# Designing Catalysts to Enable Green Hydrogen Production at the Terawatt Scale by Water Electrolysis

**Caiwu Liang**, R. R. Rao, B. Moss, S. Scott, J. H. L. Hadden, J. Riley, M. P. Ryan, J. R. Durrant, I. E. L. Stephens

c.liang20@imperial.ac.uk

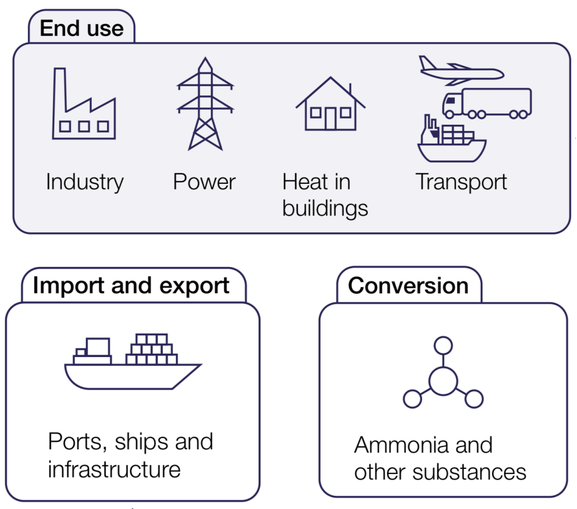
@Caiwu_Liang

Imperial College London

## 1 Why we need hydrogen from water electrolysis?

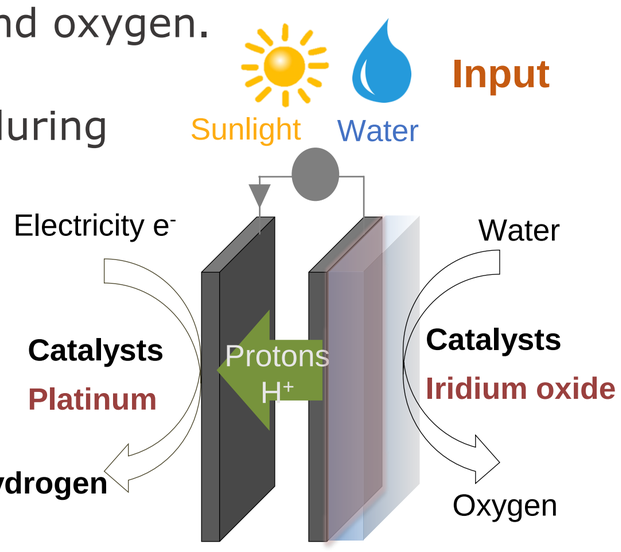
Hydrogen is the **cleanest** chemical fuel with **zero carbo emission**.[1]

- It **decarbonize** industrial process (Steel, Syngas..)
- **Store electrical energy** and reconvert it back when needed **(power production)**
- Industrial and home-used **heating**




**Water Electrolyser** uses **electricity** and catalysts to split **water** into hydrogen and oxygen.

- **Zero carbon emission** during hydrogen production
- **High efficiency** (>80%)
- Utilise waste **renewable electricity** from solar panel or wind power



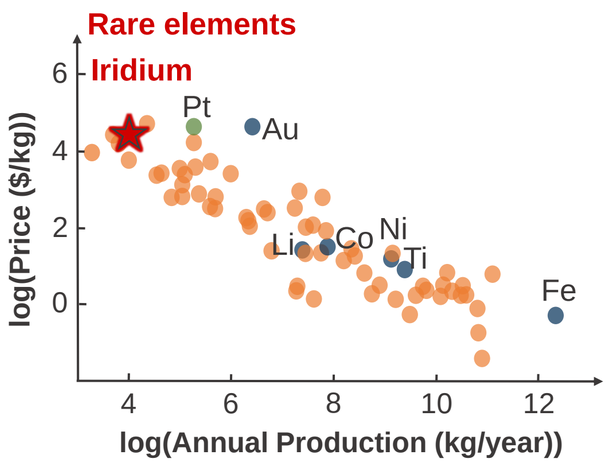

## 2 Can we scale up water electrolyser ?

Electrolyser relies on iridium oxide catalysts to speed up reaction.

Iridium's scarcity and high cost limits the scale up of this technology.[2]

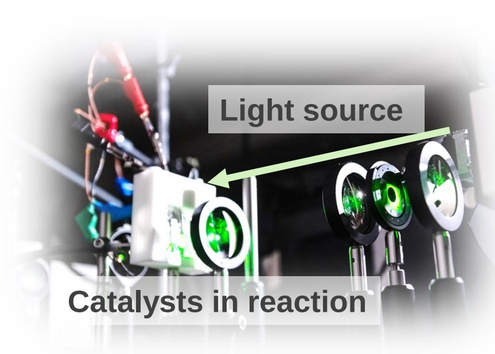
**Questions:**

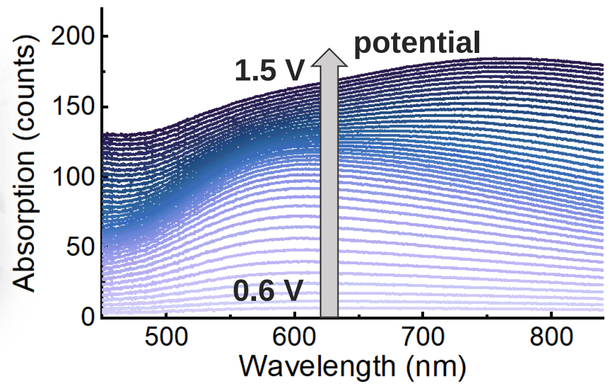
Can we **understand why iridium** is highly effective and stable, and **design** catalysts accordingly to use **less or no iridium** ?




## 3 'Seeing' atoms under reaction with light

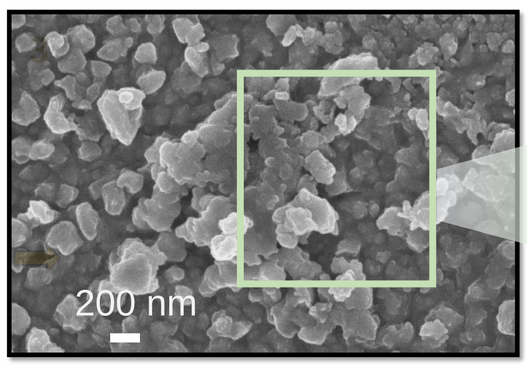
**Home-built high-resolution optical spectroscopy**

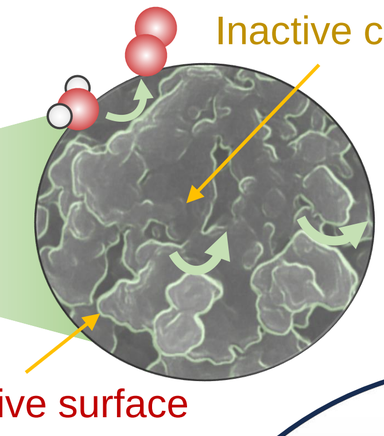



- Ultra-high sensitivity detector specifically designed for 'seeing' reaction on catalysts
- Real-time probing changes in catalysts by analysing how catalysts interact with light
- Quantify atoms that are being oxidised during reaction following Lambert Beer law.

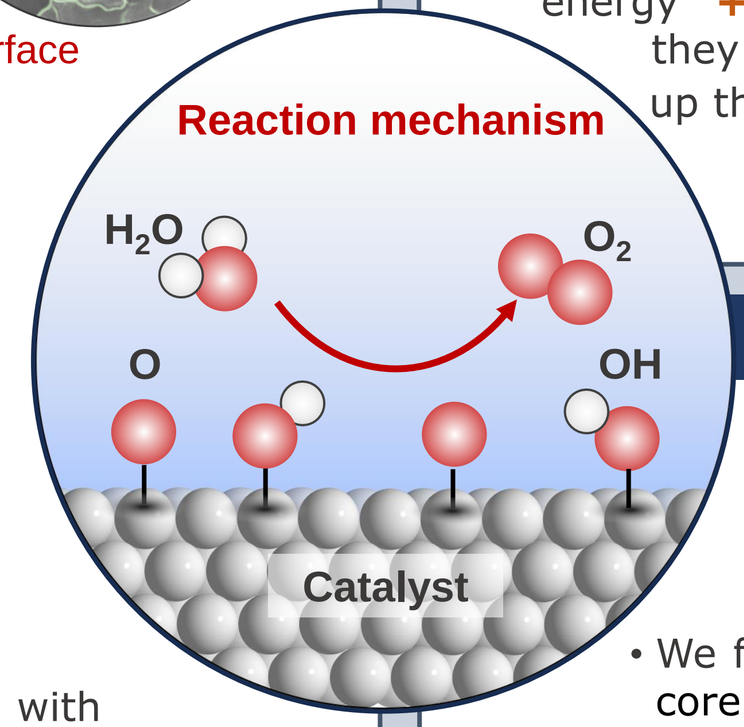
## 4 Our main findings



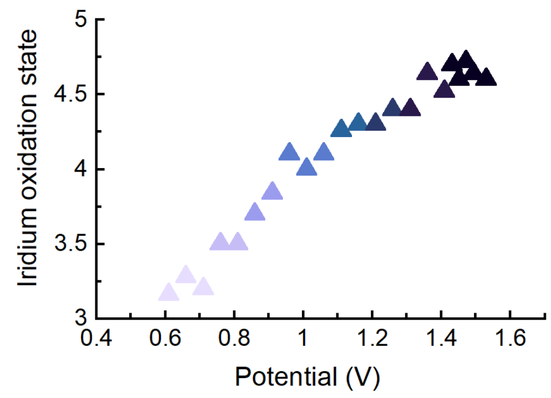

- Number of iridium atoms in the catalyst = **~2,000 atoms/nm²**
- Number of active iridium atoms = **~40 atoms/nm²** (determined from spectroscopy)
- **Iridium atoms not used = ~98%**

**Reaction mechanism**




**How does Iridium catalysts speed up reaction ?**

- Iridium atoms are **oxidised** from low energy **+3** to high energy **+5**, before they can speed up the reaction




**Indications:**

Replace the inactive iridium in the core with other conductive non-precious metals will decrease Iridium amount by 98% while has not effect on the reaction speed.

## 5 Conclusion and outlook

- We develop new optical spectroscopy set-up that can be used for quantifying active atoms in catalysts under operation condition.
- We find that currently, ~ 98% Iridium in the core are not being used in water electrolyser
- Future work is needed to selectively replacing iridium in the core with other cheap metals to significantly lower the use of Iridium.

1. UK Hydrogen Strategy, August 2021
2. Materials for end-to-end hydrogen, April 2021

C. L. thanks Imperial-CSC scholarship and bp-ICAM funding for support of this study.
C. L. acknowledge the support from Diamond light source, UK