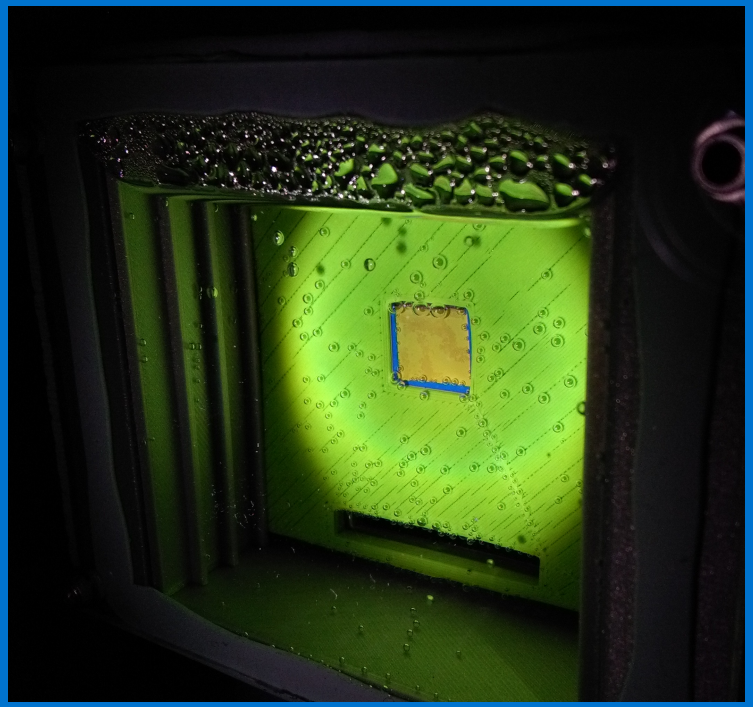
Making Sustainable Fuels & Chemicals Using Sunlight in a Circular Economy



'Integrated Photon-to-Chemical Technologies'

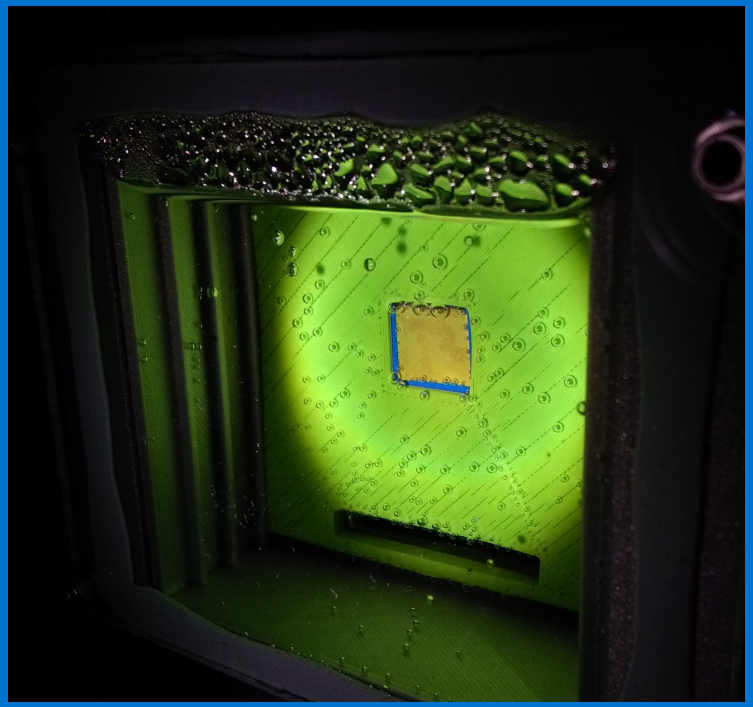
1st CO_2 WIN conference
Virtual (DECHEMA, Germany)
9th June 2021

Erwin Reisner
Yusuf Hamied Department of Chemistry
University of Cambridge

e-mail: reisner@ch.cam.ac.uk
web: www-reisner.ch.cam.ac.uk

UNIVERSITY OF CAMBRIDGE

Making Sustainable Fuels & Chemicals Using Sunlight in a Circular Economy



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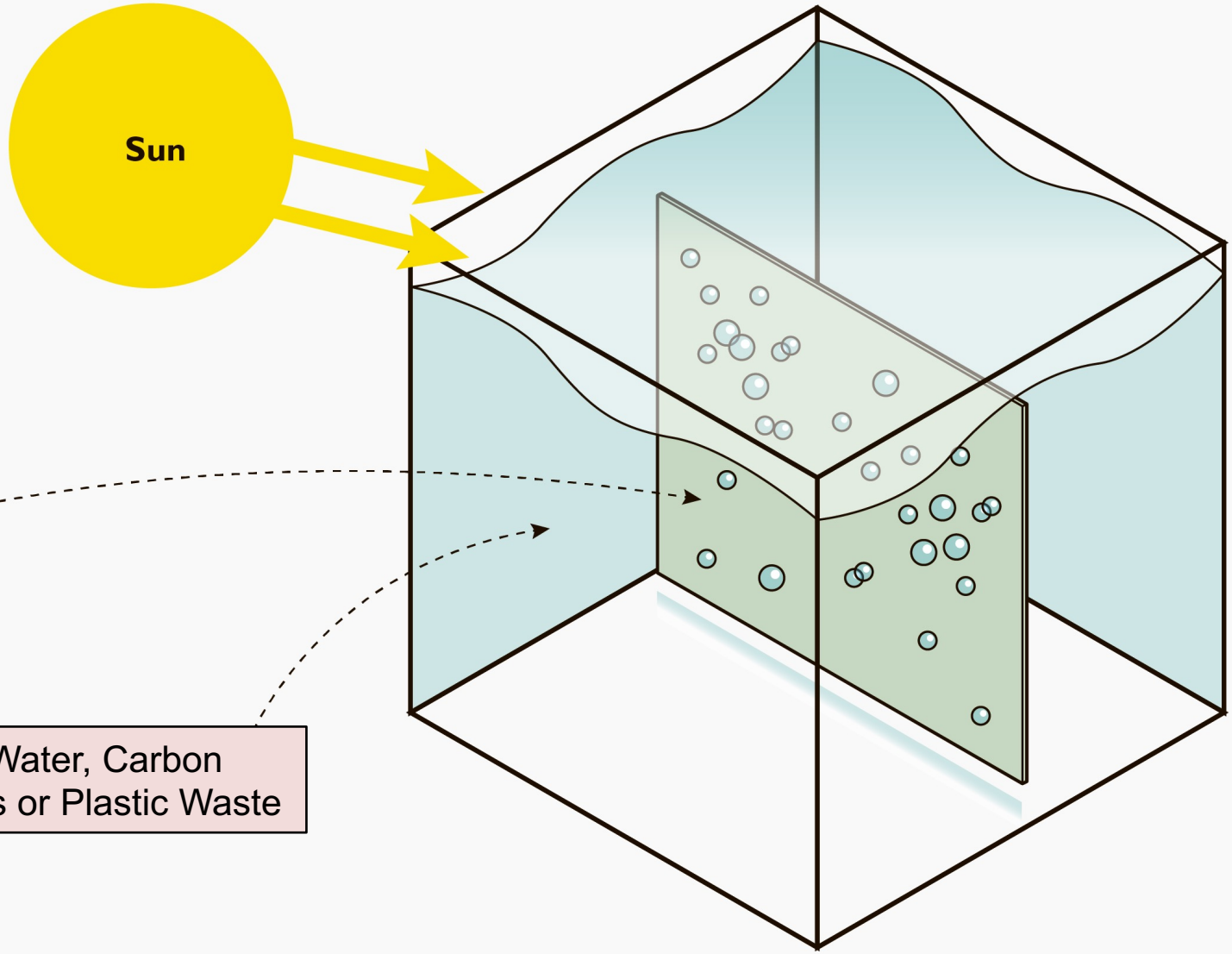
Solar Chemical Synthesis using an Integrated Device

Sunlight powers the production of sustainable fuels and chemicals



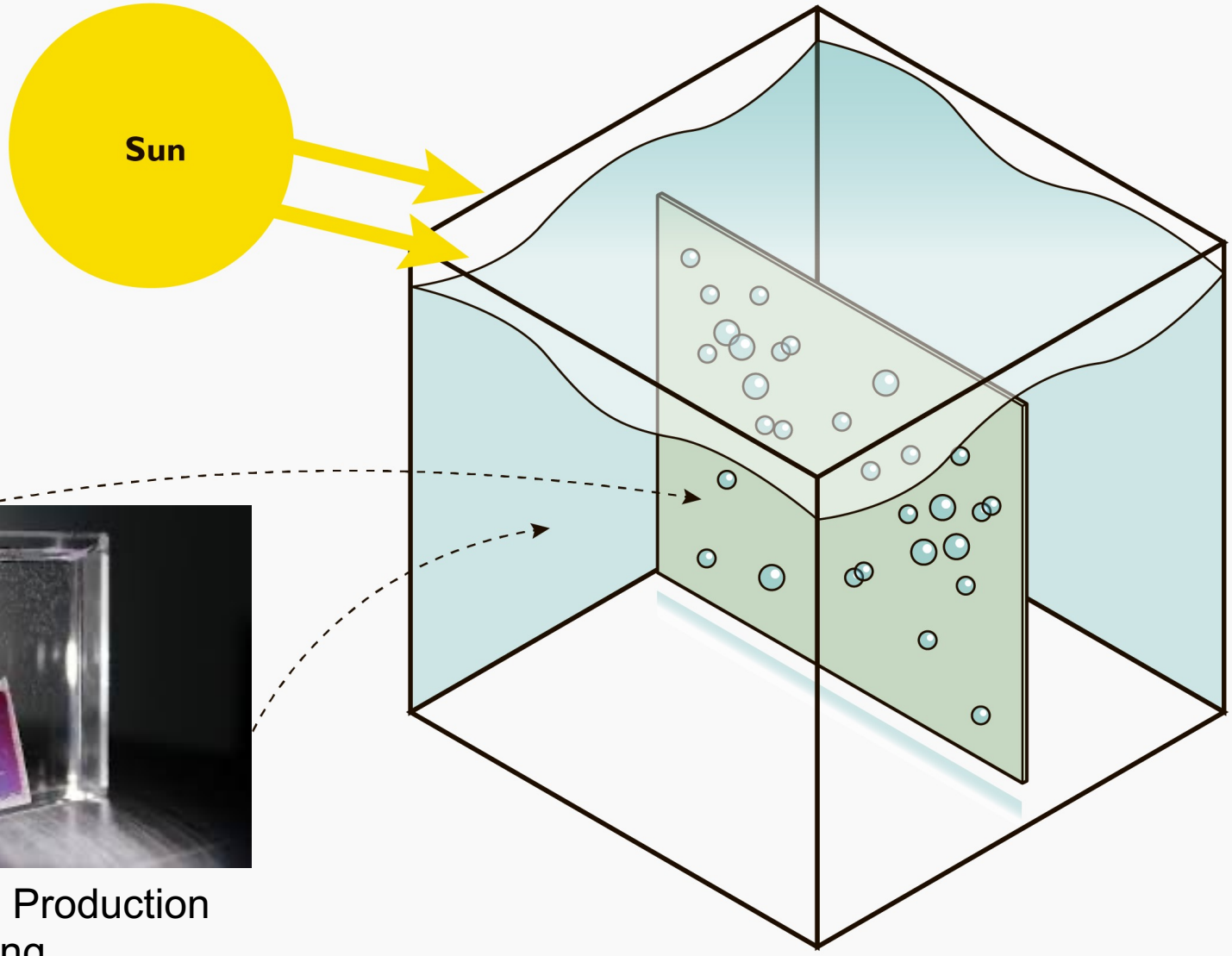
Artificial Leaf, Photo-Sheet or Panel

Bath containing Water, Carbon Dioxide, Biomass or Plastic Waste

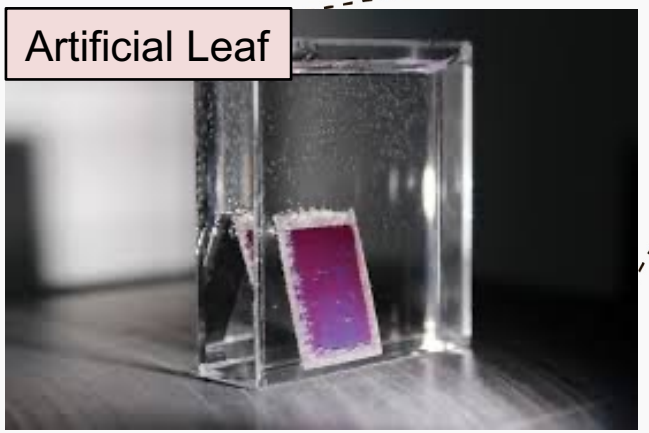
Adapted from The Times (Issue: 25th Aug 2020)

Solar Chemical Synthesis using an Integrated Device

Sunlight powers the production of sustainable fuels and chemicals



Artificial Leaf



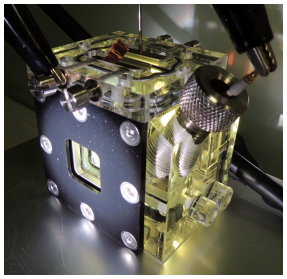
Solar Hydrogen Production *via* Water Splitting

Wang *et al.*, *Nat. Mater.*, **2016**, *15*, 611–15
Reece *et al.*, *Science*, **2011**, 645–48; Rocheleau *et al.*, *Energy Fuels*, **1998**, *12*, 3–10

Beyond Water Splitting: Solar Chemistry in Circular Economy

Input:

Water (H_2O)
Carbon Dioxide (CO_2)
Waste (Biomass, Plastics)



Ongoing

Artificial Photosynthesis or Photocatalysis

Direct Use / 'Vectors':

Hydrogen (H_2)
Carbon Monoxide (CO)
} 'syn-gas'
Formic Acid (HCO_2H)

Chemical Industry

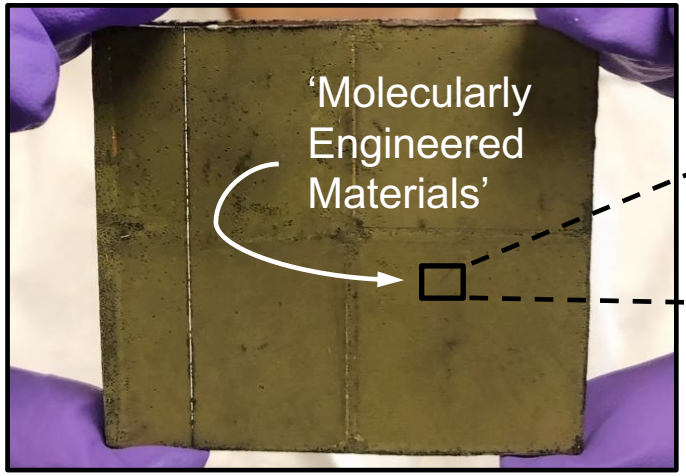
Sustainable Output:

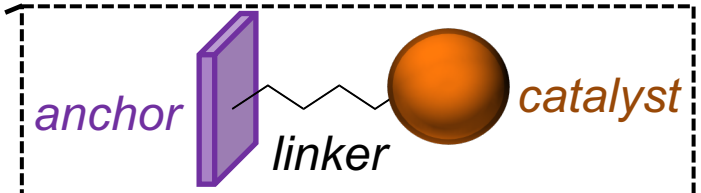
Liquid Fuels ('green gasoline')
Chemicals (plastics, fertiliser…)
Electricity

Consumption

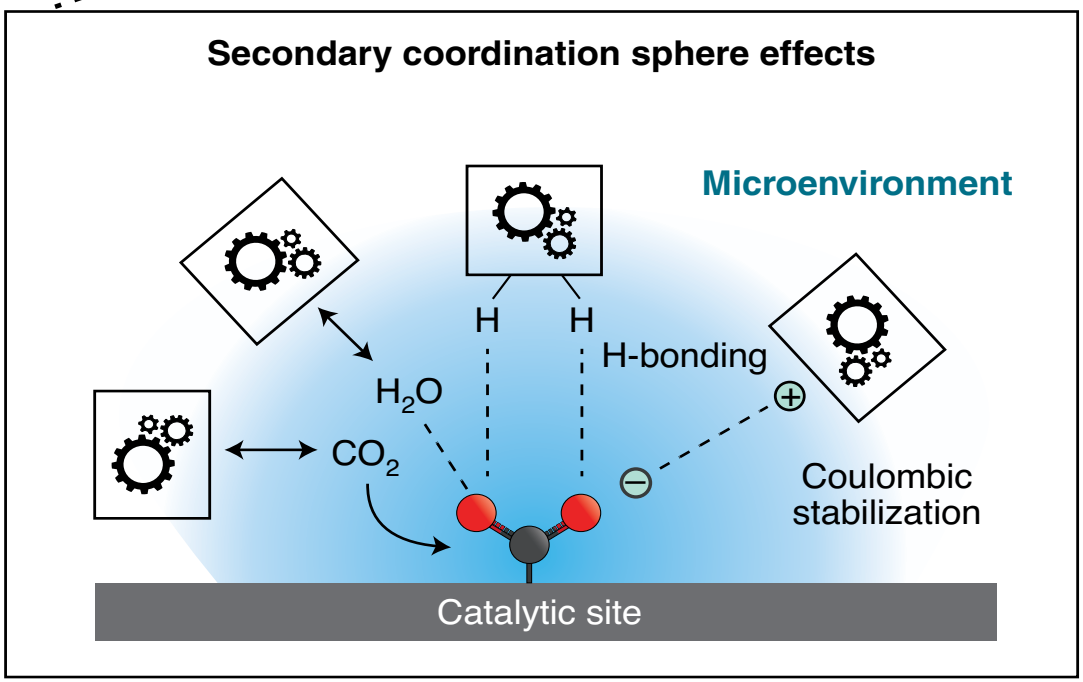
FOSSILFREE

Catalytic Surfaces for CO_2 Reduction





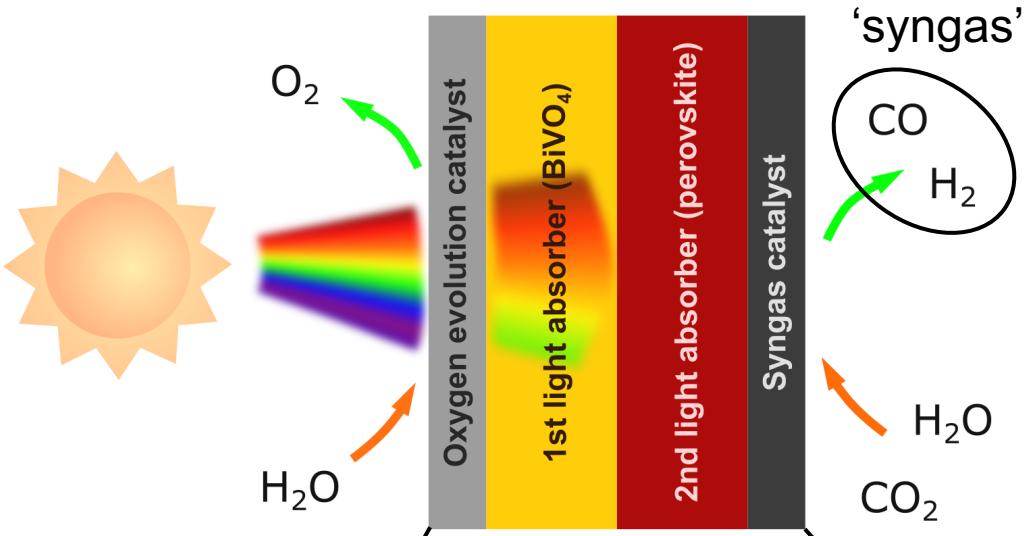
Molecular Catalysis for CO_2 Reduction

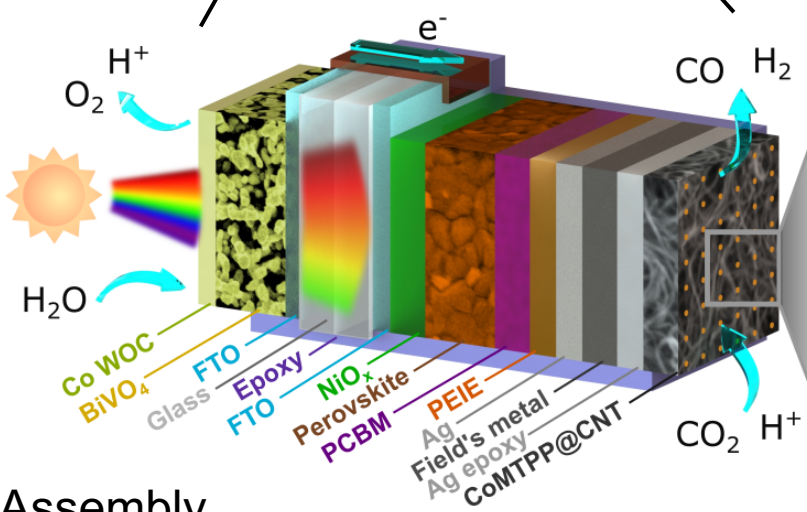


2012-2019

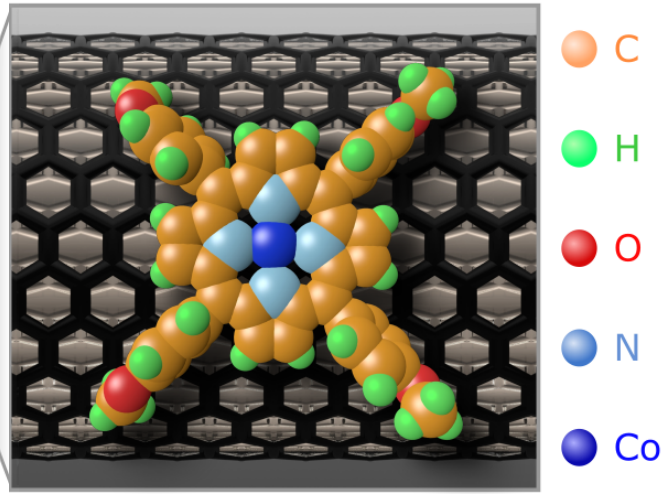
Wagner *et al.*, *Nat. Catal.*, **2020**, *3*, 775–86.

Artificial Leaf for Solar CO_2-to-syngas Conversion





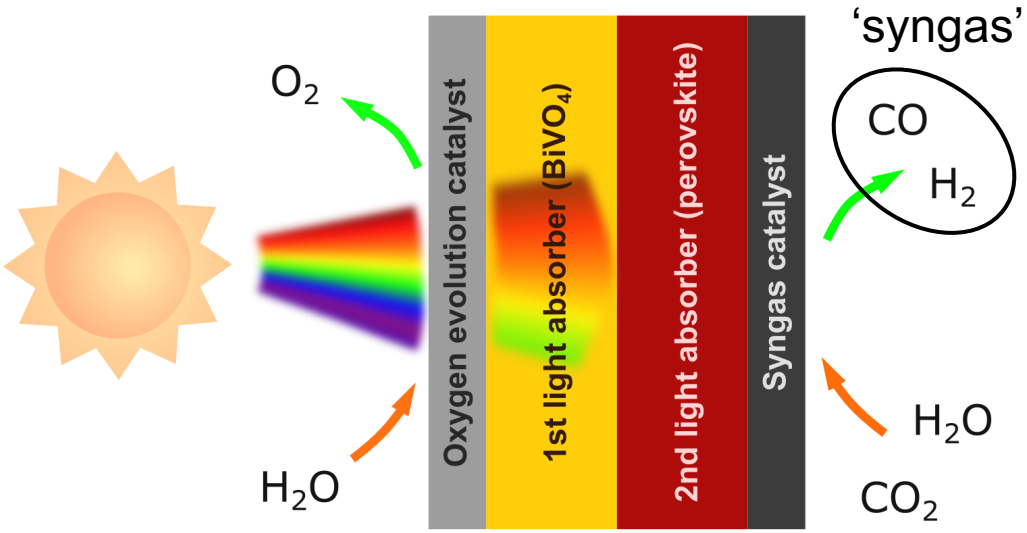
$TON_{Co} \sim 3{,}000$



Layered Assembly

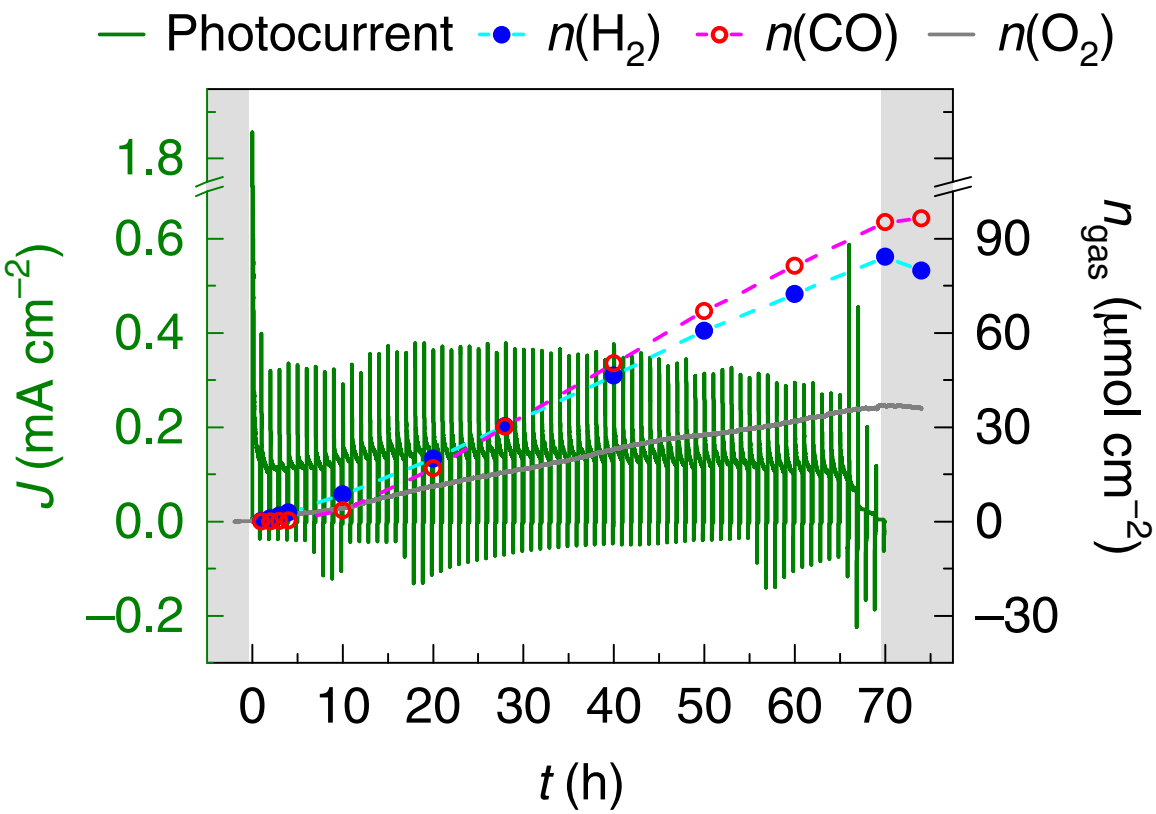
Andrei *et al.*, *Nat. Mater.*, **2020**, *19*, 189–94
CNT/CoTPP: Hu *et al.*, *Angew. Chem. Int. Ed.*, **2017**, *56*, 6468–72

Artificial Leaf for Solar CO_2-to-syngas Conversion



Andrei *et al.*, *Nat. Mater.*, **2020**, *19*, 189–94

Performance of Solar CO_2-to-syngas Conversion



Bias-free, 2-electrode PEC, 0.5 M $KHCO_3/CO_2$, r.t.; 1 Sun (AM1.5G)

STF ~ 0.1%

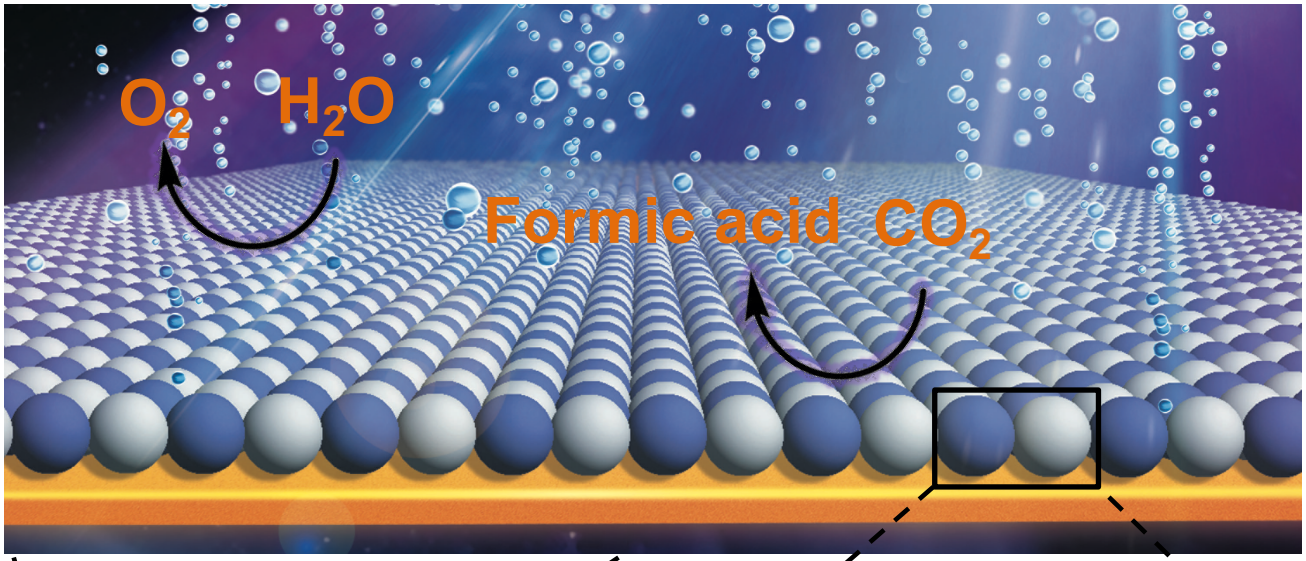
$^{13}CO_2$ ✓

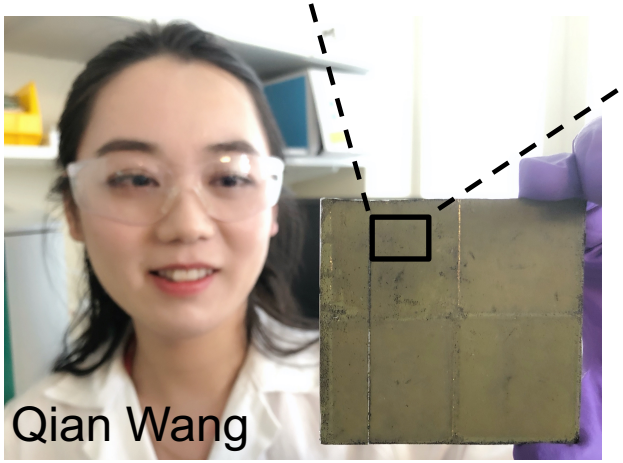
Tuneable Syngas Ratio

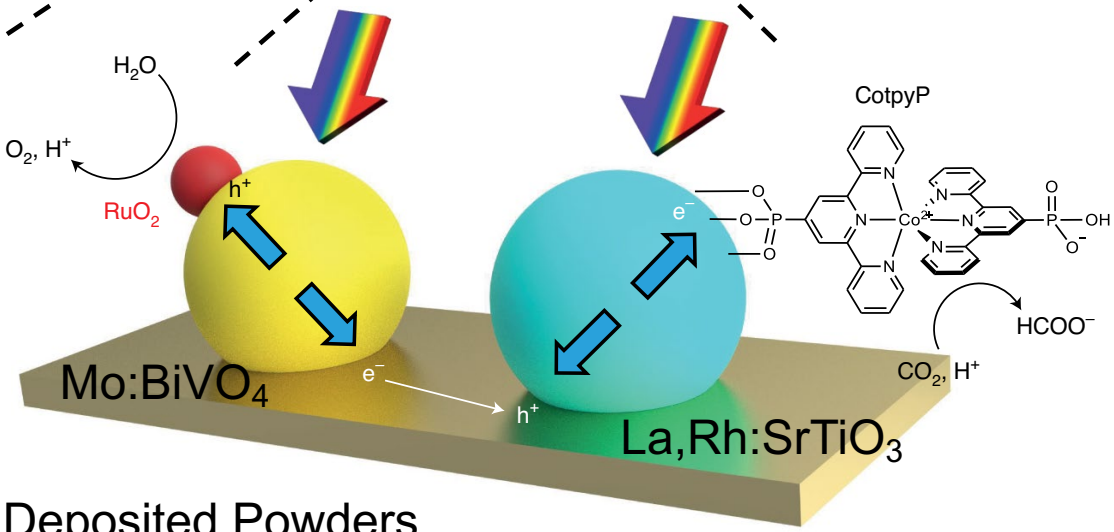
TON_{Co} ~ 3,000

Andrei *et al.*, *Nat. Mater.*, **2020**, *19*, 189–94

Photosheet for Solar CO_2-to-formic acid Conversion



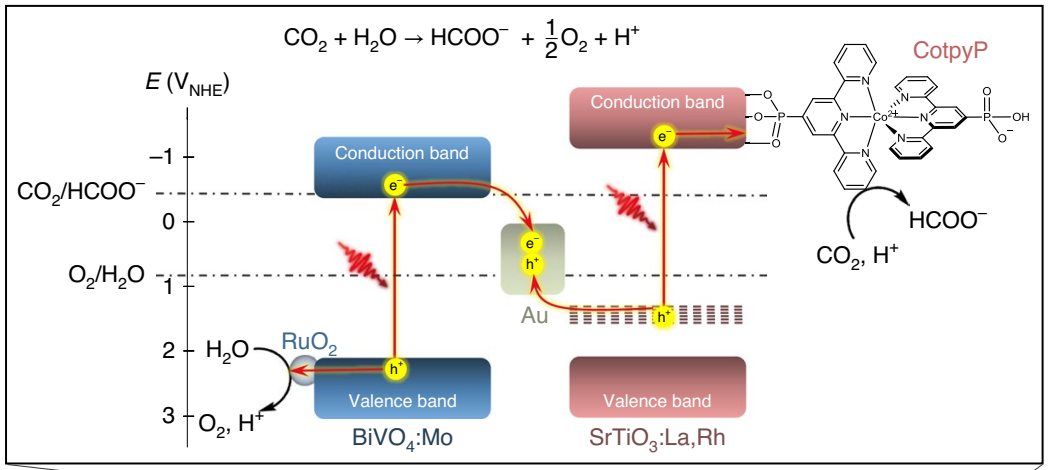


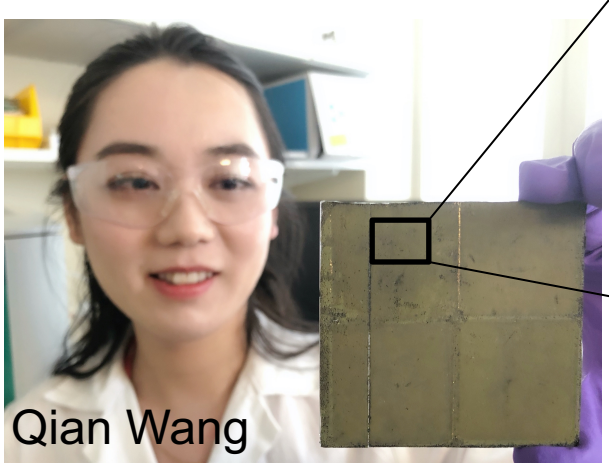


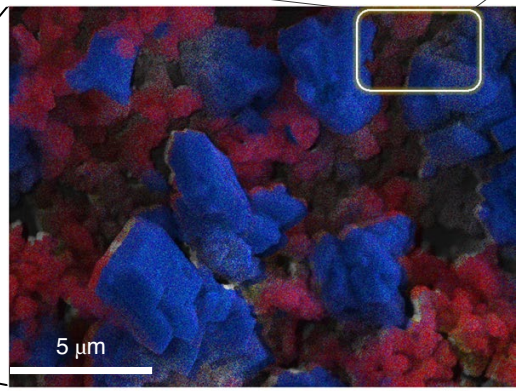
Deposited Powders

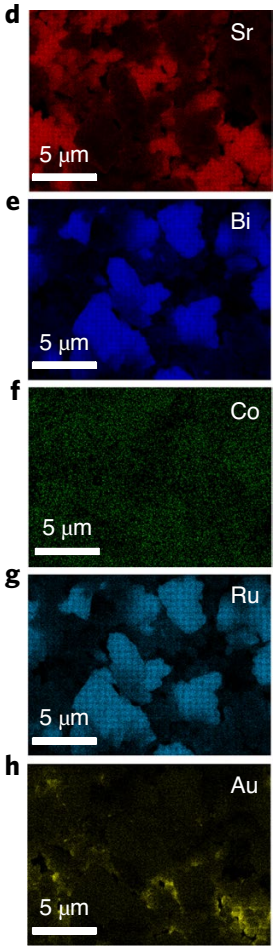
Wang *et al.*, *Nat. Energy*, **2020**, *5*, 703–10 (collaboration with Kazunari Domen, Tokyo)

Photosheet for Solar CO_2-to-formic acid Conversion



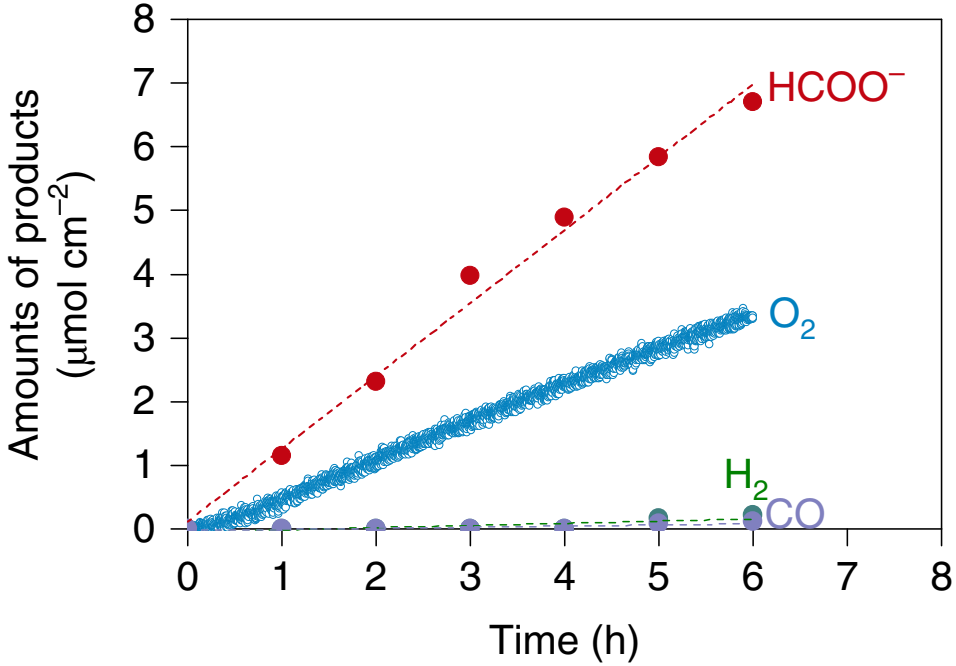






Wang *et al.*, *Nat. Energy*, **2020**, *5*, 703–10 (collaboration with Kazunari Domen, Tokyo)

Performance of Solar CO_2-to-formic acid Conversion



Bias-free, 0.1 M $KHCO_3/CO_2$, r.t., 1 Sun (AM1.5G)

STF ~ 0.1%

Selectivity ~ 97%

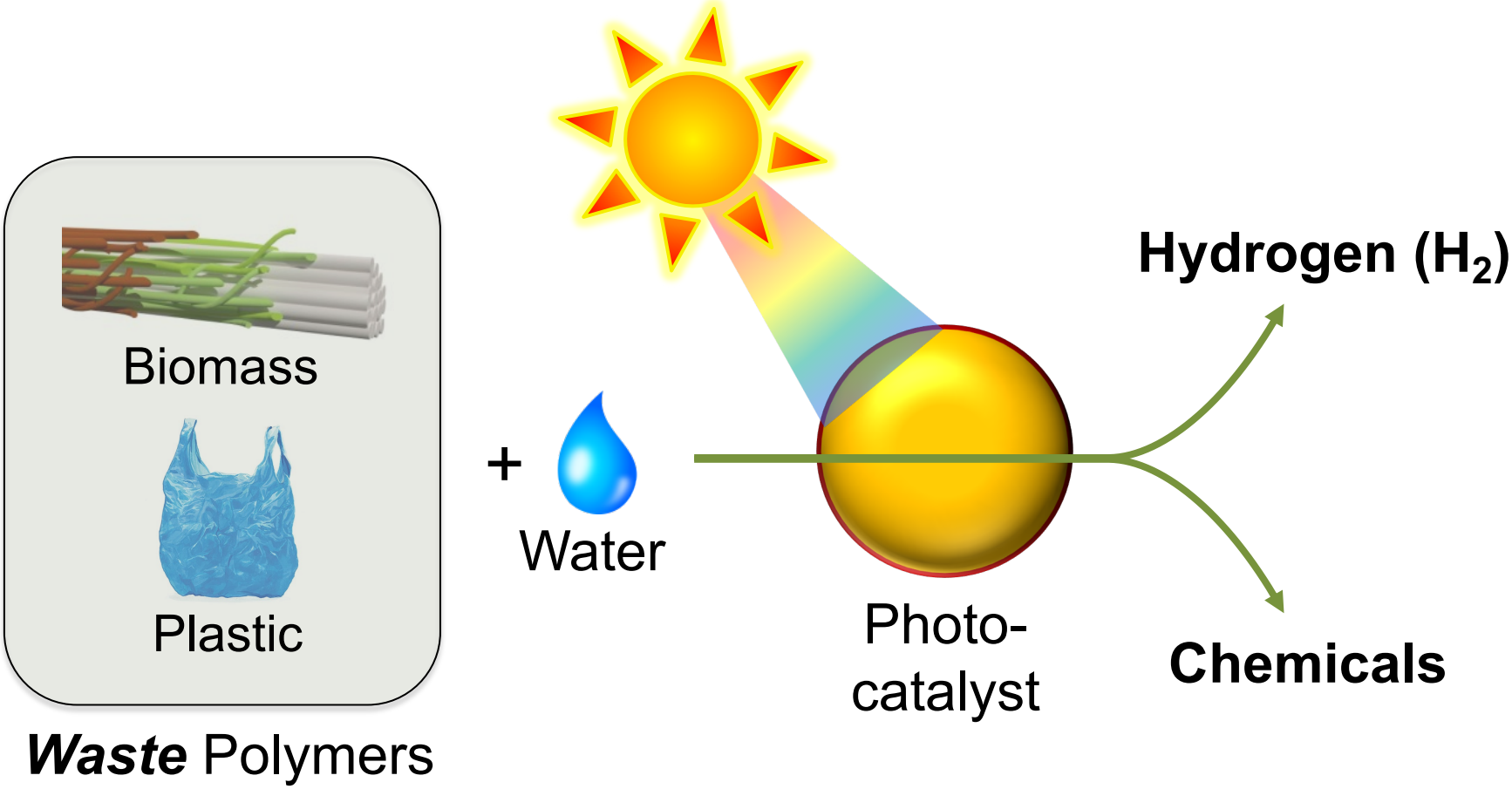
$^{13}CO_2$ ✓

AQY (420 nm) ~ 2.6%

TON_{Co} ~ 400

Wang *et al.*, *Nat. Energy*, **2020**, *5,* 703–10 (collaboration with Kazunari Domen, Tokyo)

Solar Reforming of Waste Polymers



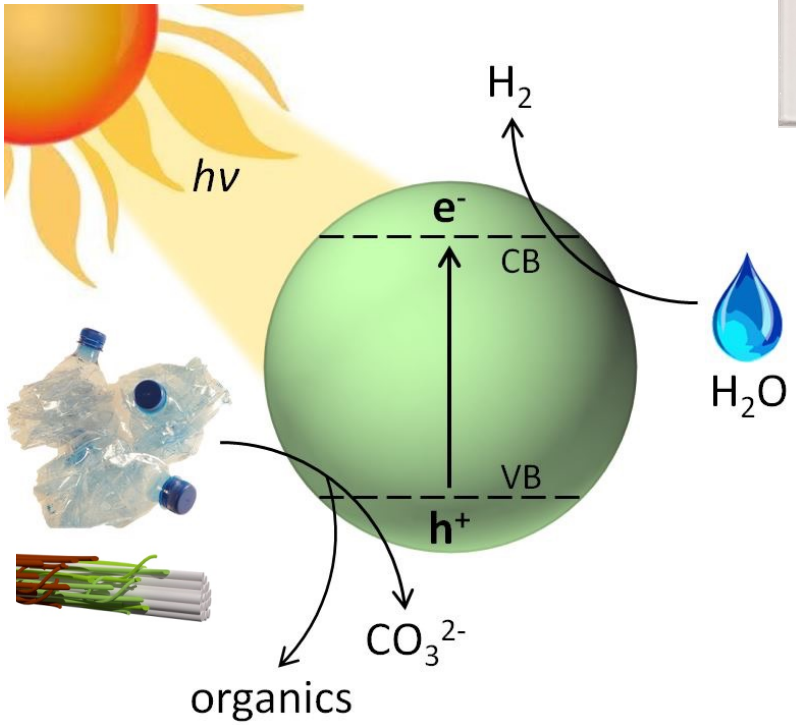
Solar Reforming of Plastic and Biomass Waste

Wood

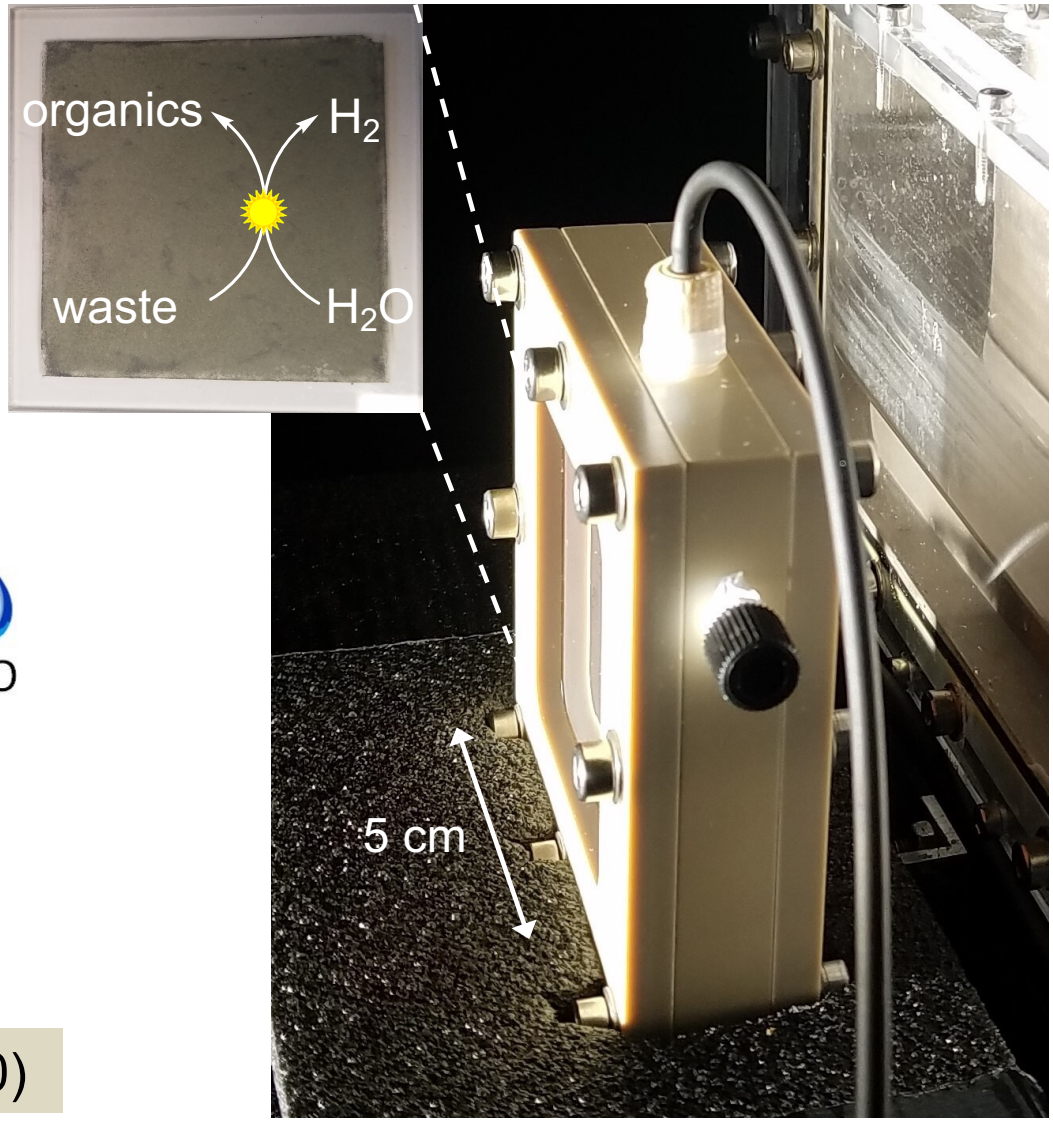
PET

Wakerley, Kuehnel et al., *Nature Energy*, **2017**, *2*, 17021.
Uekert et al., *J. Am. Chem. Soc.*, **2019**, *141*, 15201–10.

Panel for Solar Waste Recycling (Photoreforming)



E^0_{rxn} = 0.001 V (→ STH = 0)



Uekert et al., *J. Am. Chem. Soc.*, **2019**, *141*, 15201–10
Uekert *et al.*, *ChemSusChem* , **2021**, *in print* (DOI: 10.1002/cssc.202002580).

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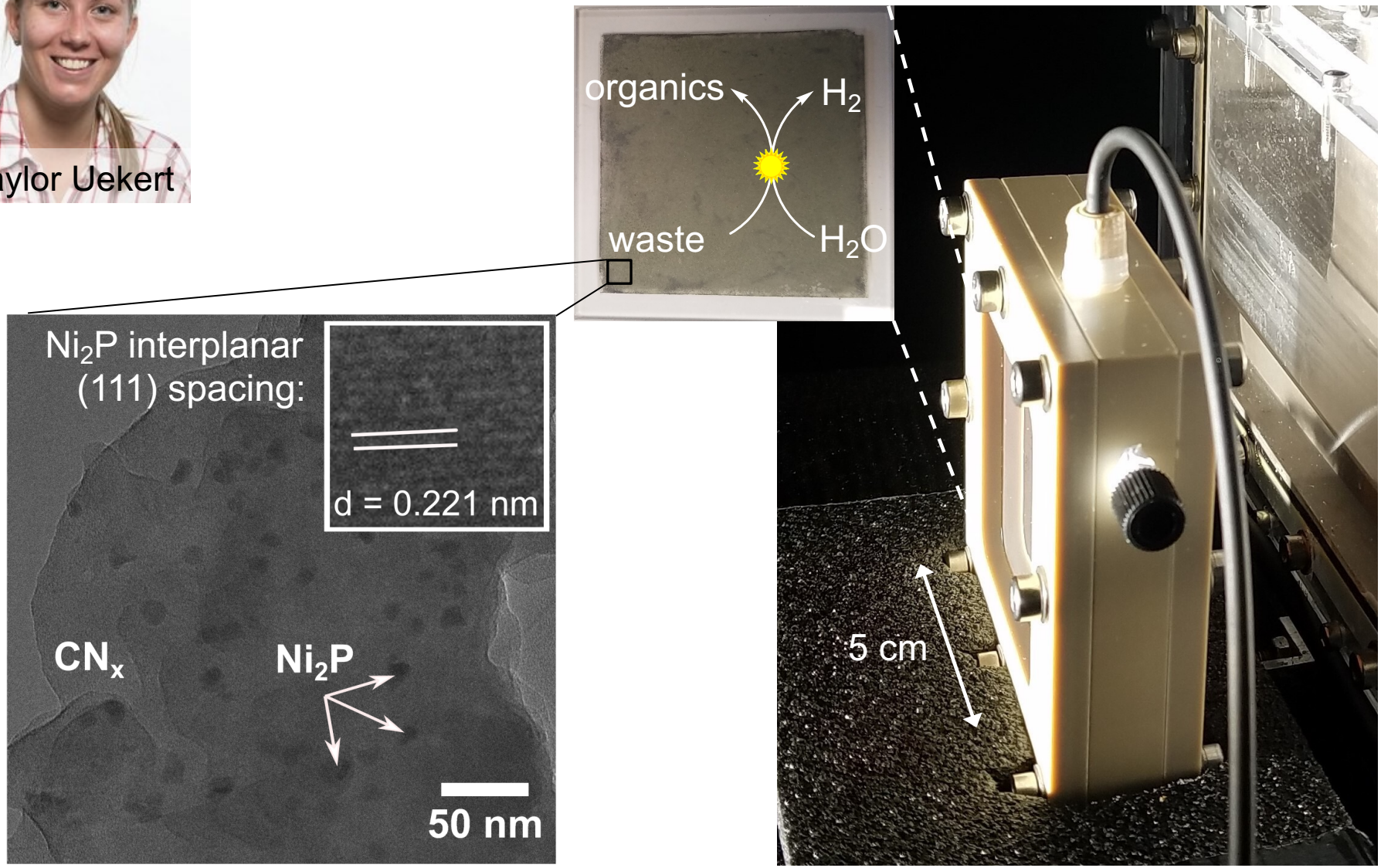

Uekert et al., *J. Am. Chem. Soc.*, **2019**, *141*, 15201–10
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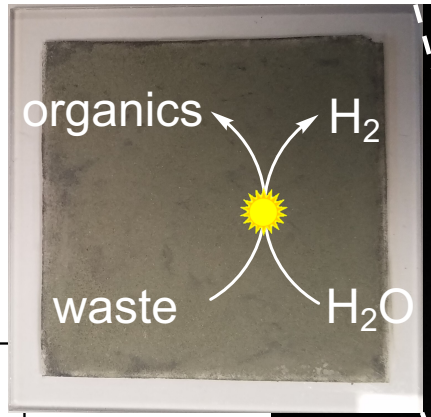
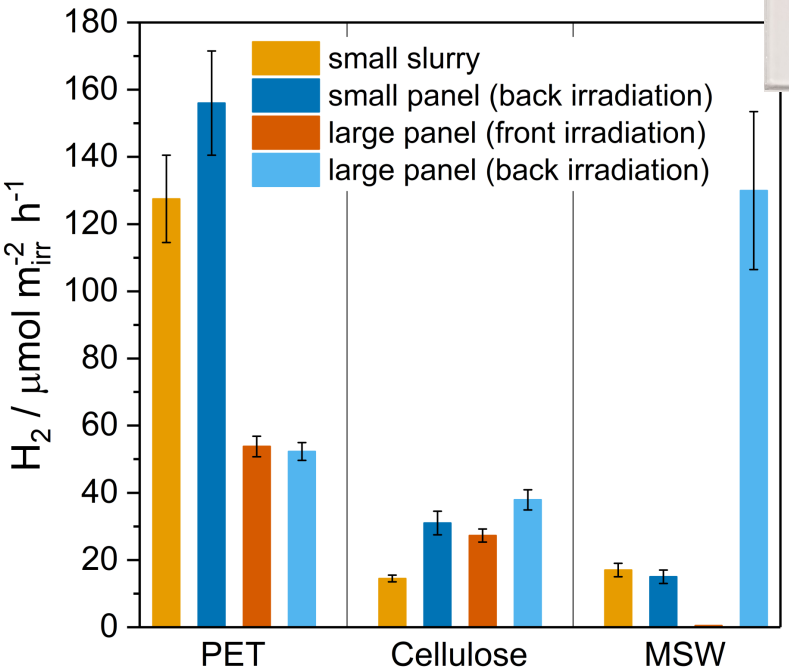
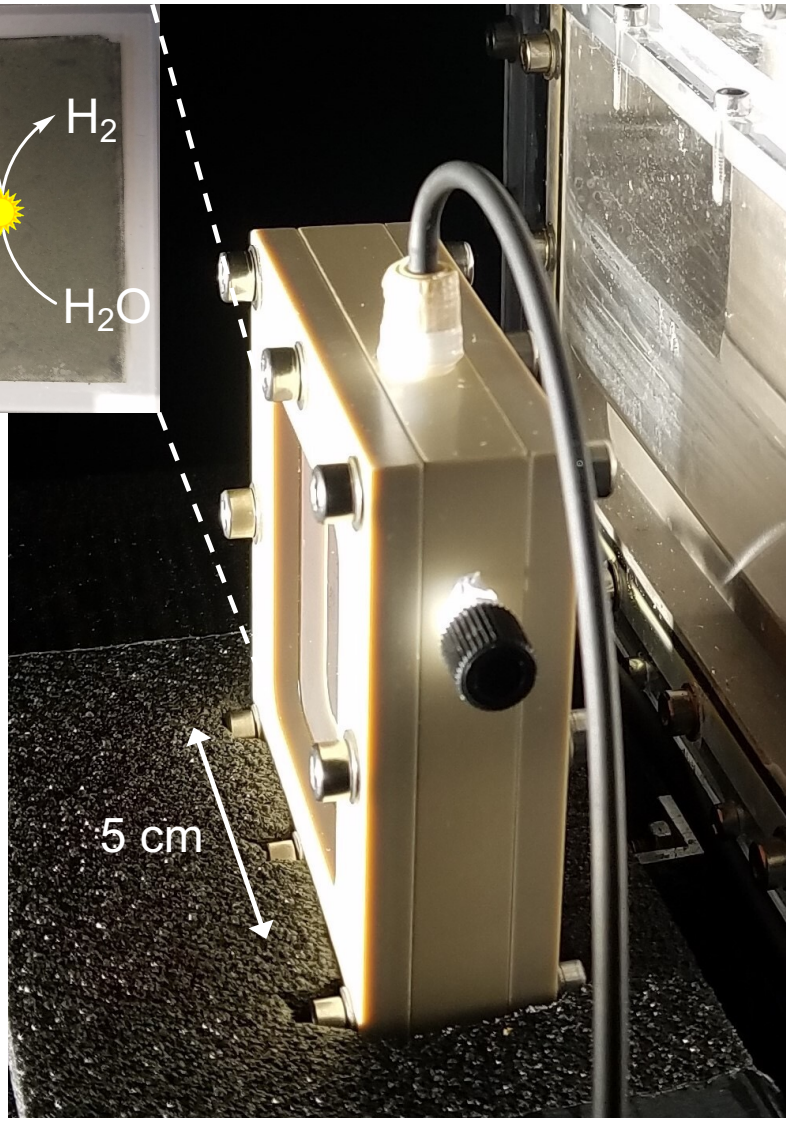


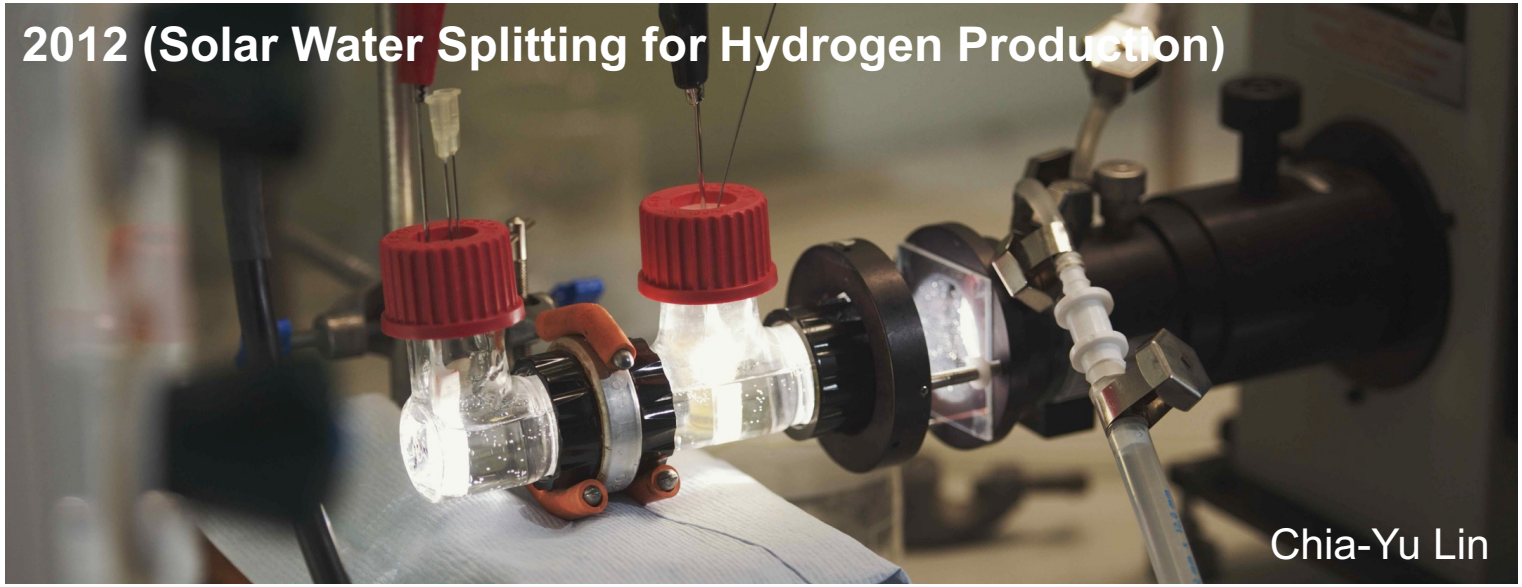




0.5 M aqueous KOH, AM1.5G, 20 h, 25 ºC

Uekert et al., *J. Am. Chem. Soc.*, **2019**, *141*, 15201–10
Uekert *et al.*, *ChemSusChem* , **2021**, *in print* (DOI: 10.1002/cssc.202002580).

Summary: Solar Fuels Technology at Cambridge



Outlook

Status Quo:

· Demonstrated conversion of waste and CO_2 into energy carriers and fuels ✓

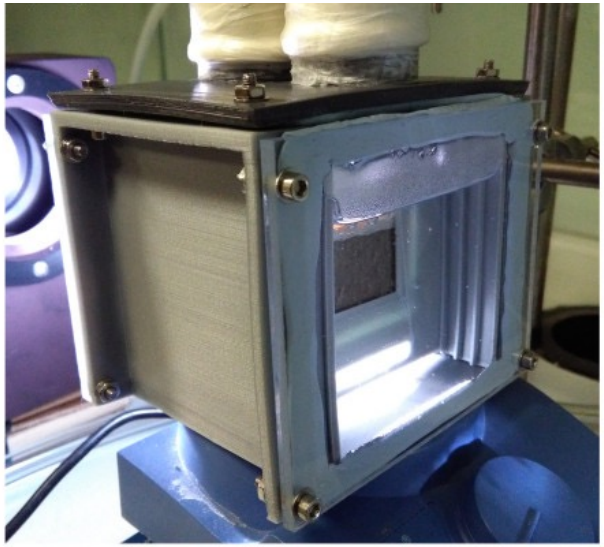
Improving Performance:

· Catalysis (e.g., CO_2 to transport fuels; production of pure chemicals)

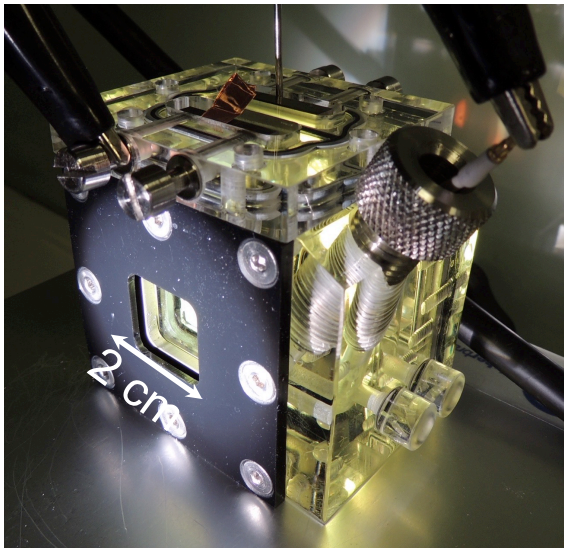
· Efficiency (from 0.1% to 10+% solar energy conversion)

· Stability (from hours and weeks to years)

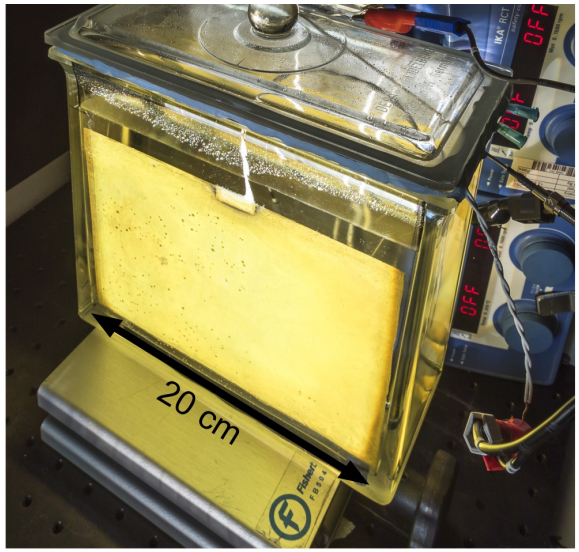
Lab Screening



Small Scale



Medium Scale



Acknowledgements

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UK Research and Innovation

Horizon 2020

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10 YEARS

@Cambridge

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Chemical Science Symposium 2021: Biohybrid Approaches to Sustainable Energy Conversion

13 - 15 September 2021, United Kingdom, United Kingdom

Invited Speakers:
- Michelle Chang (Berkeley)
- Carole Duboc (Grenoble)
- Can Li (Dalian)
- Gustav Berggren (Uppsala)
- Julea Butt (UEA)
- Abhishek Dey (IACS)
- Tobias Erb (Marburg)
- Judy Hirst (Cambridge)
- Derek Lovley (Amherst)
- Daniel Nocera (Harvard)
- Chan Beum Park (KAIST)
- Marc Robert (Paris)
- Wendy Shaw (PNNL)

Co-organisers: J. Z. Zhang (Cambridge), E. Reisner (Cambridge) & N. Plumeré (Munich)