Power-to-X & Green Hydrogen
The Jordanian Context
|
Energy, Water, Food Security, and Environment Nexus

Dr. Abdelrahman Al-Attili
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6th Mar. 2024

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❖Today's Session

Outline

- **Part 1:**

1- Motivation behind PtX.

2- Standards: Hydrogen types and requirements for GH.

3- Technicalities: Hydrogen production, storage and transport.

- **Part 2:**

4- Applications and sector coupling:
NEXUS approach reflected to the Jordanian market.
- Derivatives Map
- Energy
- Food
- Environment

5- Water & Feasibility.

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Power-to-X & Green Hydrogen
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Motivation

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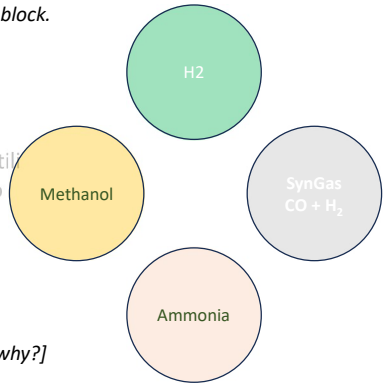
❖PtX Concept

A simple definition!

- **PtX is a brilliant idea, a fruit of years of research and planning.**
- *Power to ready-to-use products: PtG, PtL, H2 is the building block.*
  - *1- Solves the main issue facing the renewables.*
  - *2- Ready to use materials in many applications.*
  - *3- Available Infrastructure.*
  - *4- Oceans and seas are the raw material.*



- *H2 as the new oil:*
  - *1- Must be created by renewable energy [must be green, why?]*
  - *2- Any country with access to sea water is a new oil country.*
  - *3- Feasibility will ensure it is Green.*

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cost + availability + green + new markets

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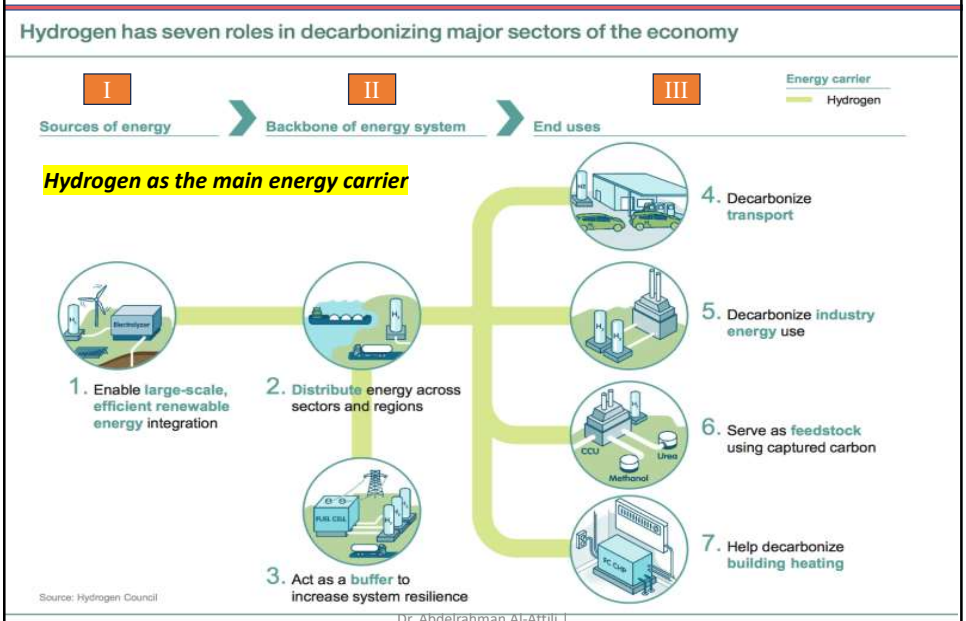
❖Hydrogen as an Energy Carrier



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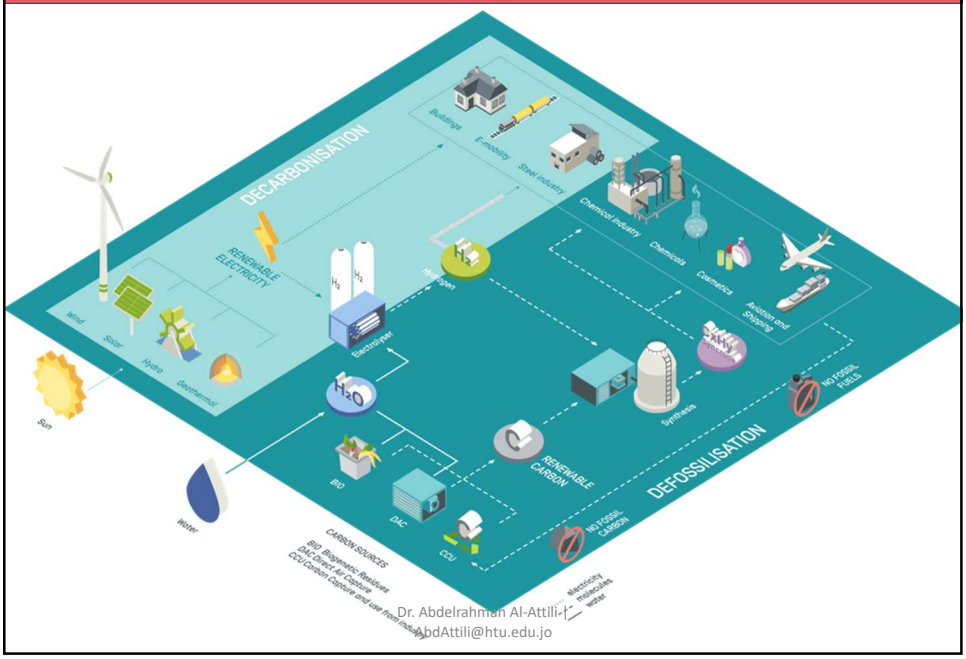
❖Sector Coupling



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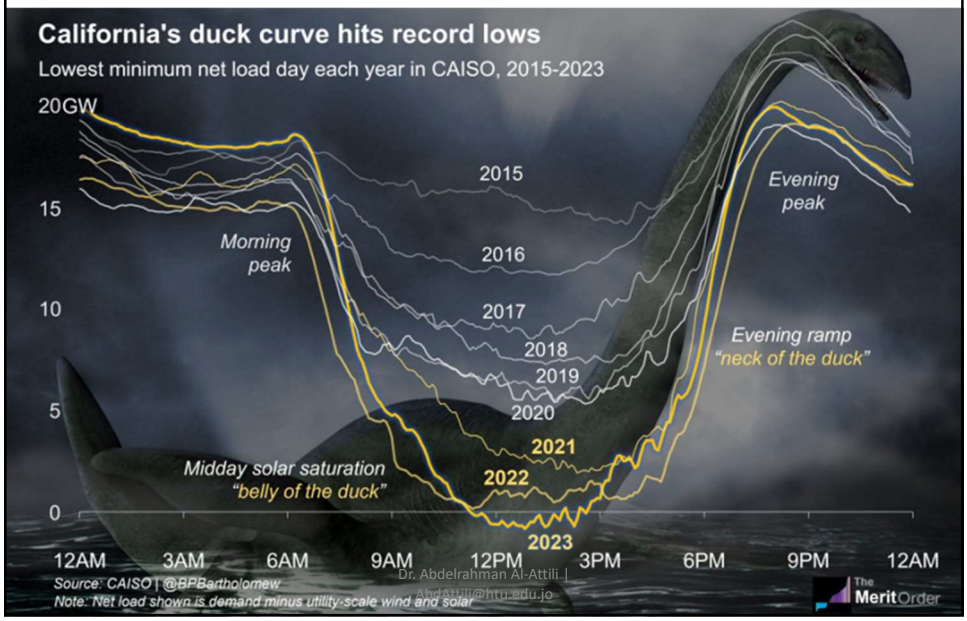
❖Renewables Penetration

The Duck Curve



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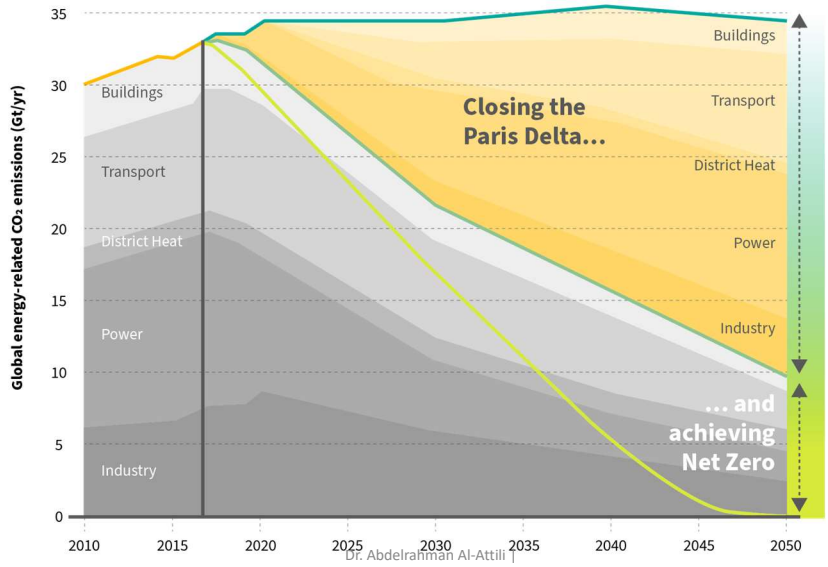
❖Pillars of the Energy Transition

Efficiency, sufficiency, RE, Electrification, and PtX!



- Source: International Renewable Energy Agency Hydrogen From Renewable Power Technology Outlook For The Energy Transition, 2018, p.10/1.

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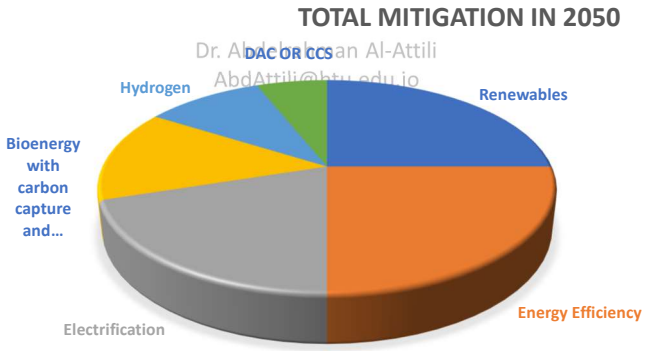
❖Reducing emissions by 2050 through six technological Methods

➢ Energy Transition Energy transition, as defined by The International Renewable Energy Agency (IRENA), is "a pathway towards the transformation of the global energy sector from fossil-based to zero-carbon by the second half of this century" (IRENA, 2020).

Enhancing the energy efficiency of the existing consumption is expected to contribute to a quarter of all CO2 reduction!



Source: IEA REPORT

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Standards:
Hydrogen types and requirements for GH.

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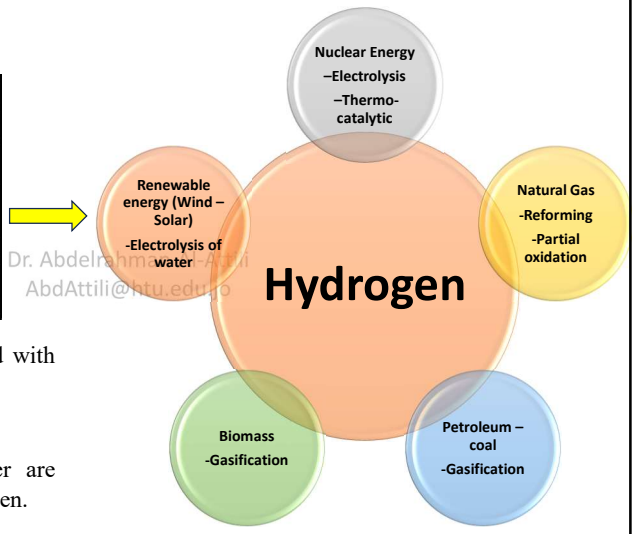
❖Colors of Hydrogen

Hydrogen is everywhere!

71% of earth surface is covered with water!

Theoretically, 9 liters of water are needed for 1 kilogram of hydrogen.

How much in practical systems?



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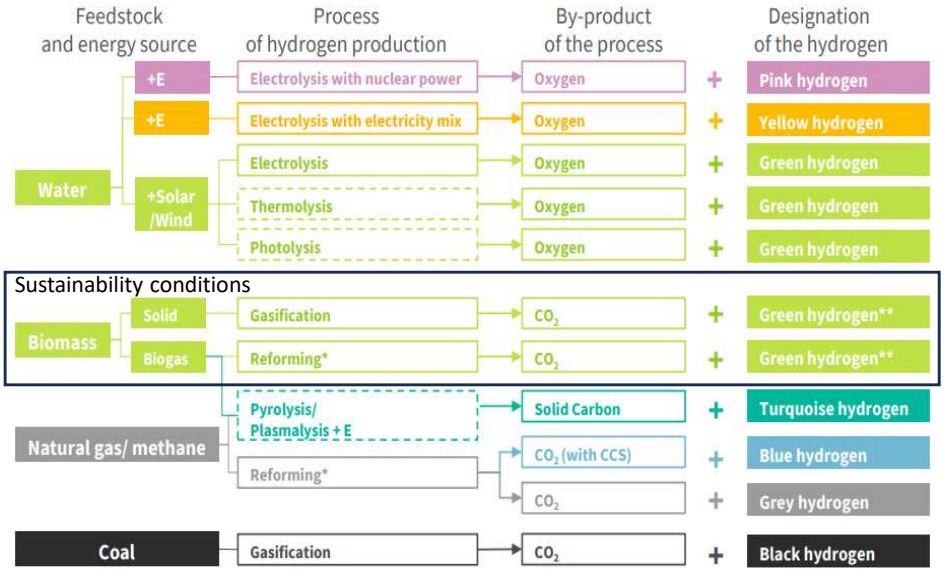
❖Colors of Hydrogen



Source: Sachverständigenrat für Umweltfragen, Wasserstoff im Klimaschutz: Klasse statt Masse, June 2021, S. 64

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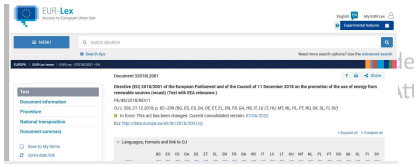
❖GH Requirements

Renewable Energy Dire

What is RED?

The RED II document:



https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2018.328.01.0082.01.ENG&toc=OJ:L:2018:328:TOC

2023 Provisional agreement to raise 2030 target to at least 42.5%, aiming for 45%

2022 REPowerEU Plan: EC proposal to raise target for 2030 to 45%

2021 Renewable Energy Directive: EC proposal to raise target for 2030 to 40%

2019 EU power production from wind and solar surpass coal for the first time

2018 Revised Renewable Energy Directive: 32% renewables target for 2030

2014 Onshore wind is cheaper than coal, gas and nuclear energy

2009 Renewable Energy Directive: EU target of 20% renewables by 2020 and national binding targets

2008 Olmedilla Photovoltaic park (Spain) - largest power plant (60MW) in the world - generates enough to power 40 000 homes/year

2003 Directive on biofuels and renewable fuels for transport: national targets for biofuels

2001 Directive on electricity production from renewables: national indicative targets

2000 First large-scale offshore wind farm (Denmark)

1997 Energy for the future: renewable sources of energy: indicative EU target of 12% renewables by 2010

Hide 9 items

1991 Germany introduces first feed-in-tarif for renewables

https://energy.ec.europa.eu/topics/renewable-energy/renewable-energy-directive-targets-and-rules/renewable

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❖GH Requirements

Strict Requirements!

To comply with the RED requirements, two Delegated Acts were approved:

The first act:

Additionality Principle

Hydrogen or hydrogen-based fuels or derivatives can be designated a renewable fuel of non-biological origin, or RFNBO, if generated using additional (36 months) renewable power.

- Green Hydrogen, or RFNBO: RE to an electrolyzer, H2 from water.
- H2 from a biomass source: biomass fuel, not RFNBO, carbon neutral
- RE H2 from biomass source can be considered green if certain sustainability conditions are met.

The second act:

Mechanism for calculating GHG emission reductions.

70% reduction in GHG emissions for replacing a fuel with another.

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❖GH Requirements

Electrolysis Requirements!

- Drinking water is prohibited.
- RE off-grid: 36-month old RE plant. *(Easiest option!)*
- RE can be on-grid (with a PPA): The RFNBO producer has signed one or more PPAs with a RE generators and each of the following requirements has been met:

1. Additionality:

   a. a) The RE plant must have been operational earlier than 36 months before the installation of the RFNBO.
   b. No governmental assistance or subsidies, such as feed-in tariffs or contract-for-difference schemes, have been given to the RE plant.

2. Temporal correlation:

   a) Hourly matching requires that the RFNBO be created during the same hour as the RE.

Source: Recent developments in the EU's requirements for certification of green hydrogen - Global Energy Blog

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❖GH Requirements

Electrolysis Requirements!

3. Geographic correlation: The RE plant must be situated in one of the following locations:

   a. In the same "bidding zone" as the RFNBO installation.
   b. In a neighboring bidding zone, provided that the RE price in the neighboring bidding zone is at least equal to the RE price in the bidding zone where the RFNBO installation is situated.
   c. In an offshore location, close to the bidding zone where the RFNBO installation is situated.

- Electricity from the grid (no PPA): RE in the bidding zone in the previous calendar year was at least 90% *(in reality, this will exclude most European electricity markets, for the time being).*
- For on-grid RE: emission intensity of the grid in the bidding zone is lower than 18gCO2/MJ.
- For on-grid RE: Curtailment of excess energy is considered renewable.

Source: Recent developments in the EU's requirements for certification of green hydrogen - Global Energy Blog

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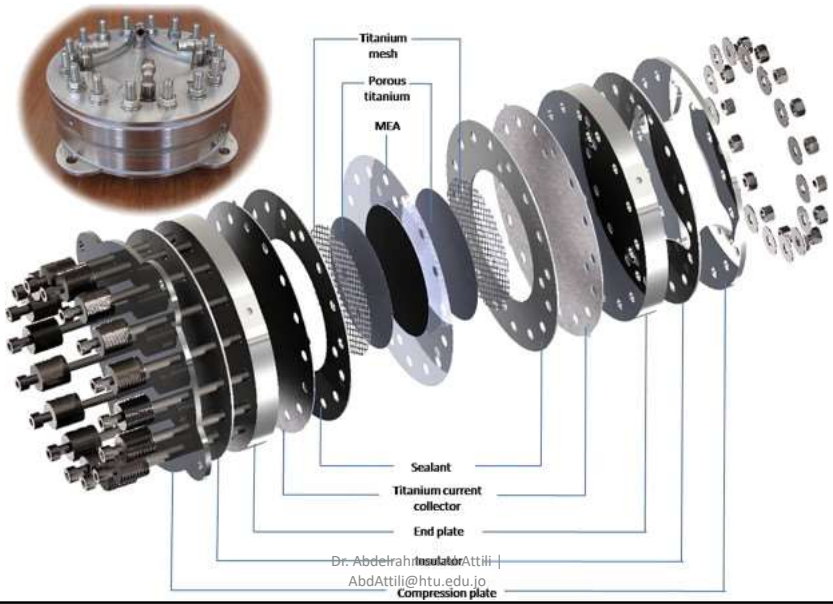
❖Electrolyzer

https://doi.org/10.1016/j.ijhydene.2011.01.129



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❖Current Applications in Jordan

Chemical Applications

- The process of BCC and NCI is very similar.
- We will consider Al-Baha as an example.

30	15	250	30000	26000
Number of Clients	Years of Experience	Number of Employee	T/Y (100% NaOH) Plant Capacity	T/Y (Chlorine) Plant Capacity

Caustic soda
Key applications:
- Detergents industry
- Water Treatment
- Non-Organic Chemicals like Paints, Glass, Ceramics and makeup
- Food Industry
- Aluminum Industry

Chlorine
Key applications:
- Water purification
- Sewage and industrial effluent treatment
- In the PVC industry (polyvinyl chloride)
- Pharmaceutical industry

Hydrochloric Acid
Key applications:
- Chloride production
- Steel industry
- Oil wells in the stages of drilling and production
- Pharmaceutical industry

Sodium hypochlorite
Key applications:
- Sanitizers and detergents industry
- Sterilization as bleach and disinfectant
- Food Industry
- Glass industry
- Paper Industry

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❖Current Applications in Jordan

Chemical Applications

- The process of BCC and NCI is very similar.
- We will consider Al-Baha as an example.


Water Desalination


PEM Electrolyzer


Gas Outputs: Chlorine + H2 Separated


Gas storage Chlorine


H2 for: Pressure Regulation 30% Boiler 50% HCl 20%


Caustic Soda Tanks

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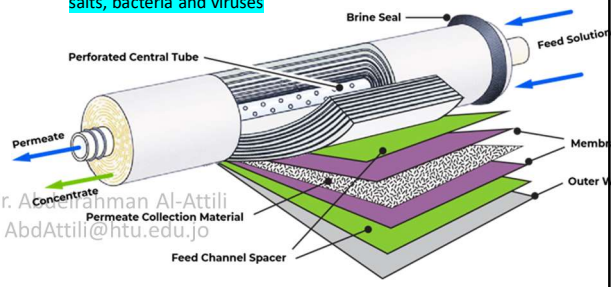
❖Current Applications in Jordan

Chemical Applications

Reverse Osmosis (pressure through Membrane)!

Photo from NCI

Permeate is clean water
Concentrate is water with extremely high concentration of salts, bacteria and viruses



This step results in 250 micro-Siemens per centi-meter.

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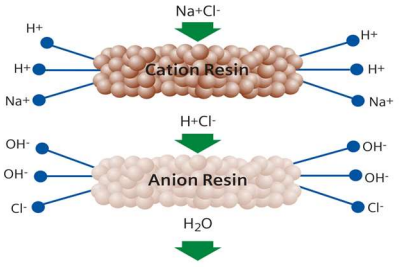
❖Current Applications in Jordan

Chemical Applications

Demineralization / Deionization
In BCC and NCI, it is resin based!



This step results in 1 micro-Siemens per centi-meter.

Deionized water ready for the electrolyzer use!

-> sometimes used to wash high voltage lines (low conductivity)

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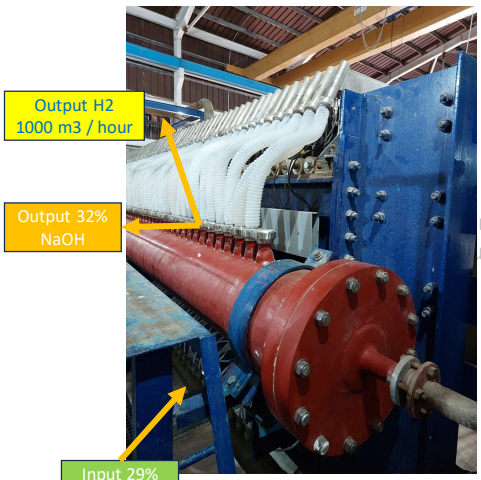
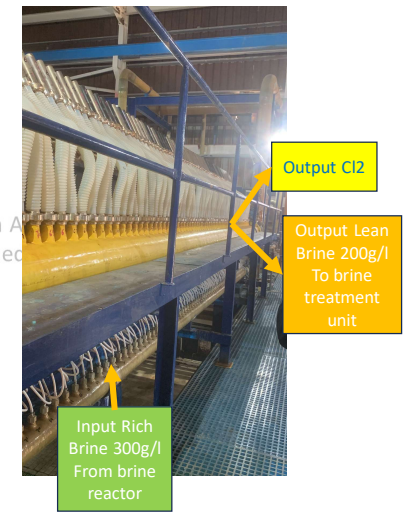
❖Current Applications in Jordan





Optimum temperature of the solution is 78C, there is also an optimum pressure.

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❖Current Applications in Jordan

Output gasses By pipes

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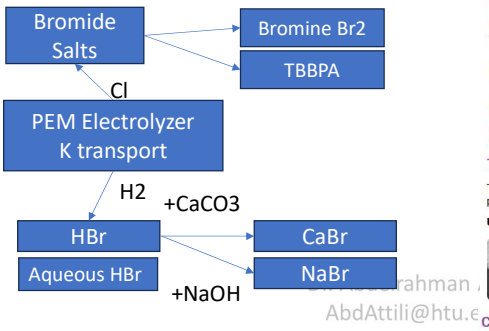
❖Current Applications in Jordan



Bromine

Bromine is used in the manufacturing of pharmaceuticals, flame retardants, water treatment chemicals, insect repellents, photographic chemicals, perfumes, dyes, oilfield completion fluids and other chemicals.

Use cases

Tetrabromobisphenol A (TBBPA)

TBBPA is a reactive component of polymers, and is used to prepare fire-resistant polycarbonates.

Use cases

$C_{15}H_{12}Br_4O_2$

Hydrogen Bromide (HBr)

HBr is used as part of the water purification process and in medications such as Ibuprofen and HIV

Use cases

Calcium Bromide (CaBr)

CaBr is utilized for hydraulic drilling and are intended to maintain the integrity of the pressure in the wells, protecting the wells from collapsing during the process. CaBr is used in shallow drilling

Use cases

Aqueous HBr

HBr is used in organic synthesis to add a bromine atom to molecules in order to produce other intermediates for pharmaceuticals.

Use cases

Sodium Bromide (NaBr)

NaBr is utilized for hydraulic drilling and are ir
pressure in the wells, protecting the wells fror
used for deep well drilling.

Use cases

DECADES OF CREATING VALUE, THIS IS JBC

370 Employees
290M In gross sales
158M Community investments
5.1% of total Jordanian exports

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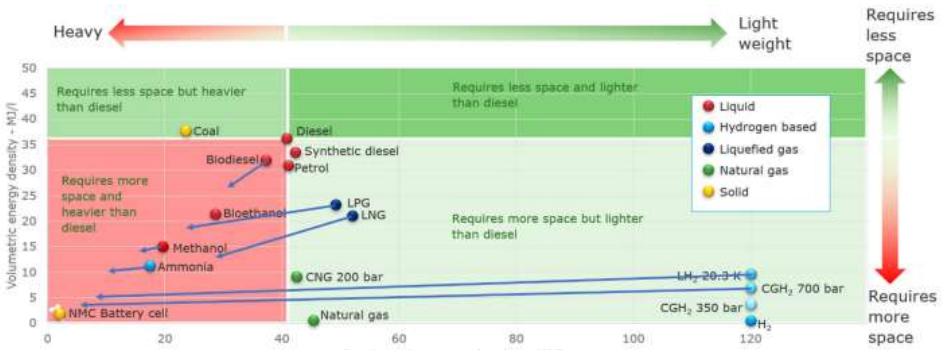
❖Storage Problem

Source: DNV GL AS Maritime Environment Advisory, Comparison of Alternative Marine Fuels, 07/2019, p.4/fig.1.

Hydrogen Dilemma.

Hydrogen has the highest specific energy (lighter than conventional fuels), but it has low energy density (requires more space).

- H2 has lower energy density per unit volume which is the main drawback.
- Yet the main plus is that it can be directly stored after electrolysis – a single-step transition from electricity.
- H2 is the main building block of Syngas, Ammonia, and Methanol.



❖Startups

Dutch startup **NPROXX** develops stationary hydrogen storage solutions. The startup's storage solutions store more than 1000 kg of hydrogen at pressures of 500 bar.

- PED Bundle 1000 bar
- 10ft PED 500 bar
- 20ft PED 500 bar
- 40ft PED 500 bar

❖Startups

Swiss startup **GRZ Technologies** creates solutions for ambient pressure hydrogen storage. The startup's *Dense and Safe Hydrogen Storage (DASH)* modules integrate with renewable energy generation systems. On coming in contact with the material of the containers, hydrogen molecules dissociate into hydrogen atoms. The hydrogen atoms are then absorbed in the interstitial sites of the metallic compound at near-ambient pressures. The stored hydrogen has pressure twice as high liquid hydrogen and four times higher than pressurized gas.

Standardized dense and save hydrogen storage module
DASH hydrogen storage modules are solid-state hydrogen storage systems, in which hydrogen can be stored in the solid, atomic form within a special metallic structure. They excel through excellent safety properties, a very high volumetric density, and a particularly long lifetime. The materials used in the storage system are easy to handle, recyclable, and require comparatively little energy to be manufactured. The modular design enables the realization of storages containing any desired hydrogen capacity

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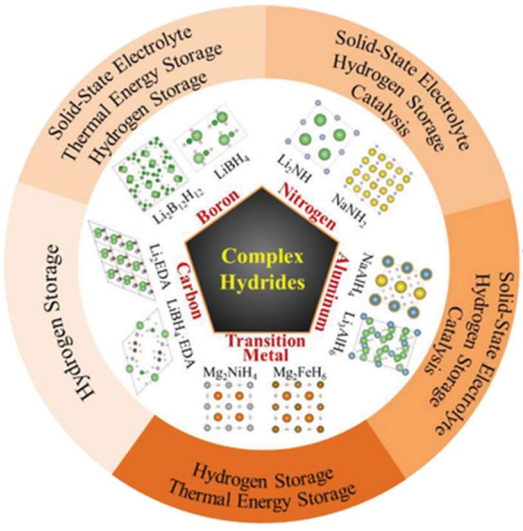
❖Metal Hydrides



MHT-MAGNUM
$LaNi_5H_6$
stores 200g H_2.

DOI:10.1002/adma.201902757
Source: https://www.mahytec.com/en/products/solid-hydrogen-storage/

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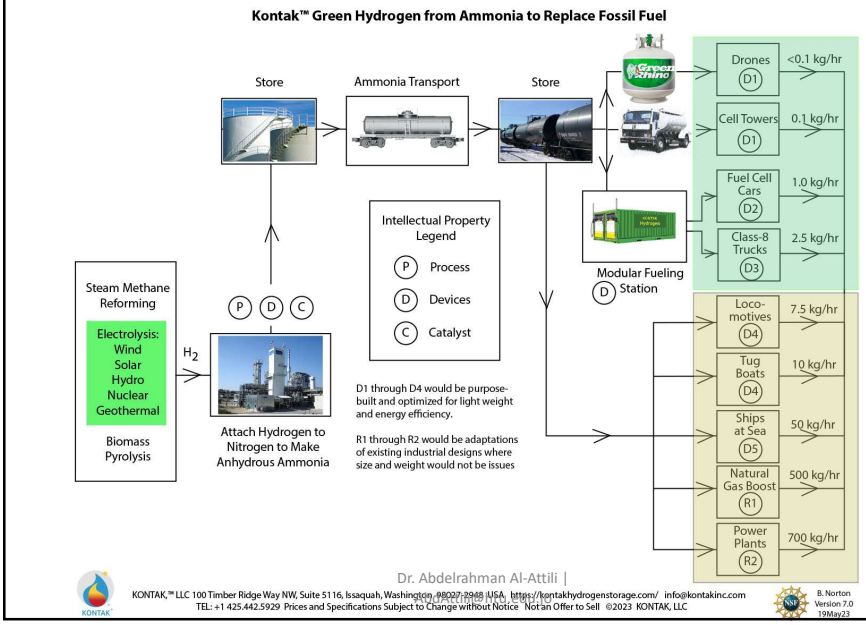
❖Startups

US-based startup Kontak specializes in hydrogen on liquid carrier storage and transportation solutions.



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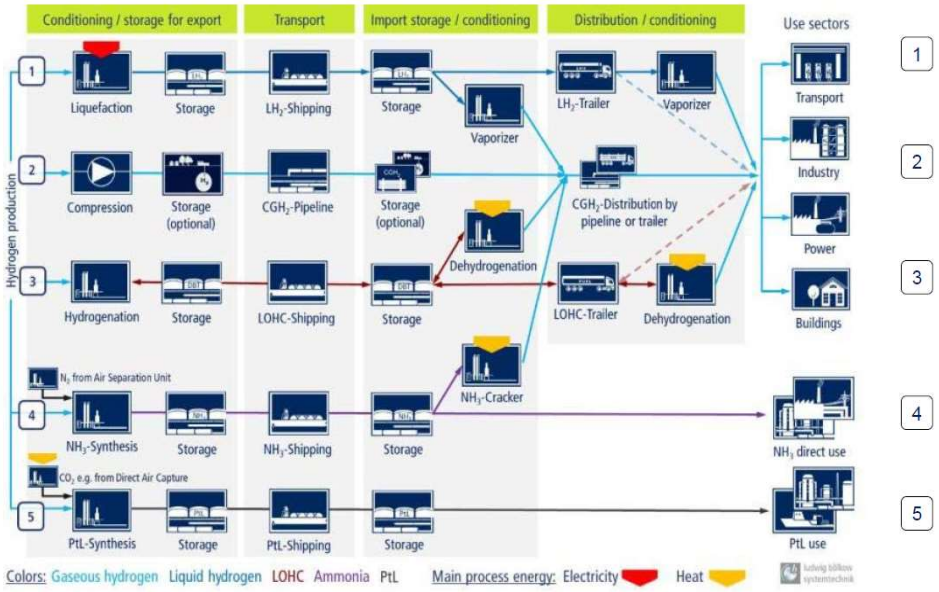
❖Hydrogen Transportation



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Source: Heinrich Böll, Grundkurs Wasserstoff Teil II, 10/2021.

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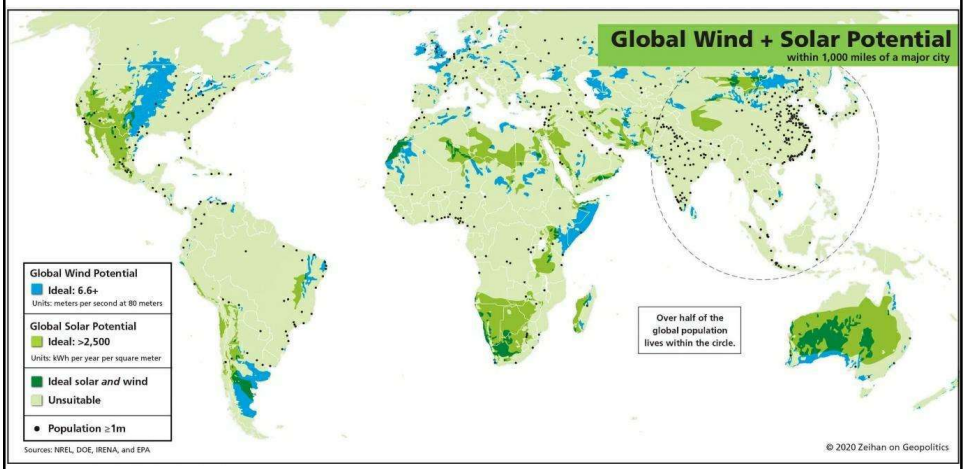
❖Hydrogen Transportation

Transport

Cost-effective Green Hydrogen



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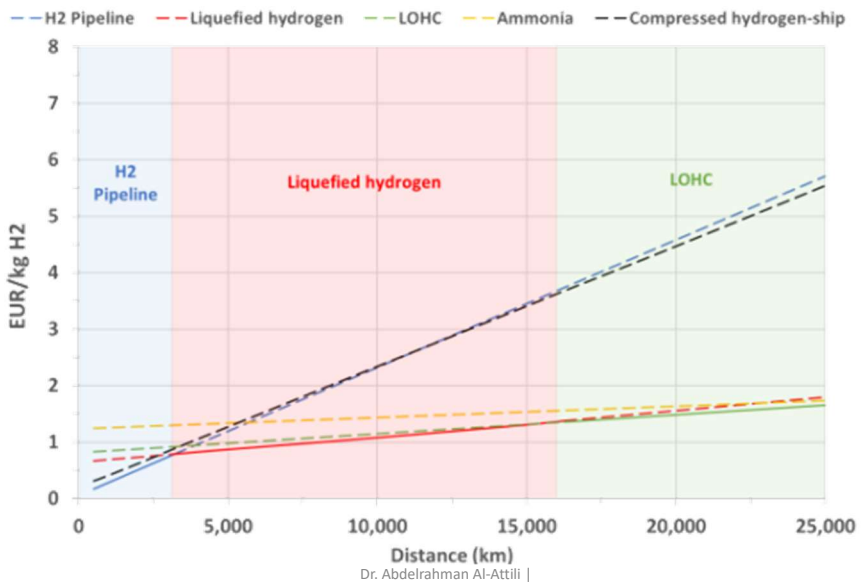
❖Hydrogen Transportation



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Source: European Union, Assessment of Hydrogen Delivery Options, 2021 – JRC124206, p.3.

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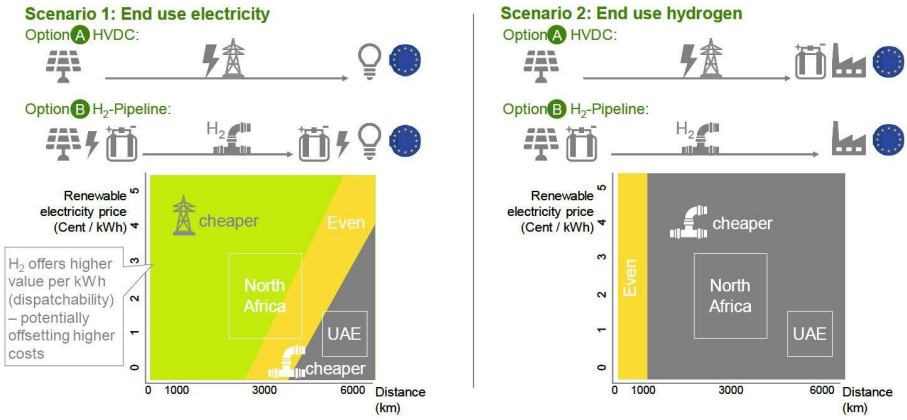
❖Hydrogen Transportation

Key question: Transport electricity or hydrogen? It depends!
Example for cost of importing electricity or hydrogen from MENA region to Germany, 2030.



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- Source: Guidehouse, Electrons or molecules: Comparing electricity and hydrogen imports from the MENA region to Europe, 2020, p.7.

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Applications & Sector Coupling:
Derivatives Map, Food, Environment, Energy and Water

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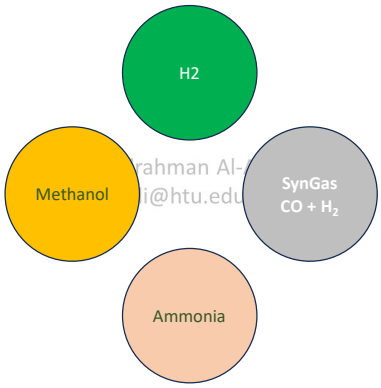
❖Derivatives Map

Hyrdogen Applications by Sector

- **Lets draw it together!**



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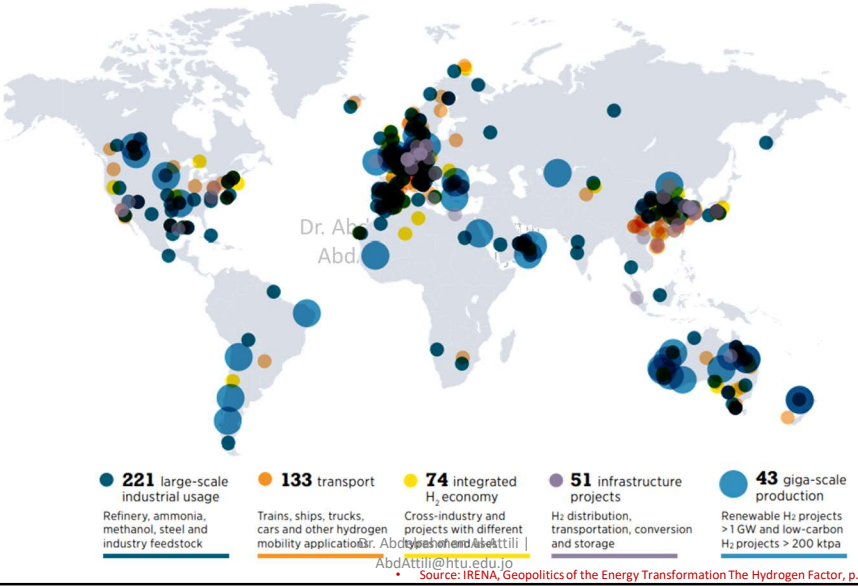
❖Hydrogen Applications

Applications and Sectors Coupling

- Green Hydrogen investments (2021)



- Source: IRENA, Geopolitics of the Energy Transformation The Hydrogen Factor, p.42/fig.3.3.

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❖Regional Projects

Sample Green Hydrogen Projects

- NEOM! https://www.nghc.com/
- Around 4 GW!

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❖Regional Projects

Sample Green Hydrogen Projects

- HYDROM (OMAN)! https://hydrom.om/

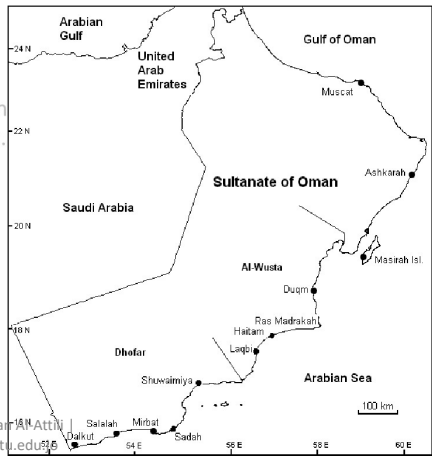
20 Billion USD Investments!

Split into 3 projects:

The three projects were signed with the consortia of Amnah, Green Energy Oman (GEO) and BP Oman.

The projects are expected to produce around half a million tonnes of green hydrogen annually from over 12 GW of installed renewable energy capacity.

All the projects are spread across 320 square kilometers of area in the Al Wusta and Dhufar.



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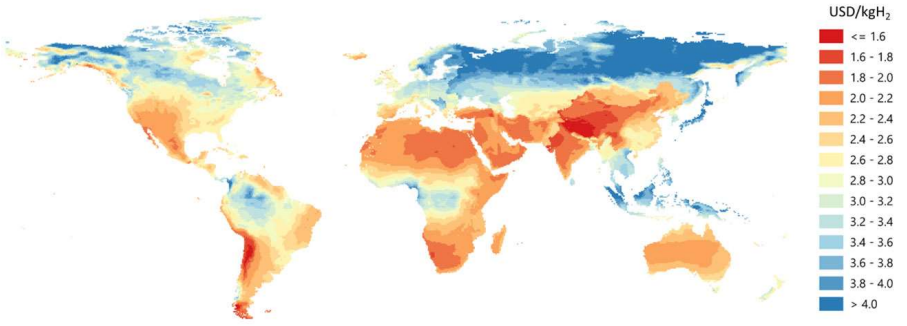
❖Potential

Hydrogen Applications by Sector

- Estimated cost of Kg H2 is one of the lowest globally in Jordan.
- Yet there are many restrictions such as, length of the sea borders, land availability for installing renewable resources, initial cost as we might need a separate grid!, Infrastructure for storage and transpiration, legislations!.
- Technicians with relevant skills!



https://aleasoft.com/green-hydrogen-fuel-future/

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❖Potential Applications

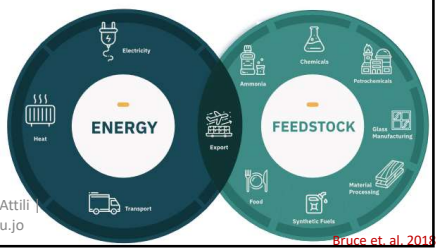
Hydrogen Applications by Sector

- Applications of H2 can be categorized based on several point-of-views.
- Sector-based categorization makes it easier to track, especially in Jordan.
- We will consider H2 applications (possible GH applications!) based on the Jordanian Context!

- **Possible Applications in Jordan:**

  - Aluminum Industries (Heat).
  - Chemicals (HCl, HBr).
  - Petrochemicals and Refining.
  - Cement.
  - Potash and Phosphate (Heat).
  - Steel Industry (Heat).
  - Ammonia Production -> Fertilizers
  - Storage (Liquid or High Pressure).
  - Transportation (ICE, or EV using FC).
  - Cooking (Direct Ignition).
  - Recycling (Heat).

  - Boilers
  - Steam generators
  - Furnaces
  - Chemical Reactions



Bruce et. al. 2018

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❖Haber Bosch Process: The route to Ammonia

Main ingredients

N

Urea
Nitrate
Ammonium

P

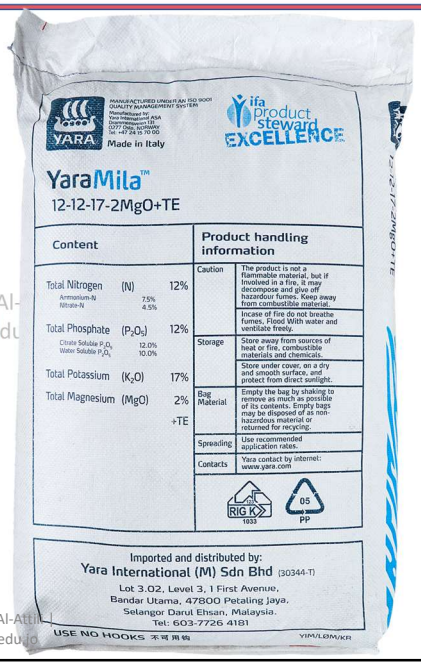
P2O5

K

K2O
KNO3

شركة مناجم الفوسفات الأردنية
المساهمة العامة المحدودة

البوتاس العربية
Arab Potash



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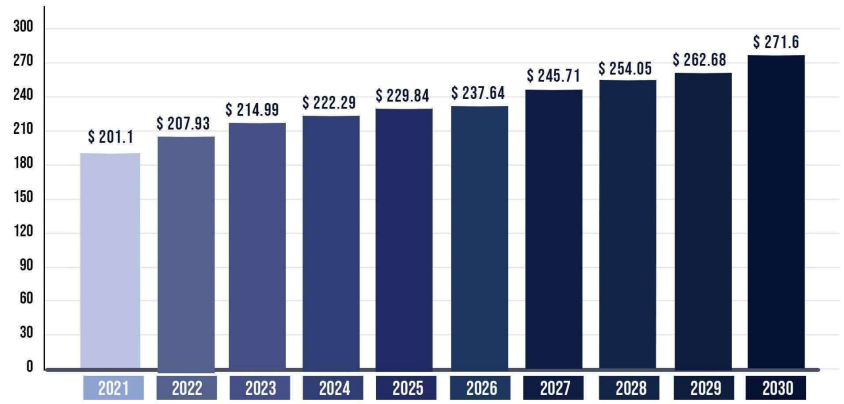
❖Ammonia Applications: Fertilizers

Fertilizers' Raw Materia

- Note that the market value is in Billions.

PRECEDENCE RESEARCH

FERTILIZER MARKET SIZE, 2021 TO 2030 (USD BILLION)



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Source: www.precedenceresearch.com

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❖Ammonia Applications: Fertilizers

Demand.

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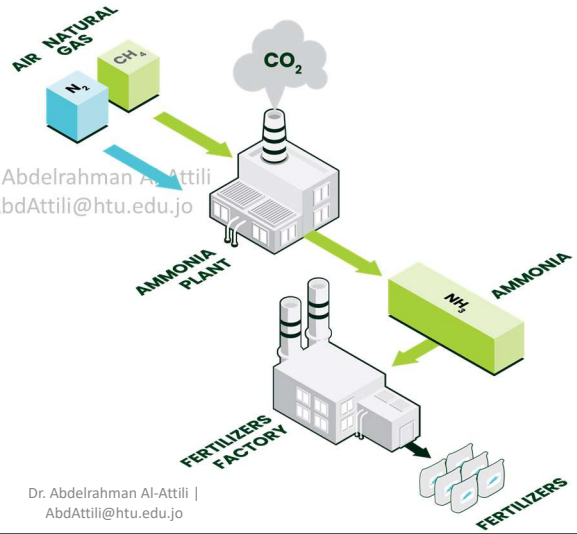
❖Ammonia Applications: Fertilizers

Current Ammonia Production

Natural Gas -> Syngas (CO+H) -> H2 + N2 -> Ammonia

https://www.fertilizerseurope.com/paving-the-way-to-green-ammonia-and-low-carbon-fertilizers/

- Ammonia production is mainly based on natural gas as a raw material and steam methane reforming (SMR) as the main technology.
- The first step involves splitting the natural gas molecules with the help of steam and high temperatures, to obtain hydrogen and CO_2.
- In a second step, this hydrogen is then combined with nitrogen from air to produce ammonia.
- Not green! generates large quantities of CO_2.



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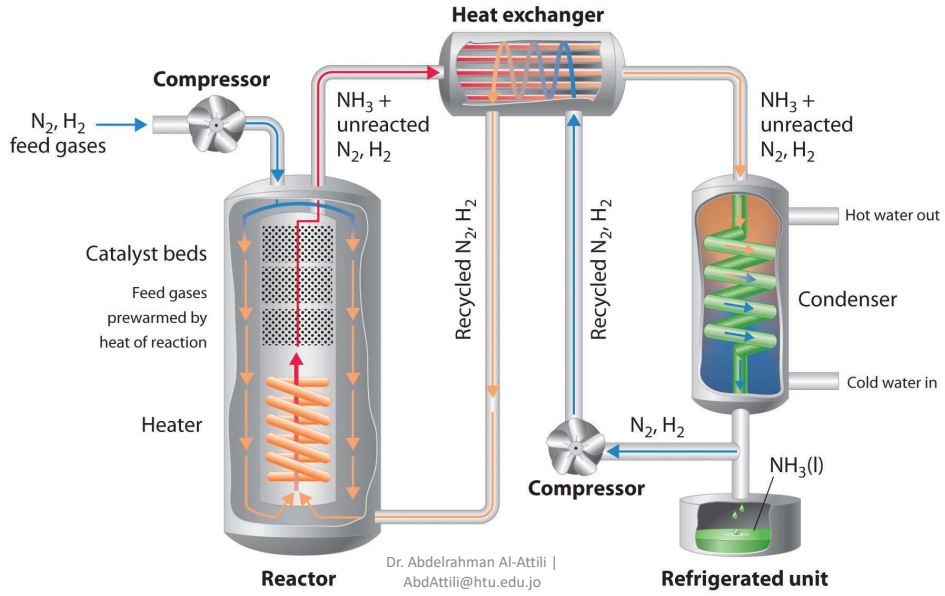
❖Ammonia Reactor

https://www.fertilizerseurope.com/paving-the-way-to-green-ammonia-and-low-carbon-fertilizers/

Haber Bosch Process



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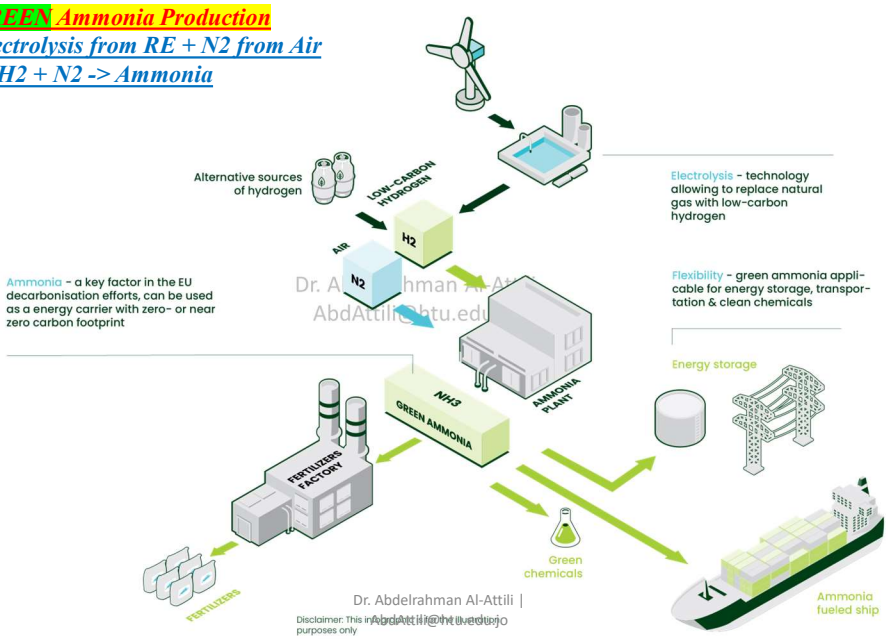
❖Ammonia Applications: Fertilizers

https://www.fertilizerseurope.com/paving-the-way-to-green-ammonia-and-low-carbon-fertilizers/

GREEN Ammonia Production

Electrolysis from RE + N2 from Air

-> H2 + N2 -> Ammonia



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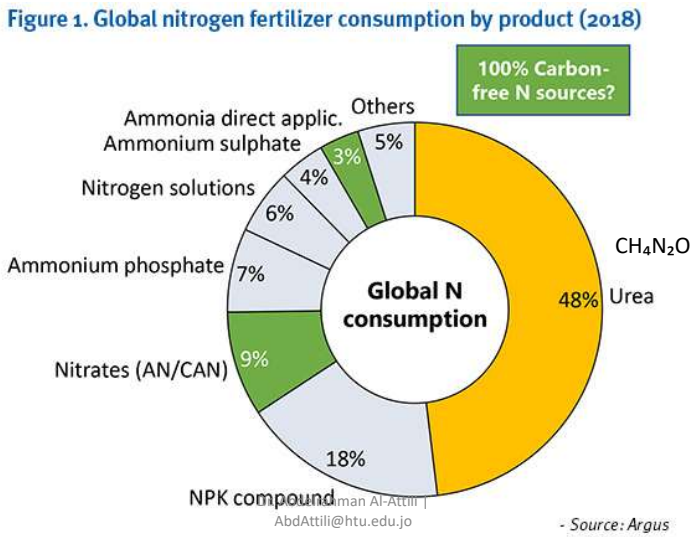
❖Ammonia Applications: Fertilizers

Urea from Ammonia

Most of the fertilizer market is in the form of Urea!



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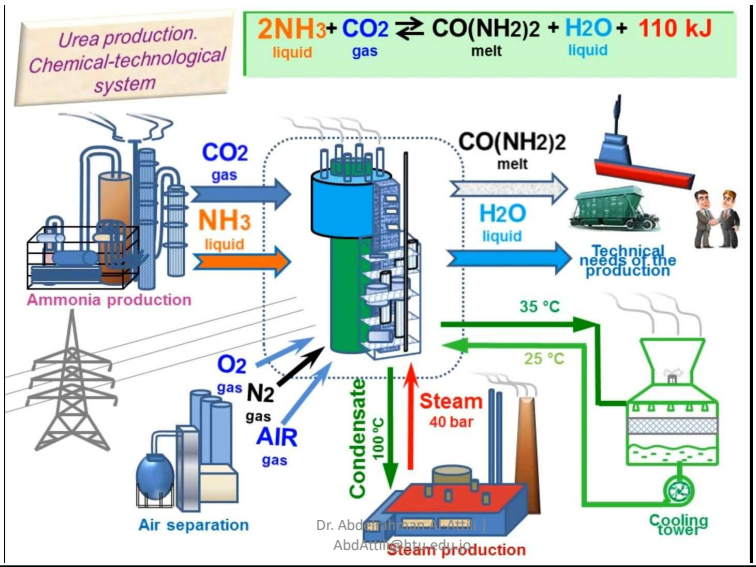
❖Ammonia Applications: Fertilizers

Urea from Ammonia

Ammonia + CO2 (to be green this must be from CCU)



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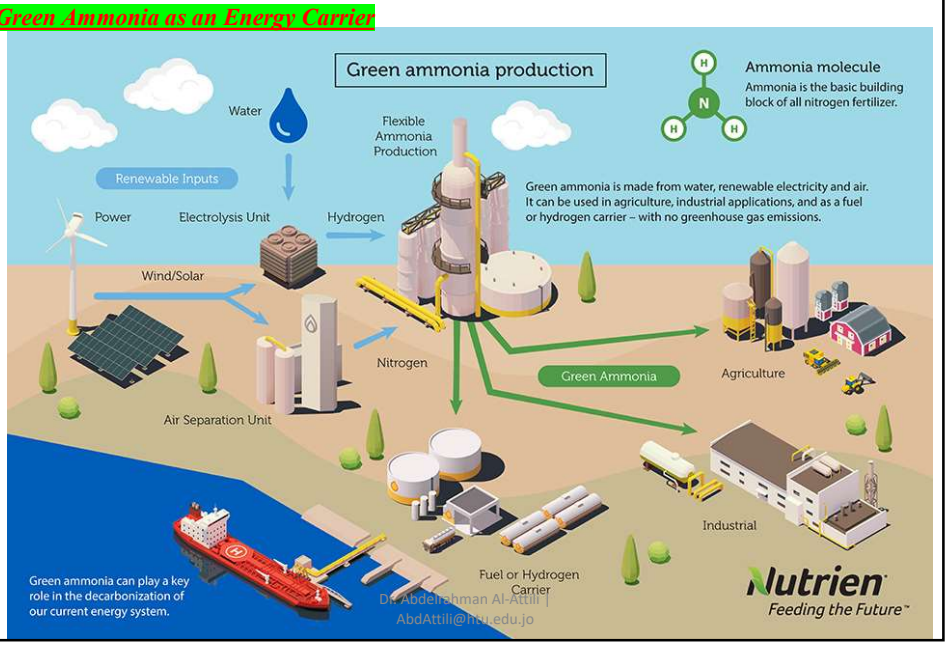
❖Ammonia Applications: Energy Carrier

Green Ammonia as an Energy Carrier



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❖Ammonia Applications: Energy Carrier

https://www.researchgate.net/publication/327875102_ReviewAmmonia_Oxidation_Electrocatalysis_for_Hydrogen_Generation_and_Fuel_Cells

Ammonia as an Energy Carrier

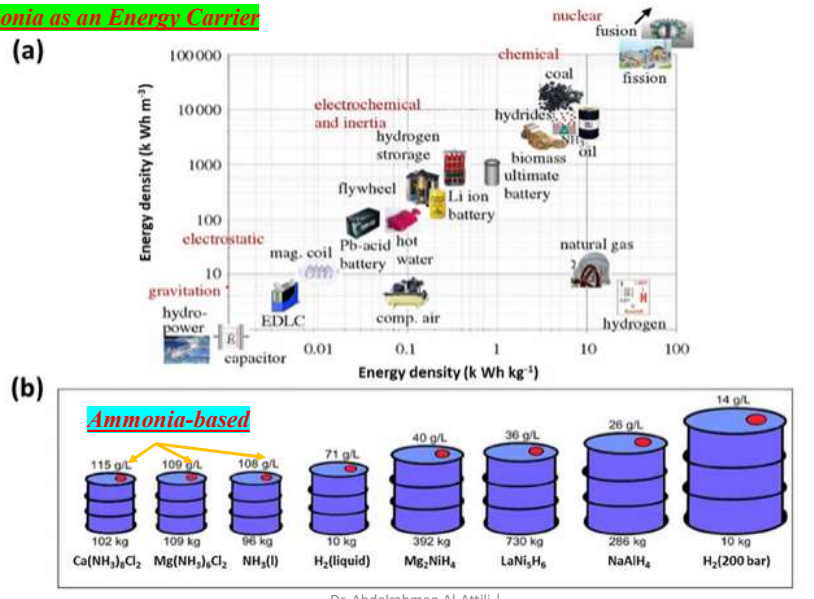

Figure 1. (a) Energy density of various fuels by mass. With permission to reprint from Ref. 10, Copyright 2010, Royal Society of Chemistry. (b) Energy density of various fuels by volume. With permission to reprint from Ref. 11, Copyright 2008, Royal Society of Chemistry.

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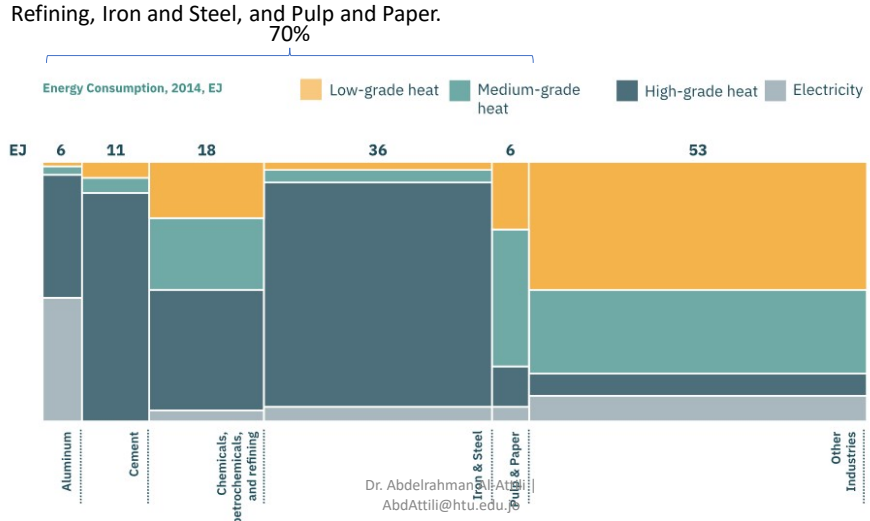
❖Environment

Hydrogen Council. (2017b). Hydrogen scaling up: A sustainable pathway for the global energy transition

Hydrogen Applications by Sector

- According to Hydrogen council (2017, global study) ~70% of energy (mainly Heat) is consumed in 5 main industries: Aluminum, Cement, Chemicals, Pharmaceuticals and Refining, Iron and Steel, and Pulp and Paper.



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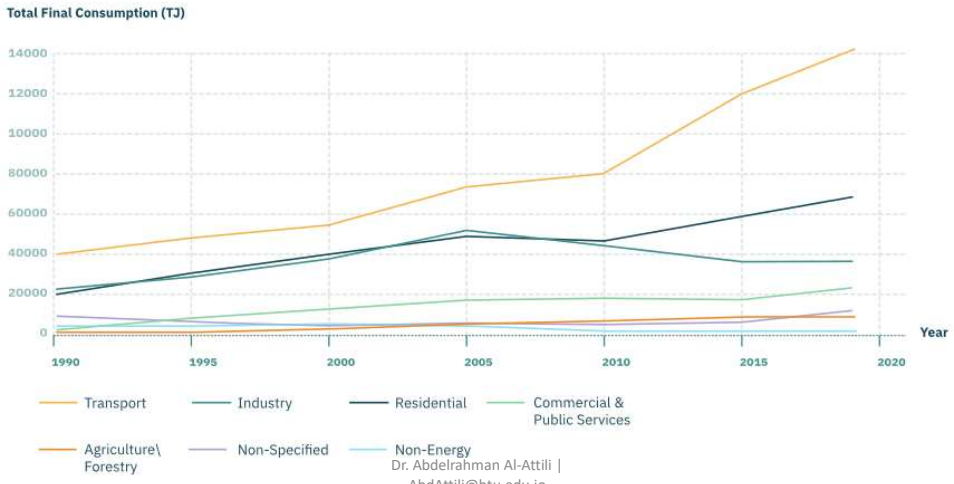
❖Environment

Hydrogen Applications by Sector

- Energy consumption in Jordan (compare it to worldwide!).
- Transport! -> Industry -> Residential!



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IEA. (2019) Data and statistics. https://www.iea.org/countries/jordan

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❖Environment

Hydrogen Applications by Sector

- CO2 emission in Jordan hints us towards the main application sectors of H2.

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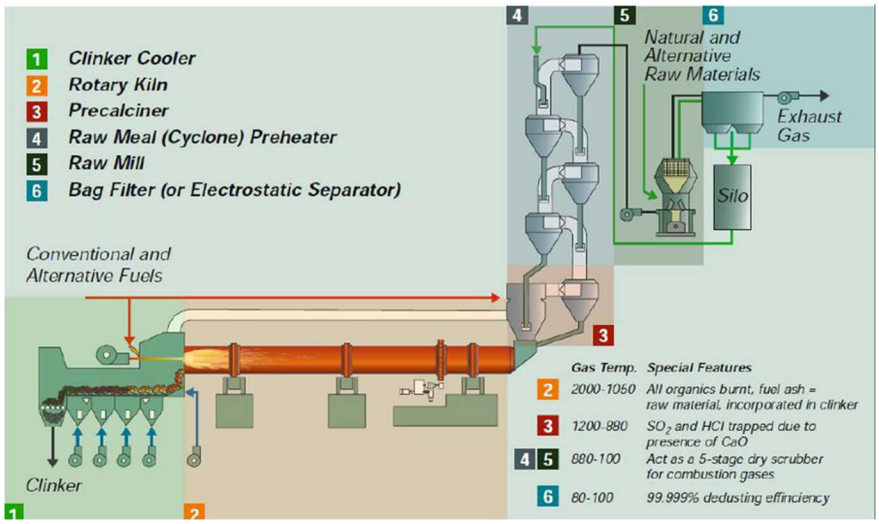
❖Industrial Applications

https://www.cementequipment.org/home/fuels-in-the-cement-industry/

Cement Applications



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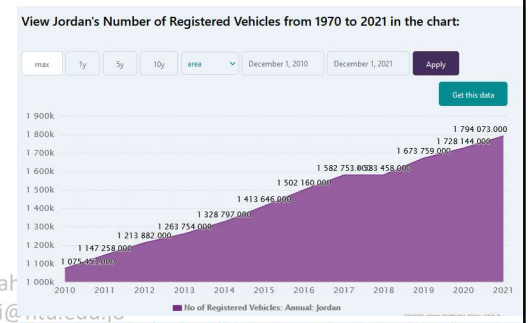
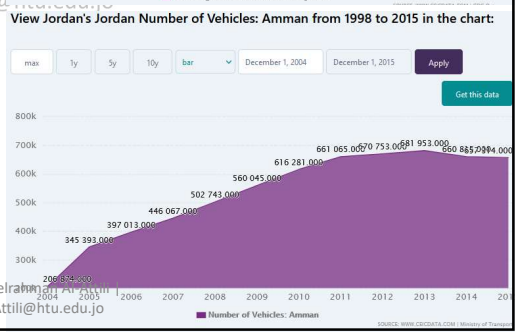
❖Transportation

Vehicles in numbers! Jordan/Amman

- https://www.ceicdata.com/en/indicator/jordan/number-of-registered-vehicles
- https://www.ceicdata.com/en/jordan/number-of-vehicles/number-of-vehicles-amman
- *"The Jordan Strategy Forum, citing data issued by the Ministry of Transport, wrote on Twitter that the total number of vehicles in Jordan reached 1.5 million, of which **1.2 million** are in Amman" Jordan Times.*





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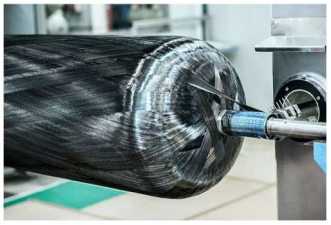
❖Transportation

Amazing Element!

- **3 – 4 minutes to fill-up the H2 tanks.**
- **500 km per charge.**
- 2 carbon-fiber hydrogen tanks, 6 kg H2 700 bar.
- Hybrid H2 combustion and plug-in EV.
- H2 Fuel-cell EV.
- Currently, 10$ / kg H2.



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https://www.bmwblog.com/2022/03/10/bmw-ix5-hydrogen-review/bmw-h

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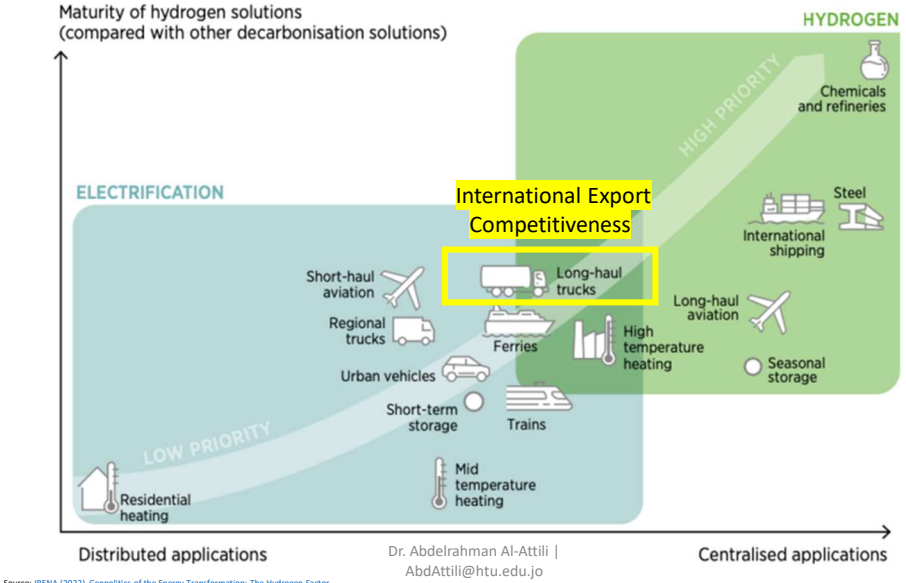
❖Transportation

Domestic Heating?!



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Source: IRENA (2022), Geopolitics of the Energy Transformation: The Hydrogen Factor,

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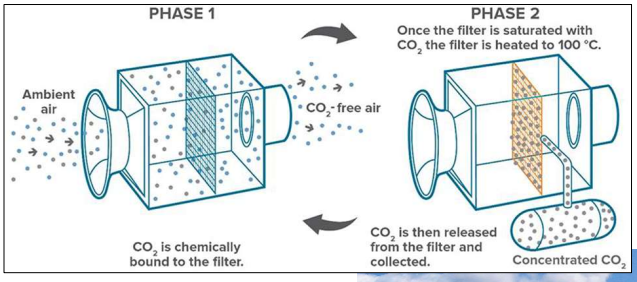
❖DAC

Direct Air Capture (DAC) technology can be used to obtain CO2 / CO from air directly.
This CO content is used with Hydrogen to produce SynGas or Synthetic fuel.
Synfuel is Green although it produces CO2 when it burns, because it emits what it already captured, so there is no increase in the total CO2 content in air. – Carbon Neutral!



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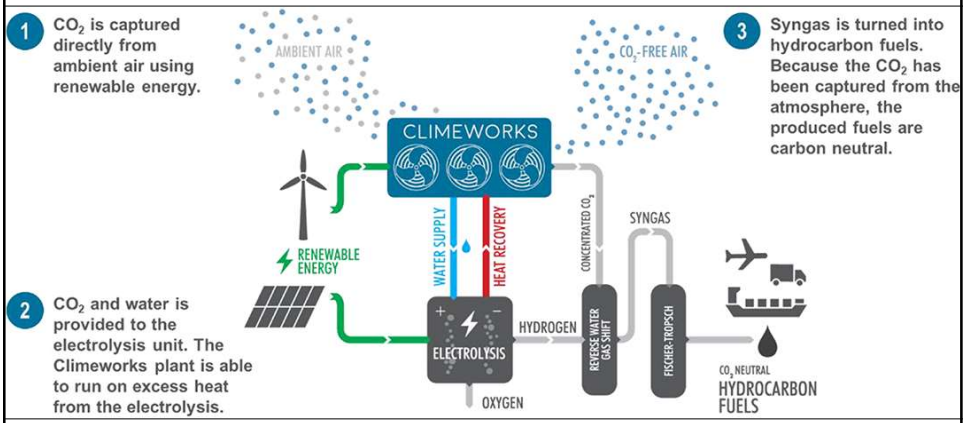
❖DAC

Notice the use of the electolyzer!

Electrolyzers emit heat that can be used to drive CO2 out of the DAC filters.
DAC systems provide water to the electrolyzers, CO2 for SynGas, and clean air.



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https://www.frontiersin.org/articles/10.3389/fclim.2019.00010/full

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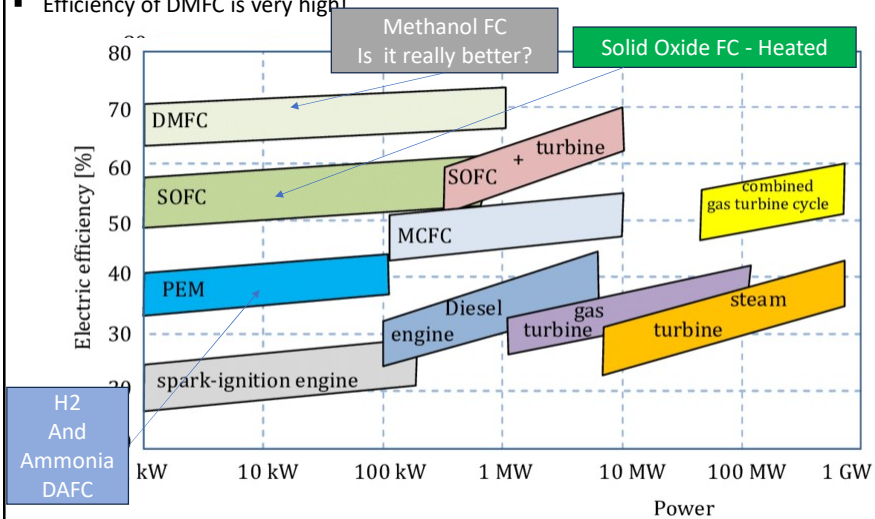
❖Fuel Cells

- Efficiency of DMFC is very high!



Electric efficiency of the systems according to their production technology [21] (DMFC-direct methanol fuel cell-MCFC-molten carbonate fuel cell-fuel cell with molten carbonate, SOFC-solid oxide fuel cell-cell-solid oxide fuel).

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DOI:10.1088/1755-1315/214/1/012019

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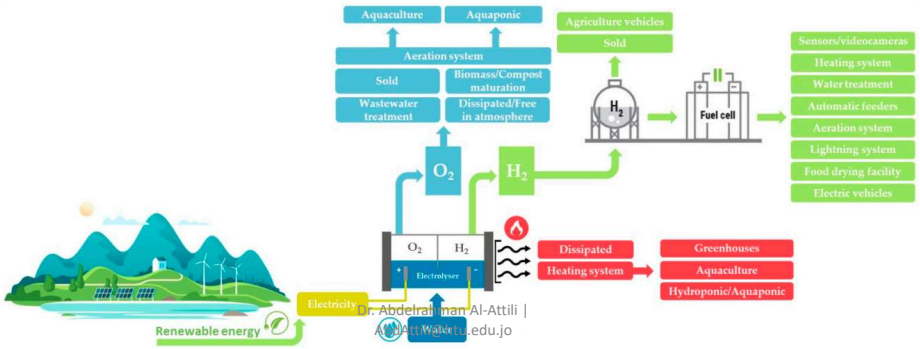
❖Wastewater Treatment

Toward Sustainability: An Overview of the Use of Green Hydrogen in the Agriculture and Livestock Sector (nih.gov

As-Samra Wastewater Treatment Plant, Jordan

With a peak flow of 840,000m³ each day, the facility treats an average flow of 267,000m³ of wastewater, serving a population of 2.2 million living in the Greater Amman and Zarqa areas



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❖Water Requirements

Green_Hydrogen_Water_Use_56b96f577d.pdf (itm-power-assets.s3.eu-west-2.amazonaws.com)
beswick-et-al-2021-does-the-green-hydrogen-economy-have-a-water-problem.pdf

Withdrawal: water returned directly to the source it was extracted from.
Consumed: water transformed into another form.

Water problem?!

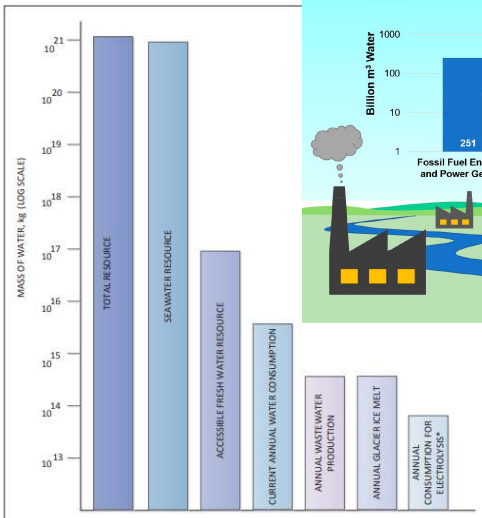
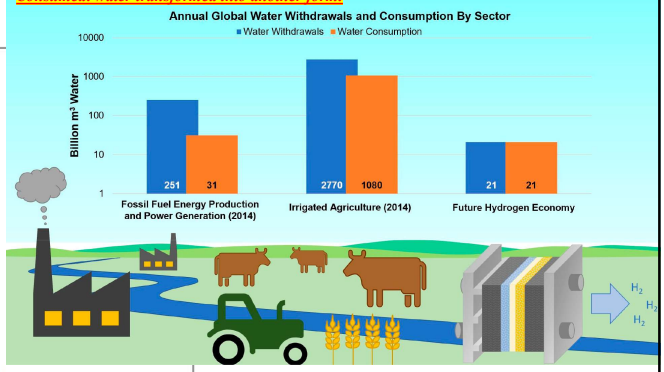


Figure 1: Annual water requirement of green hydrogen production relative to Earth's [illegible]



Optimistic view: "Based on the reaction stoichiometry, for every kg of hydrogen produced, 9 kg of water must be consumed. Therefore, 2.3 Gt of hydrogen requires 20.5 Gt, or 20.5 billion m3 , per year of freshwater, which accounts for only 1.5 ppm of Earth's available freshwater" =~ 20.5e9/1e17, not sea water!

2.3 GT Hy2 can decarbonize around 18% of energy-related sectors.
https://doi.org/10.1016/j.coche.2021.100701

However, fresh water is not uniformly distributed.

In Jordan, already water deficiency is a problem, even after **Aqaba-Amman Water Desalination and Conveyance Project (AAWDCP)**

Green must be seawater!

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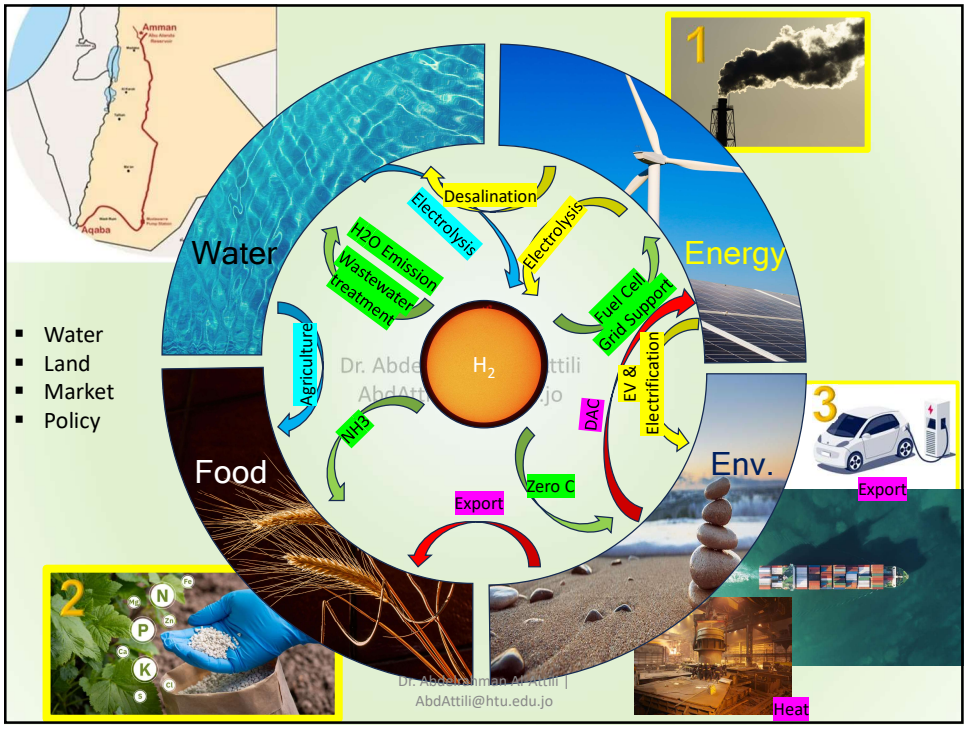

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Thank you.

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