

Homework 14 Solar Power for Africa 2023 Due Friday December 8
(Counts as two homework)

- 1) Last week we looked at wind power and went through the Betz limit. Ionic wind generators were briefly mentioned and there are several links on the webpage describing this method to harvest wind energy. Derive the Betz limit as done in class and explain why the Betz limit doesn't apply to ionic wind generators.
- 2) The PREOS.xls (Peng-Robinson equation of state) spreadsheet (<https://www.eng.uc.edu/~beaucag/Classes/ChEThermoBeaucage/Preos.xlsx>) allows the calculation of the phase behavior of common industrial chemicals such as ammonia, hydrogen, CO₂, propane, and CO. This is a useful tool to understand options available for a hydrogen-based economy. For each step show a screen shot of PREOS.xls with the result.
 - a) Use PREOS.xls to determine the temperature necessary for liquid hydrogen at 1 bar (~1 atmosphere),
 - b) the pressure needed to produce liquid propane at room temperature (~LPG),
 - c) liquid ammonia at room temperature.
 - d) Using these values explain why ammonia is appealing for storage and transport compared to hydrogen.
- 3) Most hydrogen that is available today is produced from methane reforming. Explain what conditions and catalyst are needed. What are possible sources of methane?
- 4) Hydrogen can also be produced by electrolysis. Show the design of an industrial electrolysis setup. How many kWh are needed per kg of hydrogen?
- 5) Explain how algae can be used to produce hydrogen. Is this a commercially viable process?
- 6) How is titania used to produce hydrogen? Sketch this process.
- 7) Show a simple solar-driven oxidation/reduction reaction for hydrogen production
- 8) Show a more complex multi-step solar-driven oxidation/reduction scheme for hydrogen production.
- 9) The Haber reaction can be used to produce ammonia from hydrogen. Sketch the Haber process for production of ammonia.
- 10) The Fischer-Tropsch reaction can be used to produce hydrocarbons from hydrogen. Sketch the Fischer-Tropsch process.
- 11) Catalytic cracking can be used to convert ammonia to hydrogen. Sketch this process
- 12) Consider the use of various green aviation fuels. Describe and give the advantages and disadvantages including costs for the following fuels.
 - a) lithium-ion battery driven electric turbines,
 - b) biodiesel and biodiesel/kerosine blends,
 - c) ammonia gas turbines,
 - d) ammonia/kerosine blend,
 - e) ammonia/hydrogen blend,
 - f) high-pressure hydrogen,
 - g) ammonia with an onboard catalytic cracker to produce hydrogen.
- 13) It is planned to use photovoltaics to produce electricity in the Arabian desert near the Red Sea (which connects through the Suez Canal to Europe). Compare the cost and possibilities of the following alternatives for transmission of photovoltaic energy to Europe:
 - a) the electricity could be converted to high voltage DC,

- b) it could be used to electrolyze seawater to produce hydrogen which could be pressurized to 800 bar and piped to Europe,
- c) hydrogen could be cryogenically cooled and shipped to Europe,
- d) hydrogen could be converted to ammonia at 10 bar and piped to Europe using existing liquid fuel pipelines and for storage followed by cracking to produce hydrogen fuel.
- e) Hydrogen could be converted to ammonia at 10 bar and shipped using commercial freight ships.

Option e) was chosen by the Saudi's <https://energy-utilities.com/saudi-arabia-s-5bn-green-hydrogenbased-ammonia-news111872.html>

14) Consider the automotive fuel market for:

- a) hydrogen (fuel-cell electric),
- b) ammonia through direct combustion or in blends with diesel
- c) ammonia via onboard cracking to hydrogen,
- d) electric vehicles.

Compare these technologies and consider the availability of existing infrastructure. Toyota has heavily invested in hydrogen fueled vehicles with the Mira (<https://www.toyota-europe.com/electrification/fcev>) as an example (about \$50K in the US). This can be compared with GM which has invested heavily in EVs with the Chevy Bolt (<https://www.chevrolet.com/electric/bolt-ev>) as an example (about \$24K – \$7.5K tax rebate). Hydrogen and electric refueling stations in the US and in Africa (<https://www.electromaps.com/en/charging-stations/south-africa> ; https://afdc.energy.gov/fuels/hydrogen_locations.html#/find/nearest?fuel=HY ; <https://www.glpautogas.info/en/hydrogen-stations-south-africa.html>) H₂ stations in Japan, South Korea, Europe and China. (hydrogen refueling stations in Japan <https://www.glpautogas.info/en/hydrogen-stations-japan.html> ; in South Korea <https://www.glpautogas.info/en/hydrogen-stations-south-korea.html> ; in China <https://www.glpautogas.info/en/hydrogen-stations-china.html> ; and in Europe <https://h2-map.eu> .)

15) Australia has invested in ammonia for export primarily to Japan and South Korea where the hydrogen economy has been implemented. Australia currently has the 28 GW Western Green Energy Hub, the 14 GW Asian Renewable Energy Hub, the 8 GW HyEnergy Zero Carbon Hydrogen and the 5 GW Murchison Renewable Hydrogen Project, all in Western Australia; the 3.6 GW Pacific Solar Hydrogen and the 3 GW H₂-Hub Gladstone projects in Queensland, the 2.8 GW Tiwi Hydrogen Project in the Northern Territory and the proposed Moolawatana Renewable Hydrogen Project in South Australia which will combine 3 GW of wind and 3 GW of solar with electrolyzers, a desalination plant, and a dedicated H₂ pipeline around 500km long to a local port, where the hydrogen will be used to produce green ammonia for export. Comment on the extent of the hydrogen economy in the world compared to that in the US in the context that an American company, Air Products, is spearheading the 4 GW PV/wind hydrogen/ammonia project overseas in Saudi Arabia (<https://energy-utilities.com/saudi-arabia-s-5bn-green-hydrogenbased-ammonia-news111872.html>) with little similar investment in the US.