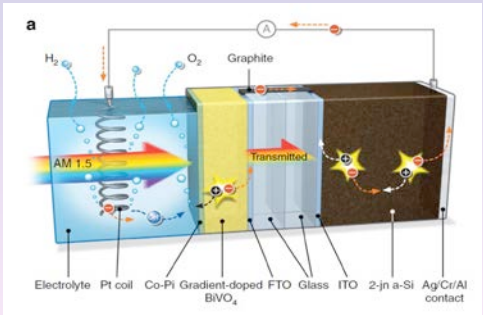


Around 22% efficiency

Inorganic devices

PV/electrolysis Integrated devices





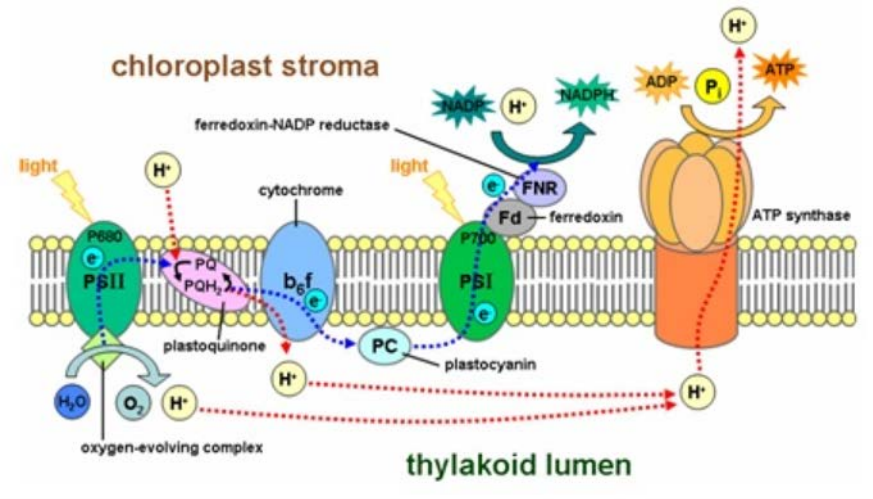
Dam, vd Krol et al. **Nat Commun** 2013

- 2-4% STH efficiency
- Platinum free!
- 3jn-a-Si needs protection, not stable in water
- Efficiency too low

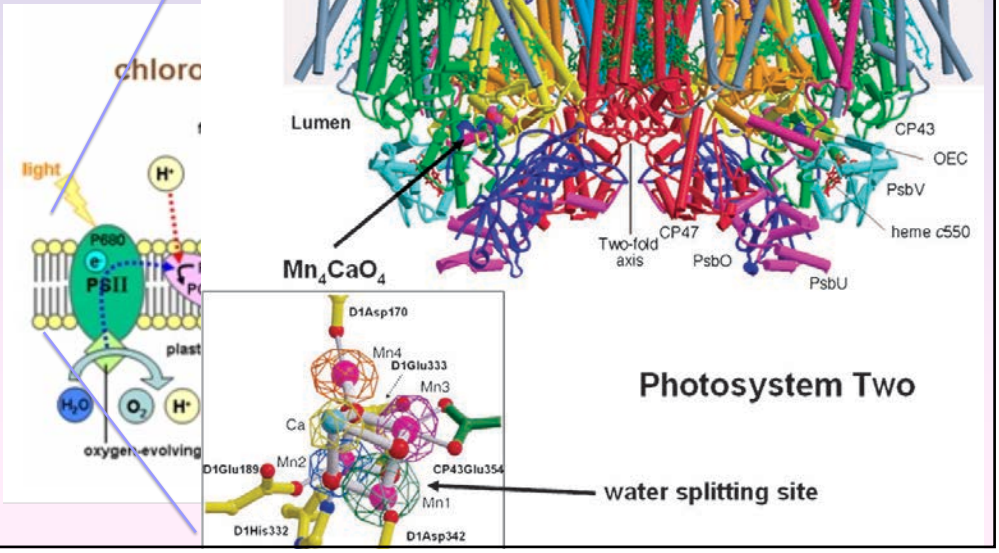
Around 5-10% efficiency

Nocera et al. Science 2011

Natural photosynthesis



Natural p

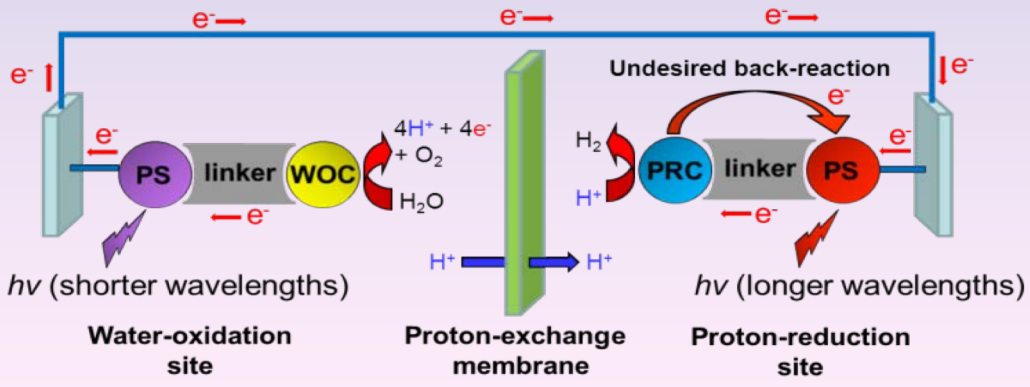


Why artificial photosynthesis for energy ….
……..and not photosynthesis

We need efficiency!!

Inspiration from Nature: molecular based devices

Solar to fuel device based on molecular components

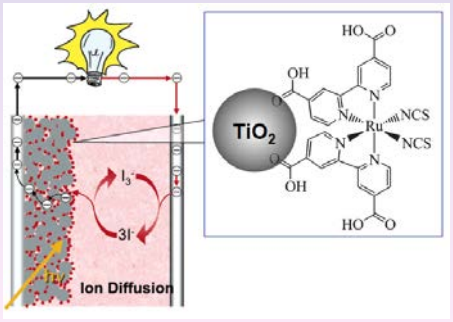


Ir, Ru, Ni, Fe

Co, Ni, Fe

Artificial Photosynthesis

Dye-sensitized solar cells (DSSC)



Michael Grätzel

O'Regan, Grätzel, Nature **1991**, *353*, 737-739

N-type DSSC

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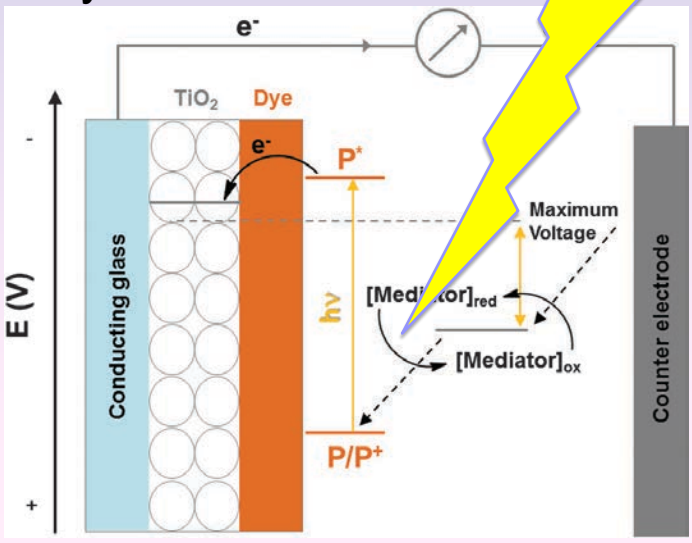
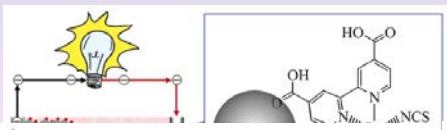
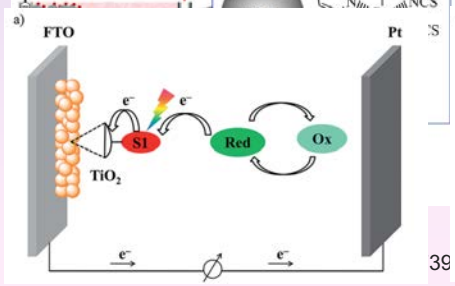
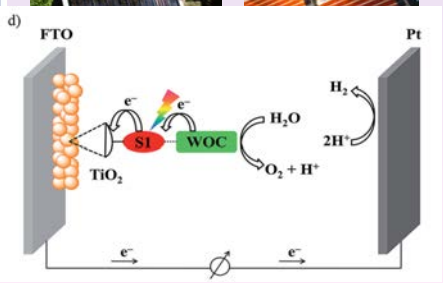
Dye-sensitized solar cell (DSSC)



Dye-sensitized solar cells (DSSC)



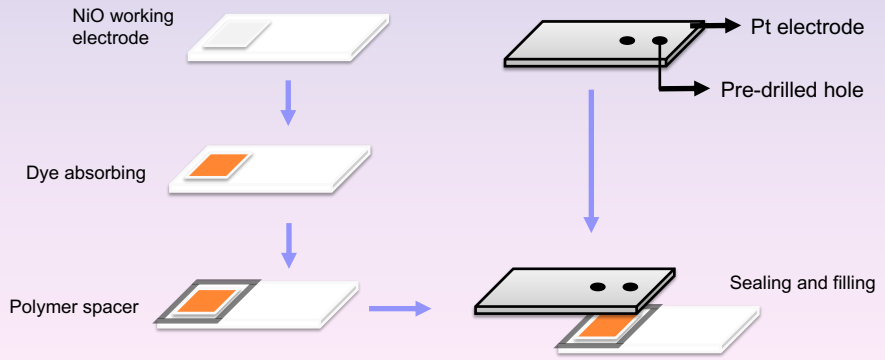


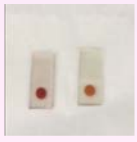


n-type DSSC

n-type photo electrochemical DSSC

DSSC assembly





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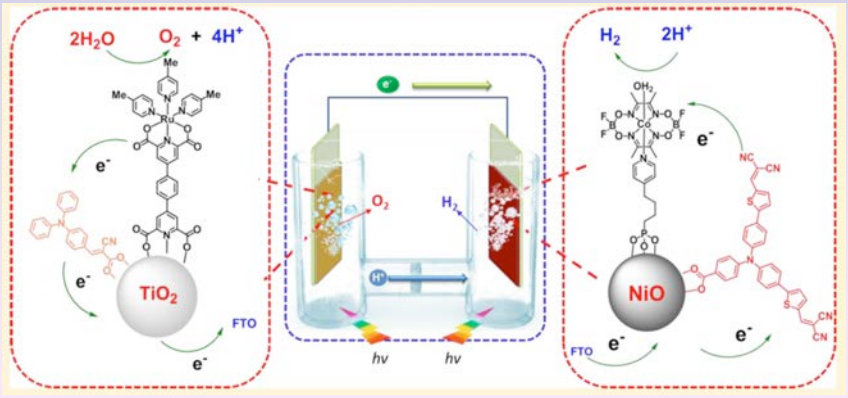
Tandem cell



Proof of principle, Efficiency low

Charge recombination
Better catalysts
Optimize light absorption

Sun et al. *JACS* **2015**, 137, 9153

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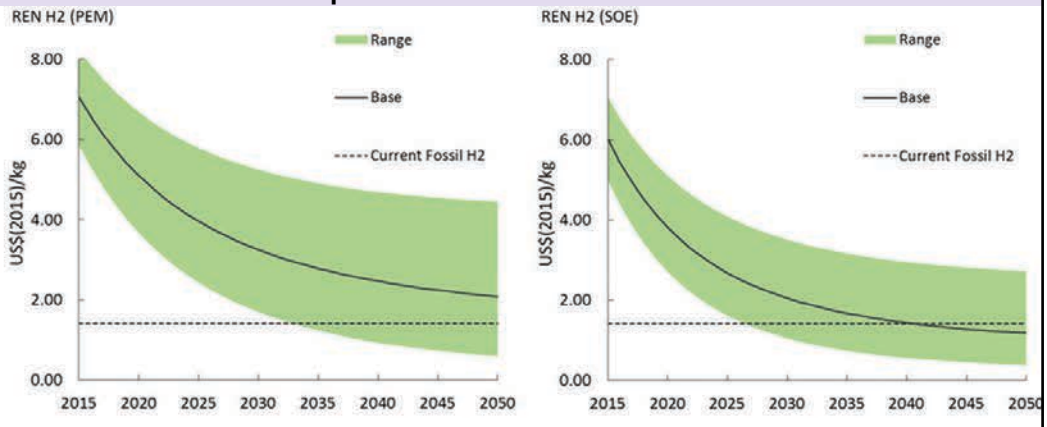
When

Solar Fuel: techno-economic analysis

Economic competitive 2025-2040



Detz, van der Zwaan, Reek *Energy Environ Sci.* **2018** ECN/TNO

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Conclusion

Photosynthesis for food

Artificial photosynthesis for energy

Start implementing now, optimization for efficiency for later

Can we make chemical compounds instead of Oxygen?

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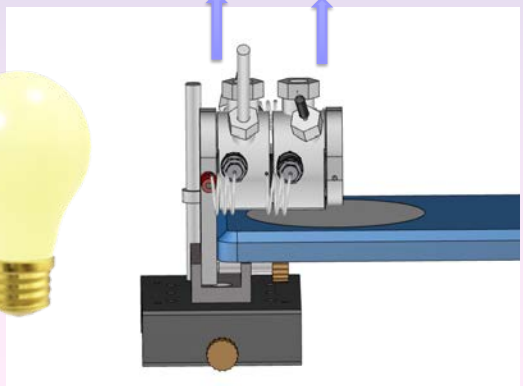
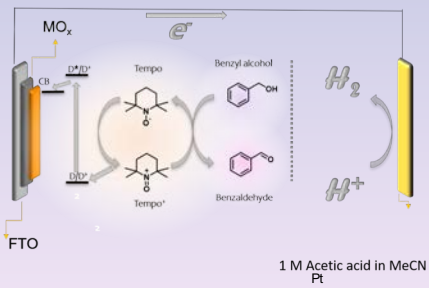
DSPEC

benzaldehyde H_2





DSPEC cell as big DSSC
~300 microA

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Acknowledgements

- Martin Koelewijn
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- **Dr. Remko Detz**
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- Prof S. Woutersen
- Prof R. Orru
- Jeroen Rombouts (VU)
- Dr. Ning Yan
- Prof Mul

BioSolarCells

FOM
NWO
ERC
Shell
Merck

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Discussion points

- How important is efficiency?
- What is the economic value of efficiency?
- Do we need always need high efficiency
- How to create a realistic holistic view?
- What technology is lacking from other perspectives? (economic, social, implementation)