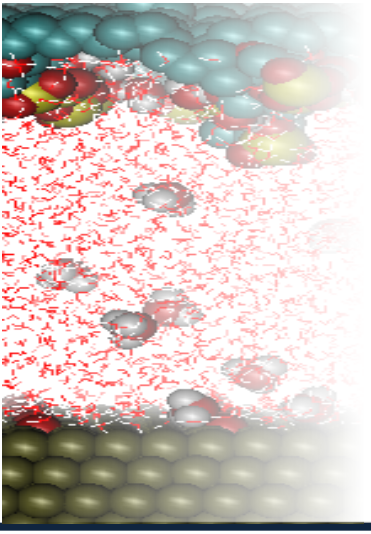

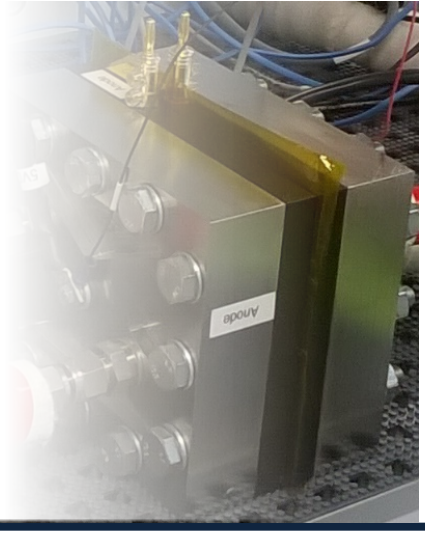

Power to Gas Technology for Renewable Electricity Storage

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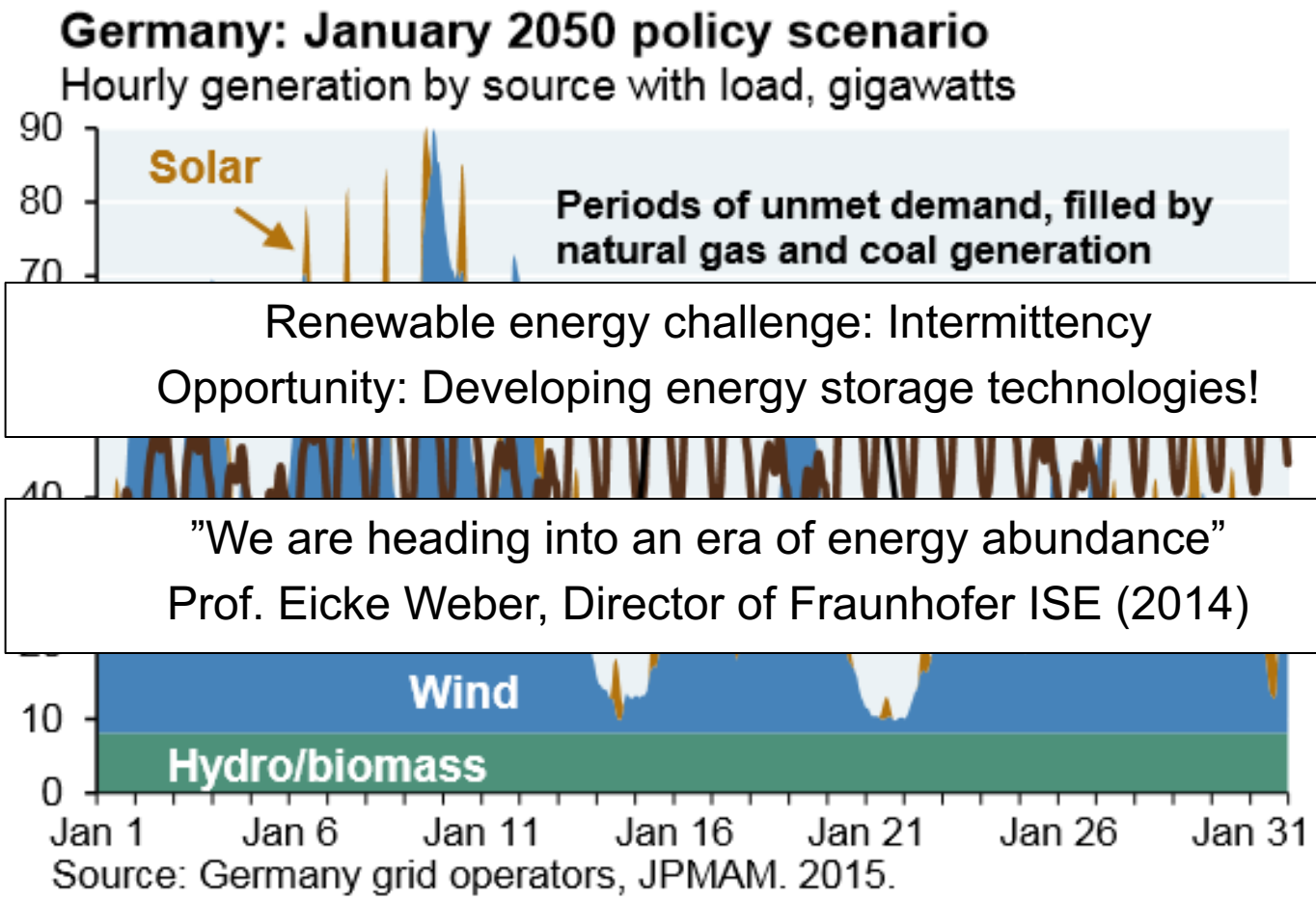
University of British Columbia

Renewable energies in the 21st century



Renewable energy challenge: Intermittency

Opportunity: Developing energy storage technologies!

”We are heading into an era of energy abundance”

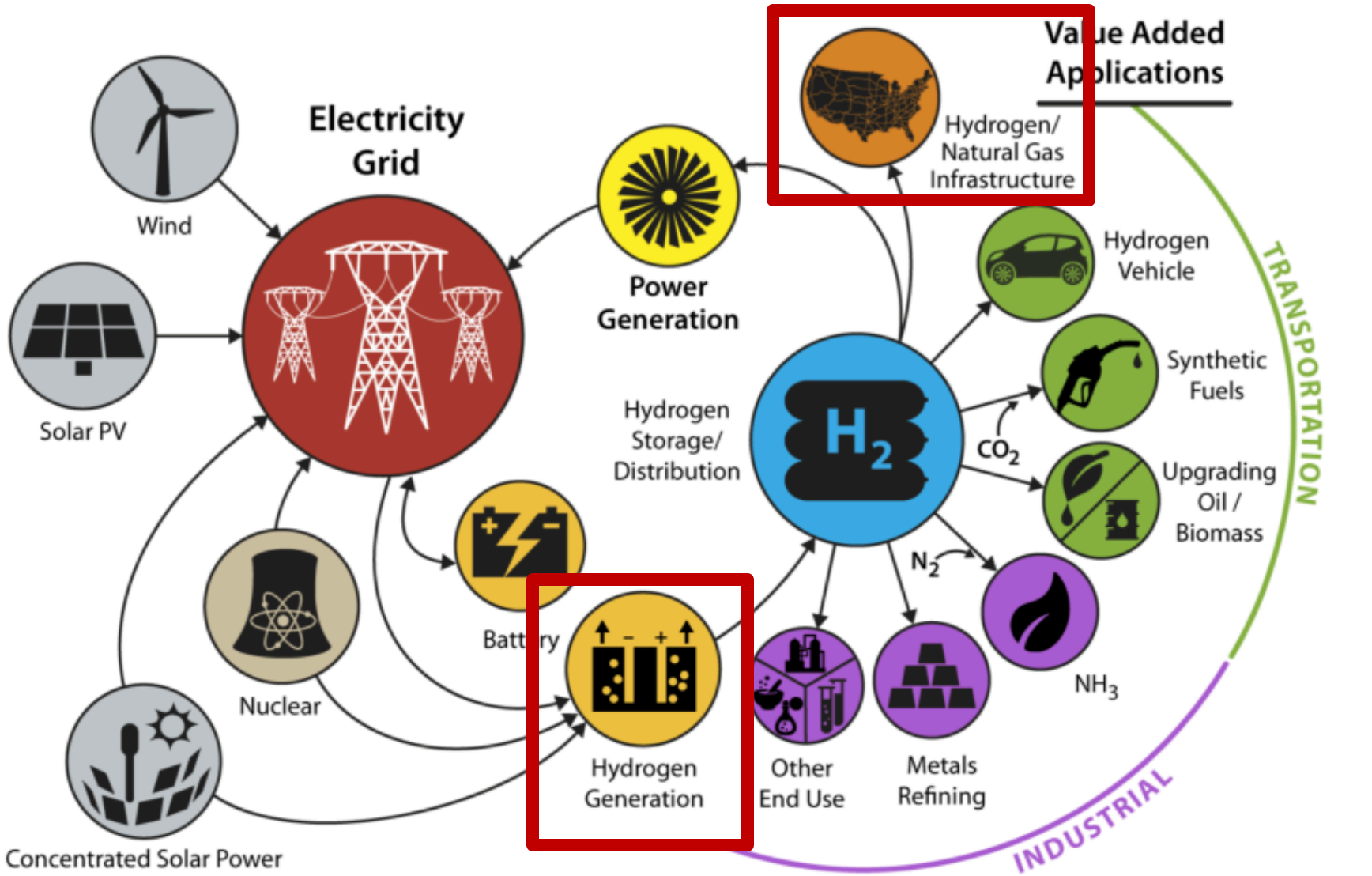
Prof. Eicke Weber, Director of Fraunhofer ISE (2014)

M. Cembalest, “A brave new world”, J.P. Morgan Annual energy paper, Oct. 2015

Outline

- Introduction to the cycle of renewable hydrogen
- Power to gas energy storage
- PEM water electrolysis
- Bubble removal in a PEM electrolysis cell
- Policies for energy storage
- Policy suggestions for P2G incentivizing
- Summary

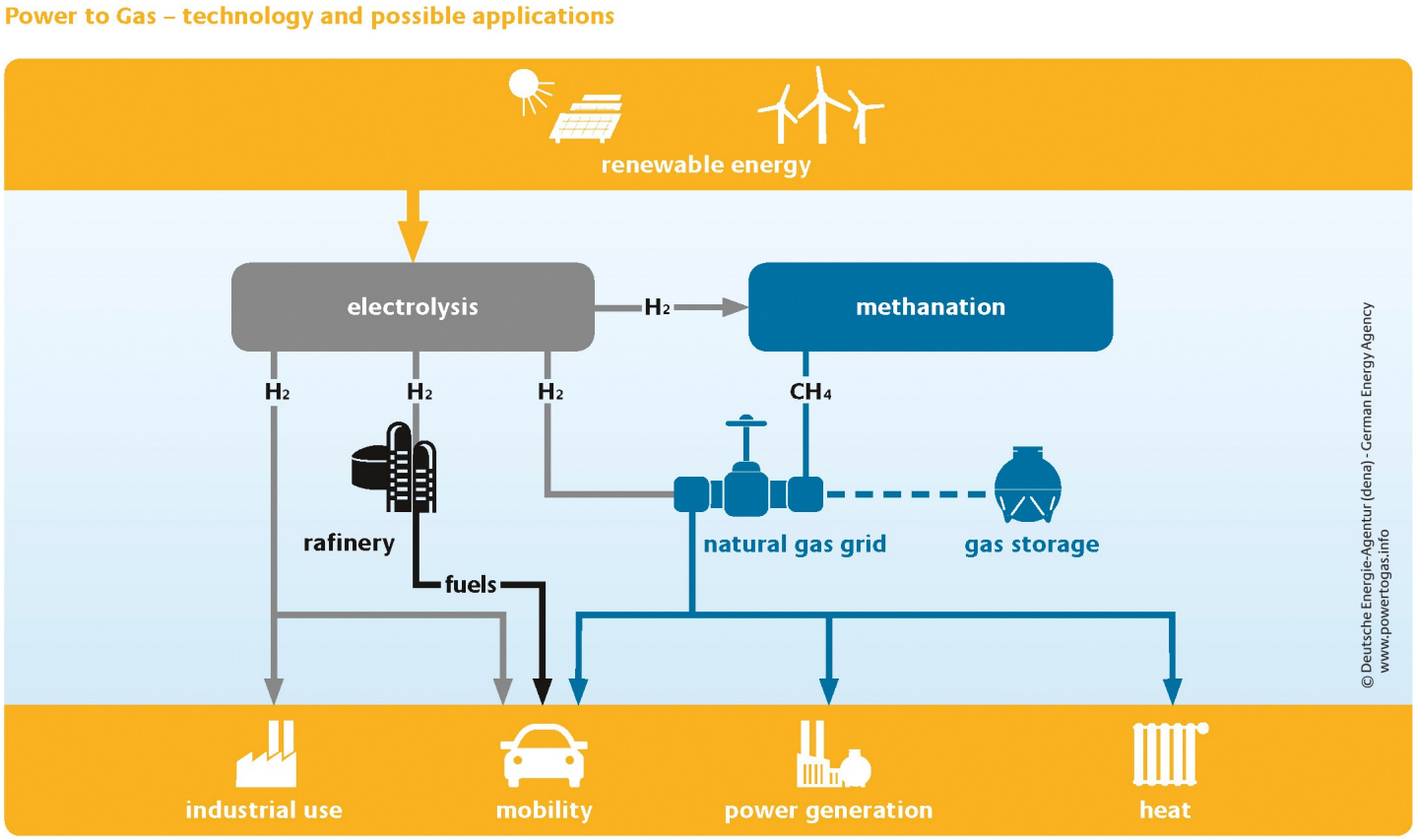
Cycle of renewable hydrogen



Picture source: hydrogen.energy.gov/pdfs/htac_apr16_10_pivovar.pdf

Power to gas (P2G) technology

- Robust framework for the electricity grid management.
- Multiple energy, chemical, and electrochemical pathways for hydrogen after production.



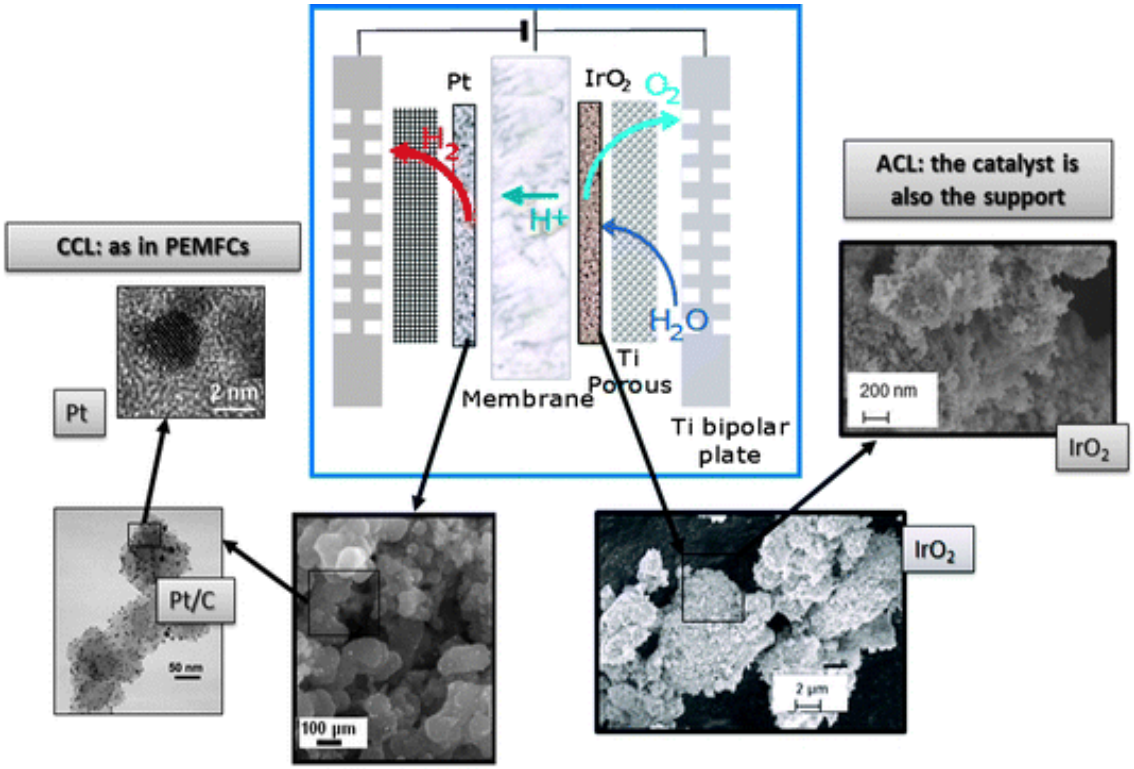
Picture source: www.powertogas.info

Part 1

Modeling oxygen bubble removal from water electrolyzers.

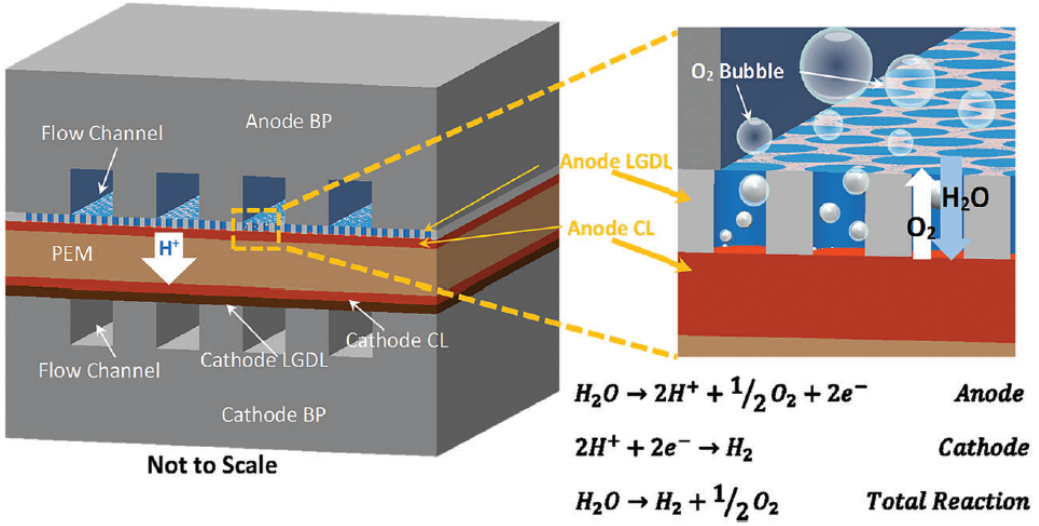
PEM water electrolysis technology

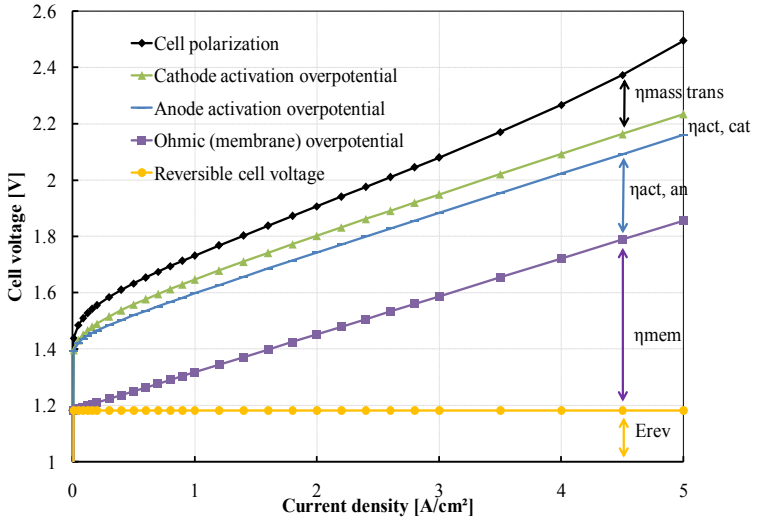
- Reactions:
  - Anode: $2\mathrm{H_2O(l)} \rightarrow O_2(g) + 4H^+ + 4e^-$
  - Cathode: $4H^+(\mathrm{aq}) + 2e^- \rightarrow 2H_2(g)$
  - Total: $2\mathrm{H_2O(l)} \xrightarrow{Energy} O_2(g) + \boldsymbol{2H_2(g)}$



O_2 bubbles in PEMWE cells

- Oxygen evolution at PEMWE anode: $2\mathrm{H_2O(l)} \rightarrow \boldsymbol{O_2(g)} + 4H^+ + 4e^-$
- O_2 bubbles obscure the reaction sites, and increase the cell overpotential (decrease the electrolysis efficiency).

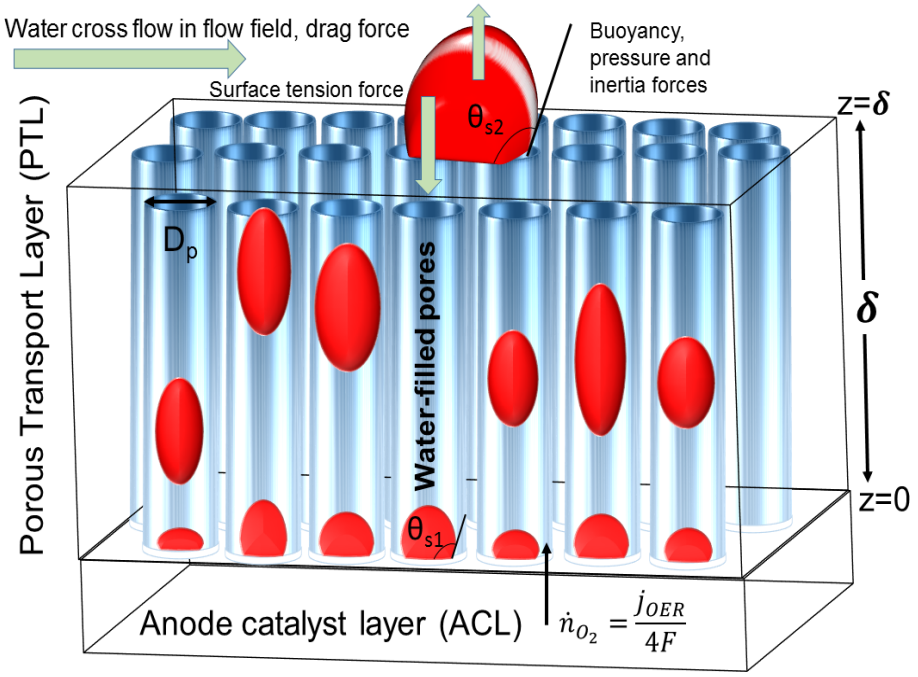


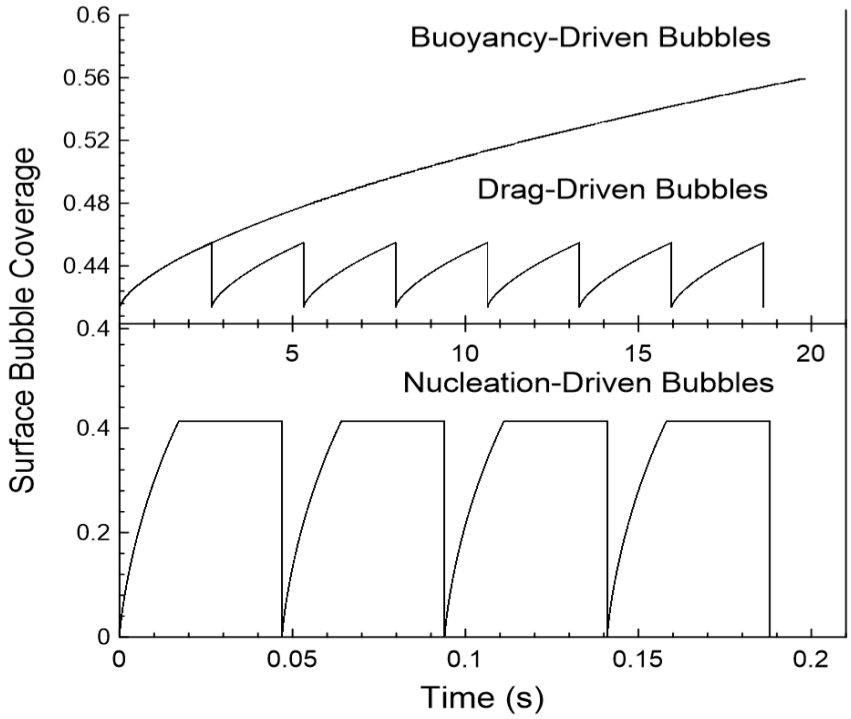


Kang, Z. et al. Energy Environ. Sci. (2016). doi:10.1039/C6EE02368A
Tabu-Ojong, E., Nouri-Khorasani, A. et al. (Submitted to Intl. J. Hydrogen Energy)

Electrolysis cell modeling

- Growth and stability simulation of O_2 bubbles in identical straight cylindrical porous transport layer.





Nouri-Khorasani, A. et al. (Submitted to Intl. J. Hydrogen Energy)

Part 2

Energy policies to incentivize Power to gas

Energy storage policy background

- Traditional perspective on energy storage: energy security
  - Dependency on foreign oil, imported natural gas

- 95% of energy storage capacity in Europe is pumped hydro storage.
  - Different policies across member states.

- New challenges:
  - Grid share of “volatile” primary renewable energies.
  - Possible “phase out” policy for coal in Germany and around the world.

Source: “Energy storage: Which market designs and trgulatory incentives are required?” S. Urgate, Report to European Parliament, IP/A/ITRE/2014-05

What is the value of energy storage?

- Curtailment costs depend mainly on the renewables penetration, grid interconnection, and energy storage strategies available.
- ”Reliability” value.

- *Power to gas offers a scalable solution to our Megawatt energy challenge!*

Surplus wind power could cost Ontario ratepayers up to $200 million: IESO

Surplus wind power could cost Ontario ratepayers millions and compromise power system, says electricity system operator. It says renewable energy market rules must change

Source: Toronto Star, February 2013

Demonstration project examples

- Thüga group demonstration project in Frankfurt (2013)
- UC Irvine campus microgrid P2G project (2016)

Policies to support energy storage

Current policy:

- (EC 2014/C 200/01): generators receiving state aid should at least adhere to standard balancing requirements.
- **Current policy cost**: 0.2-1 c/kWh for the wind energy sector.

Suggested policy change :

- **Incentives for the research on energy storage technology.**
- **Natural gas (NG) sales regulation :** Amending NG sales contracts to include acceptance of a concentration <15% of hydrogen mix with the distributed NG.
  - Cleaner burn for the NG mix
  - Advancing e-mobility targets

Conclusion

- Power to gas technology provides energy storage opportunities up to megawatts.
- Mathematical modeling research aimed at improving mass transport in the electrolysis cells by efficient bubble removal. Hydrophilicity and pressure are the most important conditions for optimal electrolysis operation.
- In the current century with an energy abundance and sustainability paradigm, policies aiming at energy storage should look beyond energy security.
- Feed-in stability regulations, and energy storage incentives can lead to developing a more balanced energy grid, cleaner natural gas mix, and smaller energy curtailment costs.