



Final Activity Report

Executive Committee Meeting, Vienna, 31 March - 2 April 2004

Activity period October 2004 - December 2004

Main Activities

- **Written comprehensive Final Report of Annex-14 (submission April 2004 Vienna)**
- **Finalised proposal for new 3-year follow-on PEC R&D Annex with broader participation**





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Other Activities

- **Finalised IEA-HIA “End Of Term” Report (1999 – 2004) and assisted secretariat**
- **Drafted and e-published “In Pursuit of the Future”, IEA-HIA’s 25th Anniversary Report**
- **Submitted application to Australia’s Federal Government for IEA-HIA membership**





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Subtask A

Photocatalysts & Light Harvesting

- Preparation of tungsten trioxide (WO_3) photoanode thin-films simplified and improved at Uni of Geneva; nanoparticulate Pt/ WO_3 films developed at UCal-SB using pulsed electrodeposition (high surface area).
- Iron oxide (Fe_2O_3) photoanode thin-film development continued, mainly on doping materials & techniques, at EPFL, UoGeneva, UoUppsala & NREL (Al, Ti & Sn).





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Subtask A Cont. ... Photocat & LH

- Increasing R&D on anion-doped **TiO₂** thin-films (C, N, In & S) to shift band-gap toward ~ 2.3 eV (VIS light); N-doped TiO₂ thin-films shown unique property of storing photogenerated holes for prolonged period.
- Improvement of photoresponse by CuInGaSe₂ (**CIGS**) with varying S-composition of bulk-material (NREL).
- Improved **Ru-dyes** (EPFL) for 11%-efficient TiO₂ DSSC, delivering a photocurrent density of up to 20 mA/cm².





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Subtask B

Photosystems

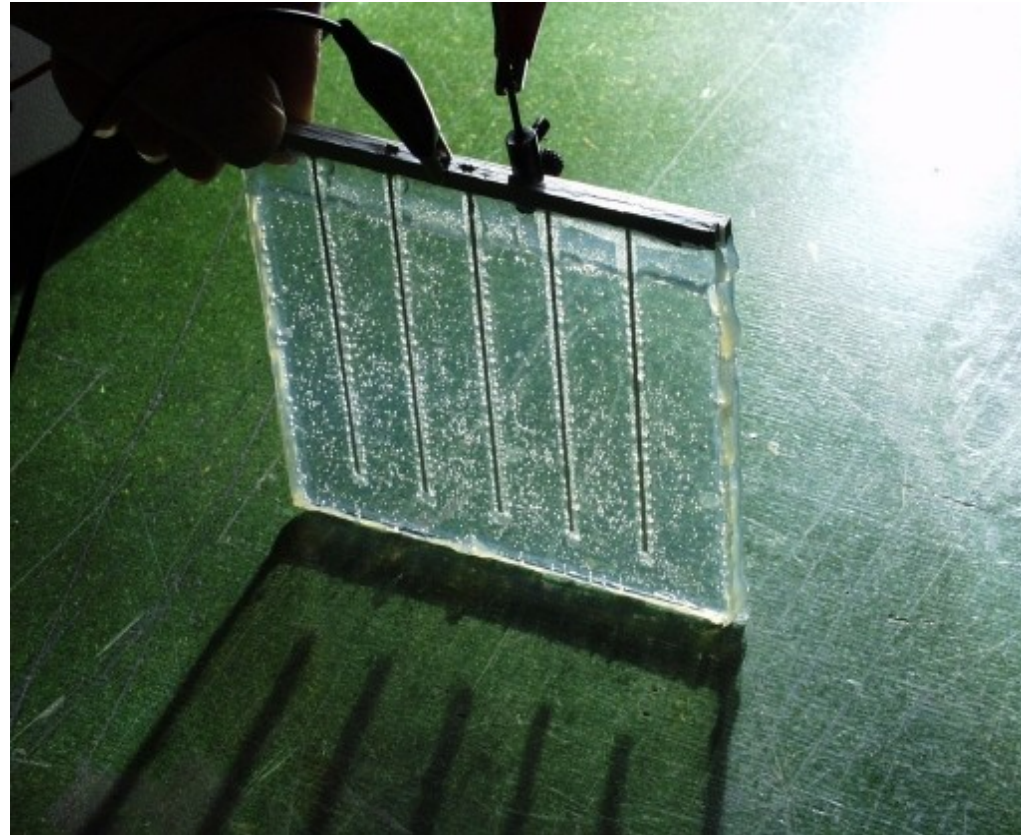
- New **WO₃ / GaInP₂** tandem system under test (UoG / NREL (complementary band-gaps; no external bias), but photocorrosion inhibition remains key challenge.
- Demonstration of **100mm x 100mm** tandem PEC cells by UoG, Solaronix & Hydrogen-Solar continues, using **WO₃ / TiO₂** system; no scale-up yet to 300mm x 300mm.





Demonstration PEC Cell

**Solar
to
Hydrogen
Conversion
Efficiency
 $\eta \sim 3\%$
(compared to
 $\sim 6\%$ with
latest, doped-
 WO_3 lab-cell)**



100mm x 100mm WO_3 photoanode tile sample by H_2 -Solar (UK), University of Geneva as well as Solaronix (both CH)



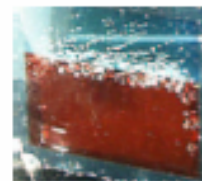
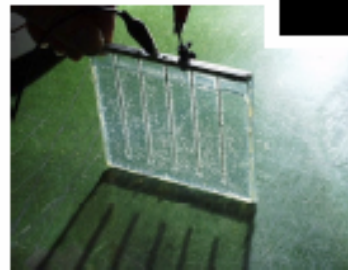
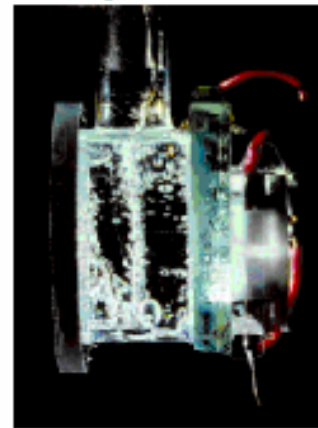


Photoelectrolytic Production of Hydrogen

IEA Hydrogen Program | "Annex-14"

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Final Report

Edited by
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Membership Drive

Executive Committee Meeting, Vienna, 31 March - 2 April 2004

Summary

- **Australia: UNSW, UoQ, UoA, ANU & STI (Ti-PEC)**
- **France: CNRS (charge-transfer) & CEA (system)**
- **Korea: Pohang Uni (photocatalysis for VIS light)**
- **Netherlands: UoDelft & Leids (doping & modelling)**
- **Mexico: UNAM (photocatalysis for monol. PECs)**
- **Singapore: NTU (H₂ co-prod. & photocat. degrad.)**
- **UK: UoBath (photo sensitisation) & H₂ Solar (com.)**
- **USA: Uni of ND (semicond.-metal charge transfer)**



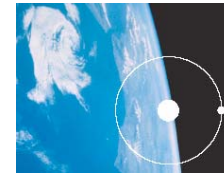


Other

Executive Committee Meeting, Vienna, 31 March - 2 April 2004

25th Anniversary Report

Refer to separate presentation



H₂ down-under

- **National H₂ Study** released by Fed. Government
- Bid preparation to stage WHEC-2008 in Brisbane
- Applied to Fed. Gov. for IEA-HIA membership via Innovation Access Program (IAP-6) grant, which is planned to involve 12 R&D groups overall, in all current Annexes, over a period of at least 2 years





ExCo Attention

Executive Committee Meeting, Vienna, 31 March - 2 April 2004

Issues in Need of Support

- **Acceptance of Final Report of Annex-14**
- **In-principle acceptance of the Draft Program of Work (PoW) suggested for follow-on PEC Annex, with PoW fine-tuning at kick-off meeting in May/June 2004 (Delft)**
- **Assuming success at the kick-off meeting, support for the follow-on PEC Annex and its experts by the ExCo in terms of securing approval and participation from the respective IEA member and non-member countries**





Annex-14

Hydrogen Implementing Agreement



“Photoelectrolytic Production of Hydrogen”

Overview

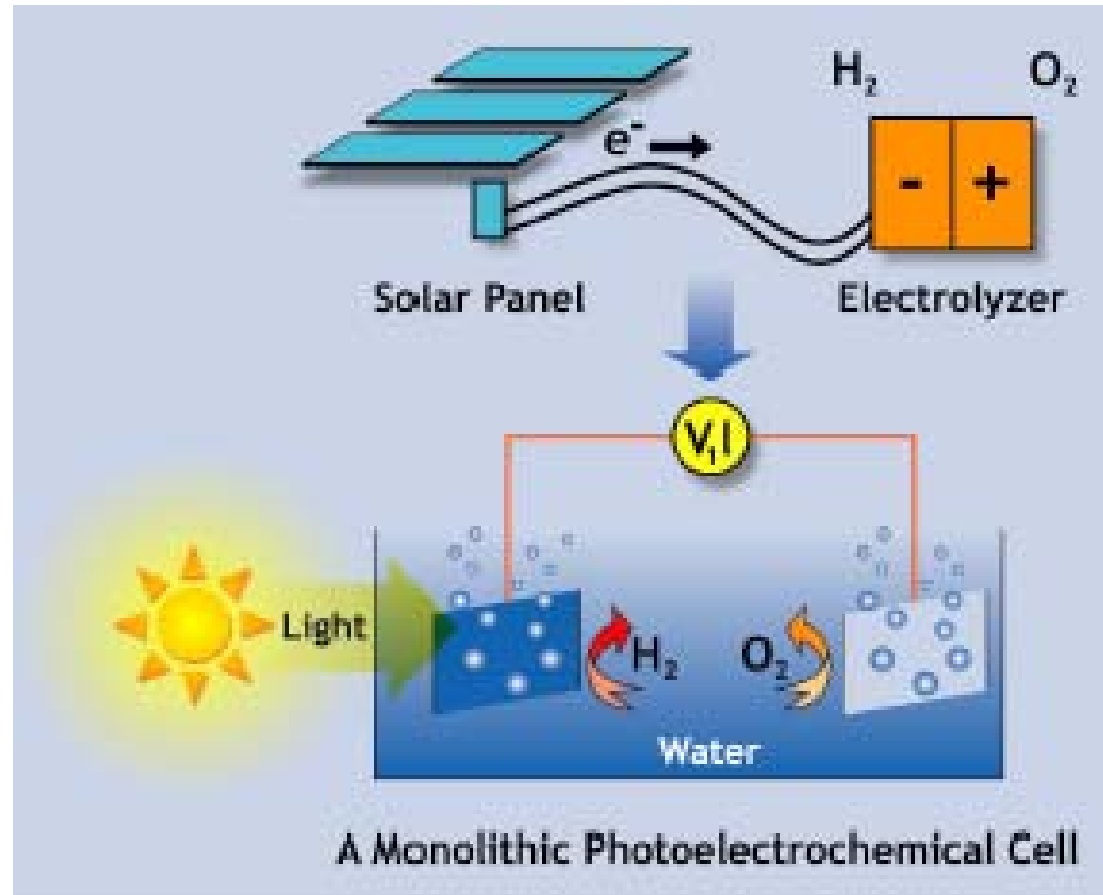
Promising New Solar Hydrogen Production Route





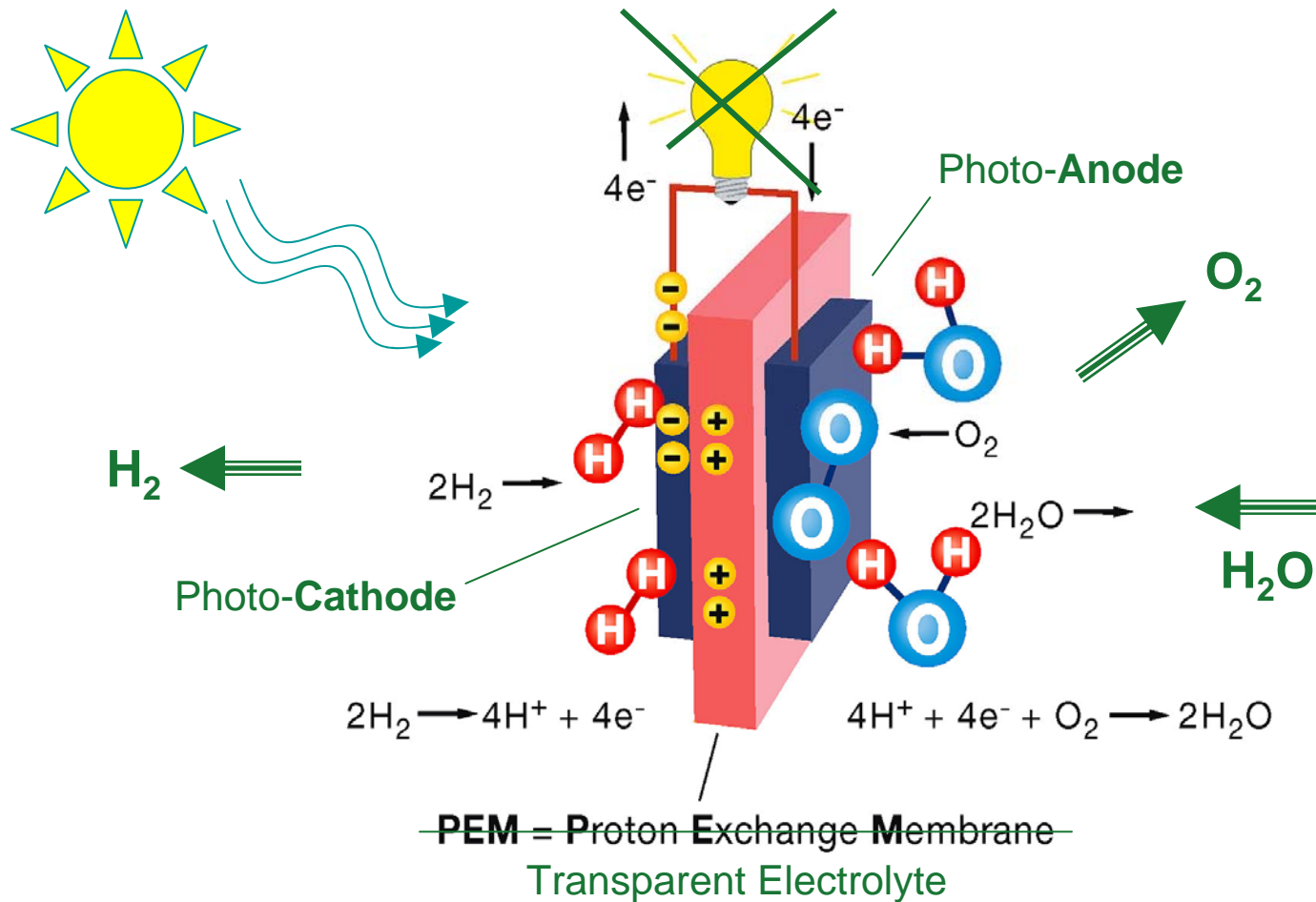
Main Goals of Annex-14

Advance
fundamental
science
and work
toward a stable
10%-efficient
photoelectro-
chemical (PEC)
system
producing
hydrogen at
US\$ 10/GJ





Concept of Photoelectrolysis





Scope and R&D Program

Scope

Conduct collaborative **pre-commercial** R&D in PEC

R&D Program

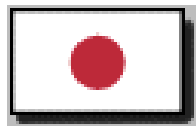
- **5-year program** of work (July 1999 - June 2004)
- R&D on **photosensitive materials** and synthesis
- Prototyping and testing **laboratory-scale devices**
- Assessing potential **techno-economic viability**





Participants

Core Group



Japan

Nat'l Inst. Adv. Ind. S&T



Sweden

University of Uppsala

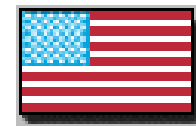


Switzerland

University of Bern

University of Geneva

CH Fed. Uni. of T. (EPFL)



United States

Nat'l Ren. Energy Lab's

University of California

Hawaii Natural En. Inst.

Florida Solar En. Centre

New Groups

Expressions of interest by: Australia, France, Germany, Israel, Korea, the Netherlands, Mexico and the UK





Program of Work

Subtask-A: Material Studies

- A1: Screening of **semiconductor material** options and improvement of **light absorption** of photoelectrodes
- A2: Development of **catalytic and protective layers**

Subtask-B: System Studies

- B1: **Efficiency optimisation** of multi-junction systems
- B2: Investigation of **particle reactor design options**
- B3: Assessment of **dual-bed systems**



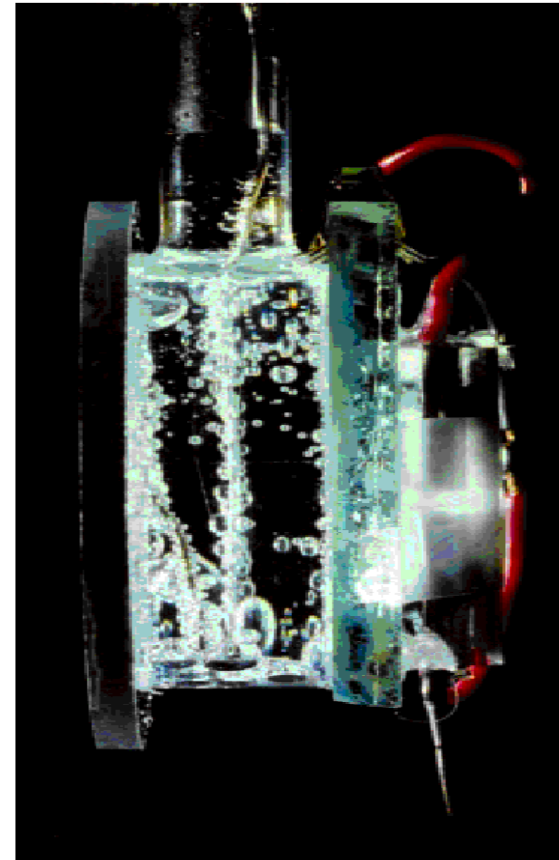


Laboratory Demonstrations

Fe_2O_3



GaInP_2



$\text{WO}_3 / \text{TiO}_2$





Some Highlights

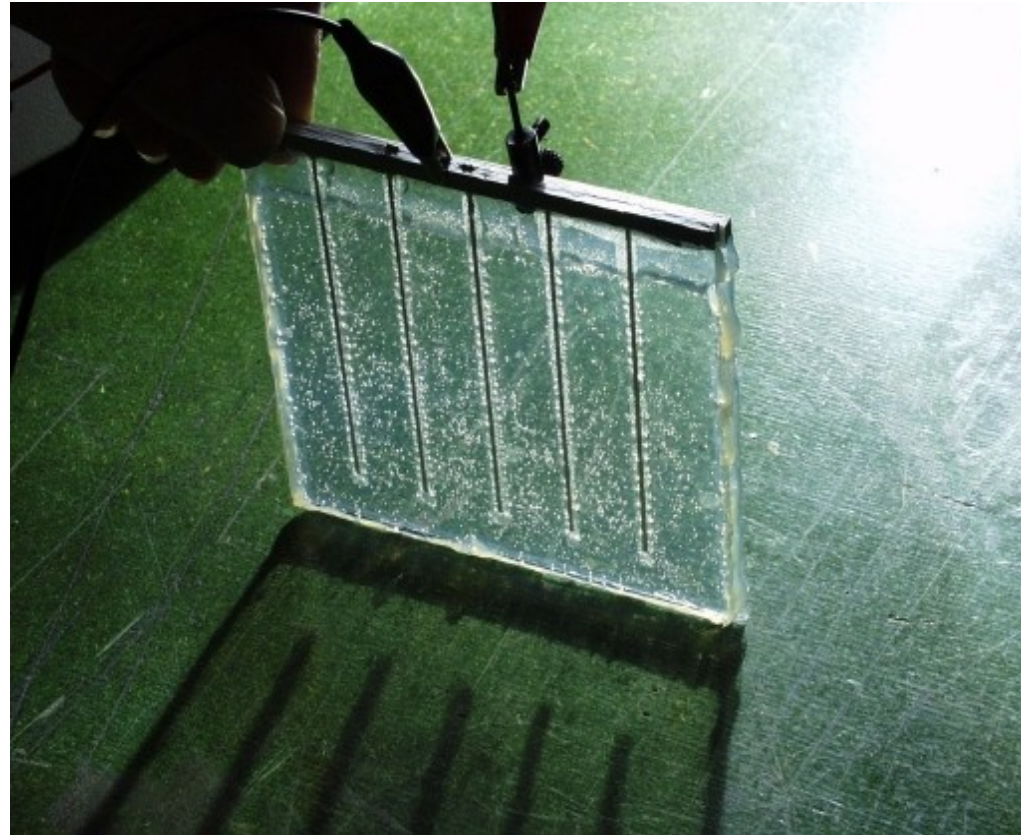
- **World-first water-splitting catalyst powder** ($\text{In}_{0.9}\text{Ni}_{0.1}\text{TaO}_4$) for VIS light
- Encouraging **photoelectrode performance enhancement results** from successful transition-metal-oxide (TiO_2), metal-oxide (ZnO) and III-V compound (Ga , GaIn) **doping** using **anions**, N_2 and C in particular
- Strong engineering **progress** with the **preparation and characterization of photoanode thin-films** (WO_3 , Fe_2O_3), including doping (Ti , Al) using ultrasonic spray-pyrolysis, sputtering or sol-gel
- Development of **novel planar, multi-junction PEC water-splitting cells**
- Completion of deposition and characterisation equipment for **ultra-fast screening of new electrochemical materials** (combinatorial chemistry)
- Development of **modelling capability of photo-oxidation** based on quantum transition theory
- Pioneering manufacture of 100mm x 100mm **demonstrator PEC water-splitting tandem cells** (WO_3/TiO_2 ; $\text{Fe}_2\text{O}_3/\text{TiO}_2$)
- **Solar-to-hydrogen conversion efficiency** of **4.5%** with WO_3 - TiO_2 -based tandem and **16%** with monolithic Ga-based laboratory PEC devices





Demonstrator PEC Device (H2-Solar)

**Solar
to
hydrogen
conversion
efficiency
 $\eta \sim 3\%$
when combined
with DSSC ...**



10cm x 10cm Tile Sample by Hydrogen Solar (UK)





200 m² DSSC-Demonstration

TiO₂
~ 50-W/m²



10 kW_e Plant by Sustainable Technologies International (AUS)





Future Plans

New Follow-on PEC R&D Annex

- Focus on **fundamental material science** challenges (tailoring of bandgaps, corrosion resistance, surface chemistry modification, light absorption, interfacial charge transfer, etc.)
- **Expansion of international R&D collaboration group** (above all Australia, France, Korea, Mexico and the Netherlands)
- **Manufacturing & economic analyses** with industries (large-scale deposition on glass; cost-to-performance ratio of 10)

Commercial Interests

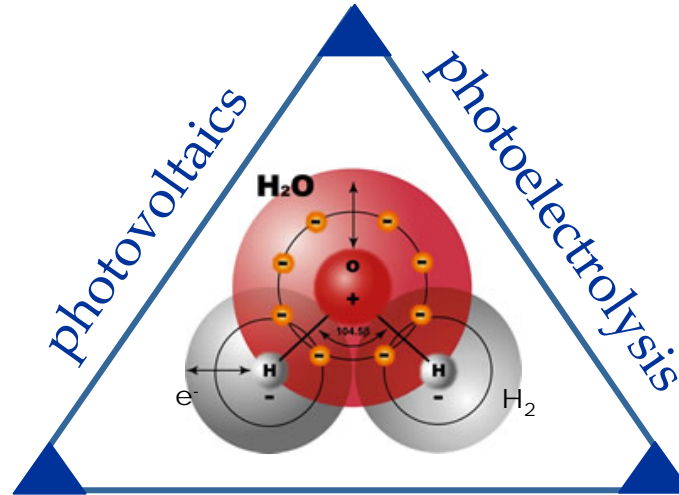
- Toward **demonstration of pre-commercial PEC devices** (particularly WO_3 or Fe_2O_3 -based systems with bias from TiO_2 DSSC)





Energy Triangle of post fossil-fuel era

source Sunlight



prime carrier

Power

storage & fuel

Hydrogen

