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SYSTEM DESIGN OF A GREEN HYDROGEN PLANT

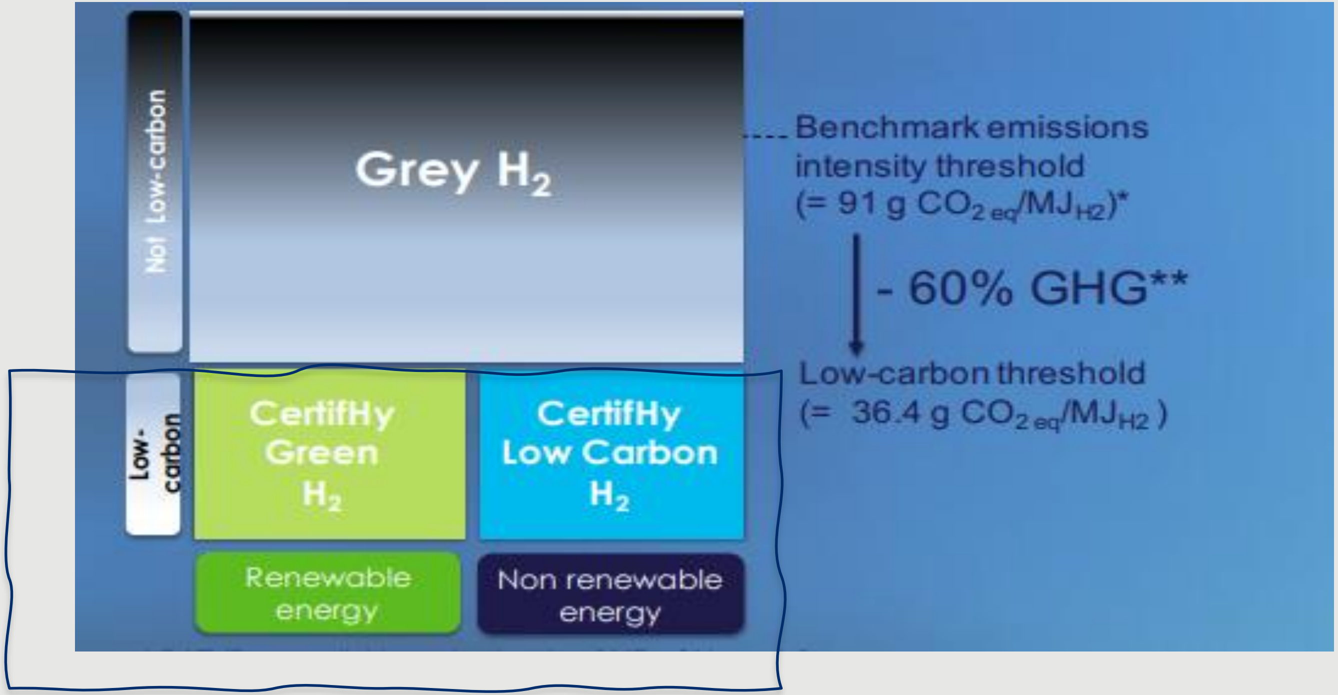
Guidelines for sizing of RE Power, Electrolyzers and H2 Storage

Hydrogen needs extremely careful handling

Using a broom as a detector to locate an invisible hydrogen flame by NASA.

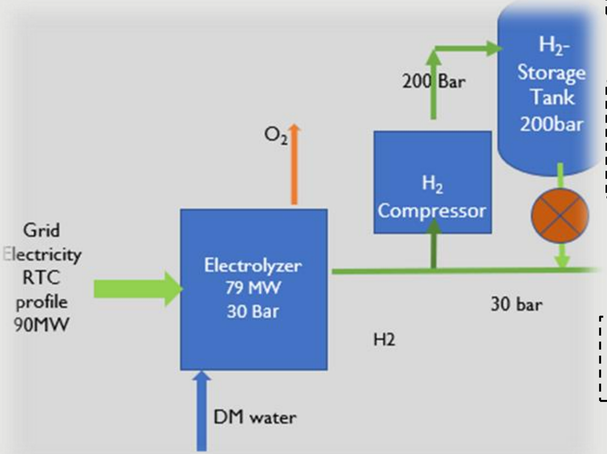
In the wild old hydrogen days firefighters responding to a hydrogen fire had to give the suspect area "the broom test" by carefully probing the suspect area with a corn straw broom to determine the presence and location of a fire. 😏

What is Green Hydrogen



1. Benchmark Emission for Green Hydrogen 2. Source: CertiHy 3. MNRE as the regulator will be*nchmark Low carbon GHG emission e.g., 36,4g CO2eq / MJH2 is global standards at CertiHy. 4. Energy to kg conversion for hydrogen is -- > 120MJ of energy in 1kg of hydrogen.*

Hydrogen Generation Plant and its Applications



Hydrogen Loop

- Hydrogen used in production of green ammonia using Haber Bosch Process
- Fertilizer is regulated market with subsidies using natural gas

Green Ammonia

Fertilizer mfrs.

- Hydrogen to make fuel used for heating and mobility
- Methanol is used to produce acetic acid and formaldehyde.

Hydrogen Energy

Ammonia

Methanol

Liquid Hydrogen

- Hydrogen is used as a reducing agent and fuel
- natural gas

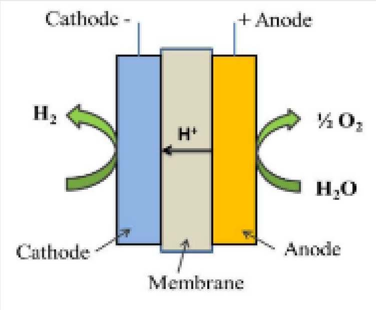
Green Steel

- Hydrogen is used as a reducing agent for Sulphur impurities.

Refinery

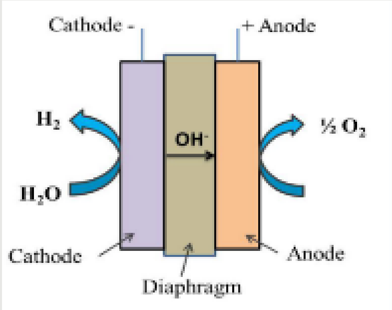
Key Electrolyzer Types

Proton Exchange Membrane (PEM)



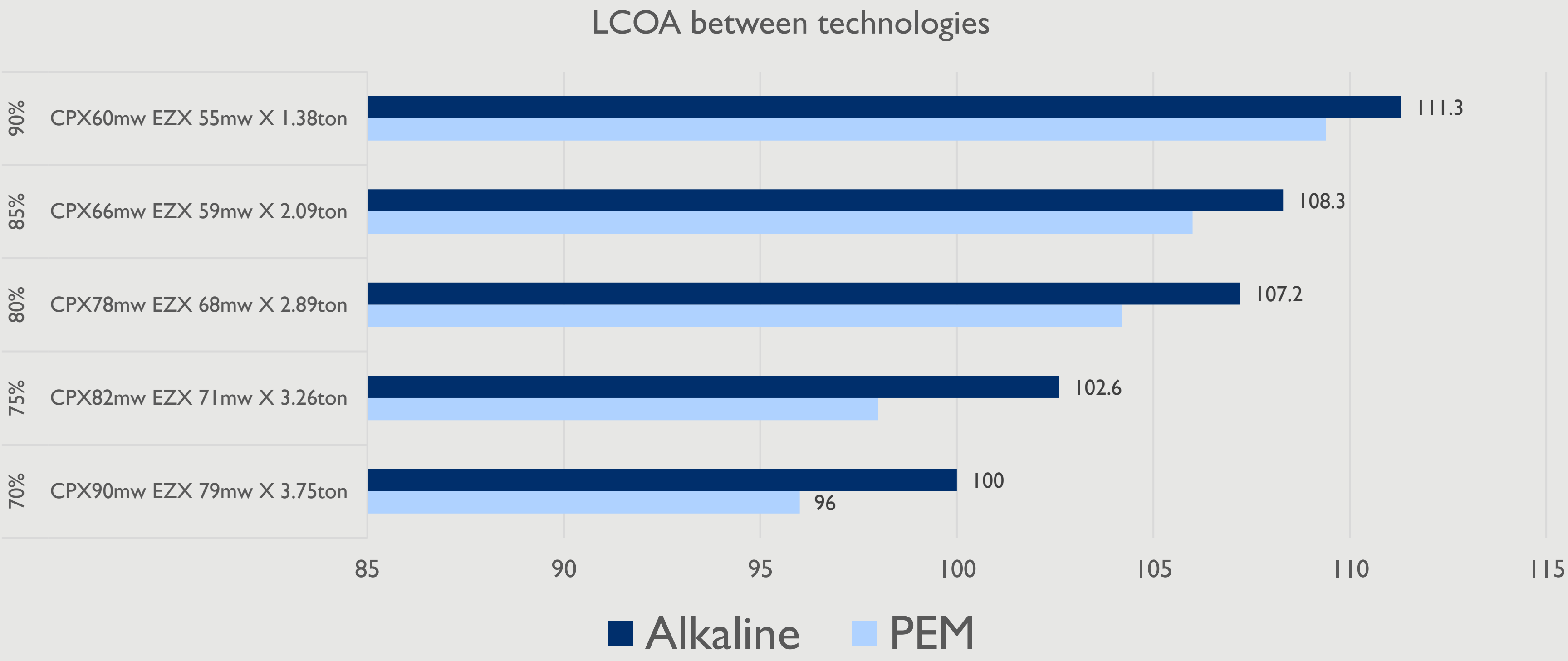
Anode: $H_2O \rightarrow 2H^+ + 0.5\ O_2 + 2e^-$
Cathode: $2H^+ + 2e^- \rightarrow H_2$
Overall Cell: $H_2O \rightarrow H_2 + 0.5\ O_2$

Alkaline (ALK)



Anode: $2OH^- \rightarrow H_2O + 0.5\ O_2 + 2e^-$
Cathode: $2H_2O + 2e^- \rightarrow H_2 + 2OH^-$
Overall Cell: $H_2O \rightarrow H_2 + 0.5\ O_2$

PEM has lower LCOA compared to Alkaline



Source: Technical data sheets of manufacturers

RTC availability is lowest in the months of Dec and Jan

70% Availability		**90% Availability**	
April	81%	April	97%
May	92%	May	100%
June	79%	June	96%
July	74%	July	95%
August	69%	August	90%
September	69%	September	92%
October	70%	October	92%
November	61%	November	89%
December	57%	December	84%
January	56%	January	85%
February	64%	February	88%
March	75%	March	96%

* *RED highlights months with least RTC Power availability*

- The lower months of RTC Power availability decide the storage size
- Low availability of electricity in the months of Sep-Jan is compensated for via seasonal storage of hydrogen in the remaining months
- These months also decide the capacity of contract power

Hydrogen Storage – Horton Sphere

Horton sphere tank.

Quantity – 1 nos

Area

1 Ton of Hydrogen stored at

---- > 30 Bar[1] has area 1700m2 (30bar)

----->200 Bar[2] has area 350m2(200bar)

Volume :

3.75 t of hydrogen will require 220 m3 volume at 200 bar and 15 C

Hydrogen Storage –above ground storage cylinders

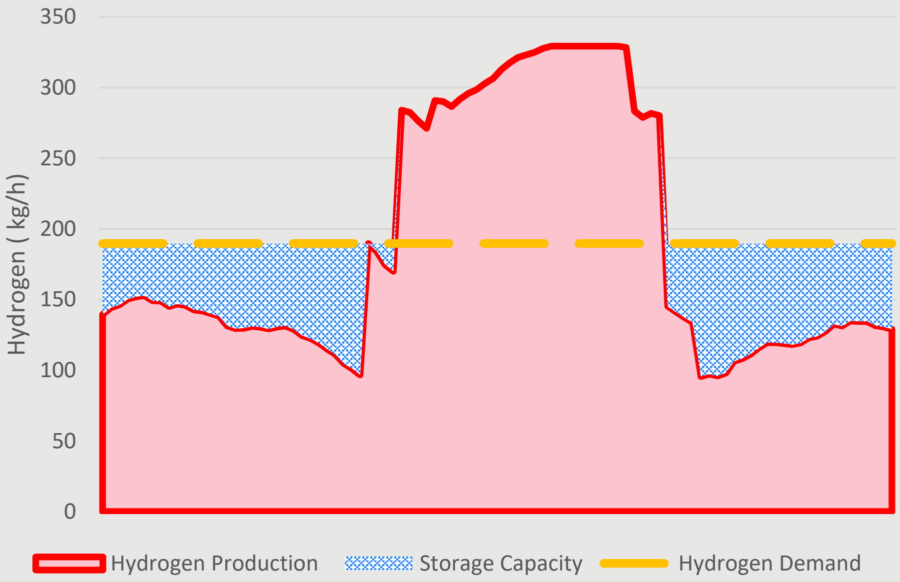
Pressure (Bar)	Sizes (Meters) (L X D)	No of cylinders	Storage Space (M^2)	Storage Capacity (Kg)
140	12 X 1 m	10	15X6	700
240	12 X 1 m	10	15X6	2000

Four types of Cylinders for storage

- Type I and II are mainly for stationary storage. Made of steel, low cost and low pressure (< 300 bars) , Available in large range of sizes to store MWh scale energy
- Type III and IV are for mobility applications. Composite material with a steel or Aluminum liner and high pressure (< 700 bars)
- Underground energy storage is suitable for GWh scale storage

If high pressure is not used, then storage container weight and volume impose severe practical limitations

Continuous Ammonia : Different Profiles have different hydrogen storage size



Hydrogen Storage is needed to support the ammonia process when production is more than demand

Continuous Ammonia	
RTC Profile	Hydrogen Storage (Ton)
70%	3.75
75%	3.26
80%	1.60
85%	1.02
90%	0.14

1 ton = 1000kg

ISTS Waiver

- Issued by MOP

- Exemption Applicable to Green Hydrogen , Ammonia producers and DISCOMs who are supporting this area

- Drawee entities, including Green Hydrogen/Green Ammonia Plants and Discoms, which contract energy (or capacity) from an ESS Project/Scheme, shall be granted exemption from the payment of ISTS Charges if they draw a minimum of 51% of the annual energy contracted with or consumed from ESS as renewable energy.

No. 12/07/2023-RCM
Government of India
Ministry of Power

Shram Shakti Bhawan, New Delhi,
Dated, the 29 May 2023

ORDER

Subject: Waiver of Inter-State Transmission Charges on transmission of the electricity generated from solar and wind sources of energy under Para 6.4 (6) of the Tariff Policy, 2016 - Addendum reg.

In continuation to the Ministry of Power Orders No. 23/12/2016-R&R dated 23.11.2021, 30.11.2021, 01.12.2022 and 06.12.2022 on the waiver of Inter-State Transmission (ISTS) Charges on transmission of the electricity generated from solar and wind sources of energy, the following addendum is being issued.

2. Whereas it is deemed necessary to facilitate the execution of offshore wind energy initiatives, to promote the expansion of Green Hydrogen/Green Ammonia Projects, to promote development of Pump Storage Plants, and to encourage the off take of renewable energy from Energy Storage System Projects, it has been duly resolved that:

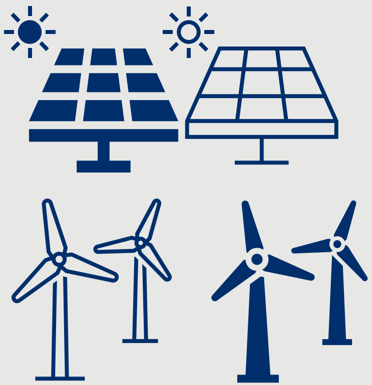
a. Offshore wind power projects commissioned on or before 31.12.2032 and established via Power Purchase Agreements (PPAs) or under merchant basis, shall be granted exemption from the payment of Inter-State Transmission (ISTS) Charges for a period of 25 years, starting from the date of commissioning of the project. Further, the offshore wind power projects commissioned after 31.12.2032 shall be levied ISTS charges as per the trajectory specified below.

S. No.	Period of Commissioning of Offshore Wind Power Projects	Applicable ISTS Charges
1	01.01.2033 to 31.12.2034	25% of the applicable ISTS charges
2	01.01.2034 to 31.12.2035	50% of the applicable ISTS charges
3	01.01.2035 to 31.12.2036	75% of the applicable ISTS charges
4	From 01.01.2037	100% of the applicable ISTS charges

b. Green Hydrogen/Green Ammonia Plants commissioned on or before 31.12.2030, and which utilize renewable energy from Solar, Wind, Large Hydro commissioned after 8th March 2019, or Energy Storage Systems (ESS) (such as Pump Storage Plants or Battery Energy Storage Systems) or any hybrid combination of aforementioned technologies, for the production of Green

Key electricity assumptions for 100TPD Gren Ammonia

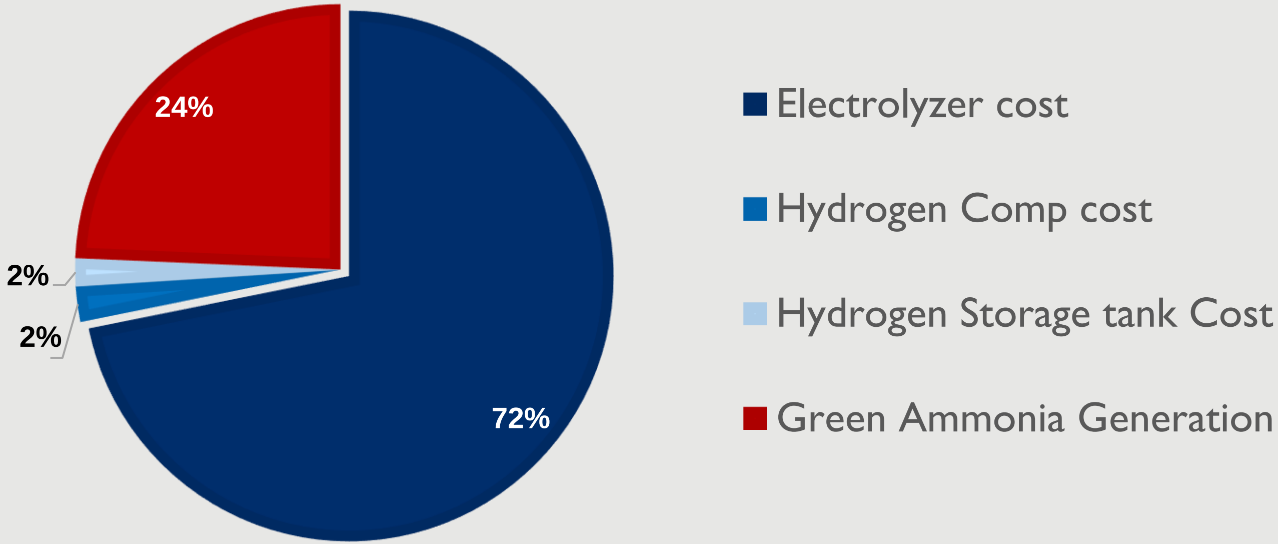
Energy Requirements	Value	Unit	
Energy per day for H2	1092	MWh	
Energy per day for N2/NH3	120	MWh	
Energy per day (total)	1212	MWh	
H2 per day	18.2	Tons	
H2 per hour	0.190	tons per 15 min slot	
Energy per kg of H2	60	kWh/kg	



- Energy needs of electrolyzer (55kWhr) and its BOP (5kwhr) is ~60kwhr per kg of Hydrogen
- 100 TPD ammonia production must be met on a per day basis and not as an annual average
- The RE availability is lowest during the months of November, December and January resulting in lower production of hydrogen and as a consequence of ammonia.

Electrolyzer has the largest share in capital cost

TOP CAPITAL COST EXPENSE

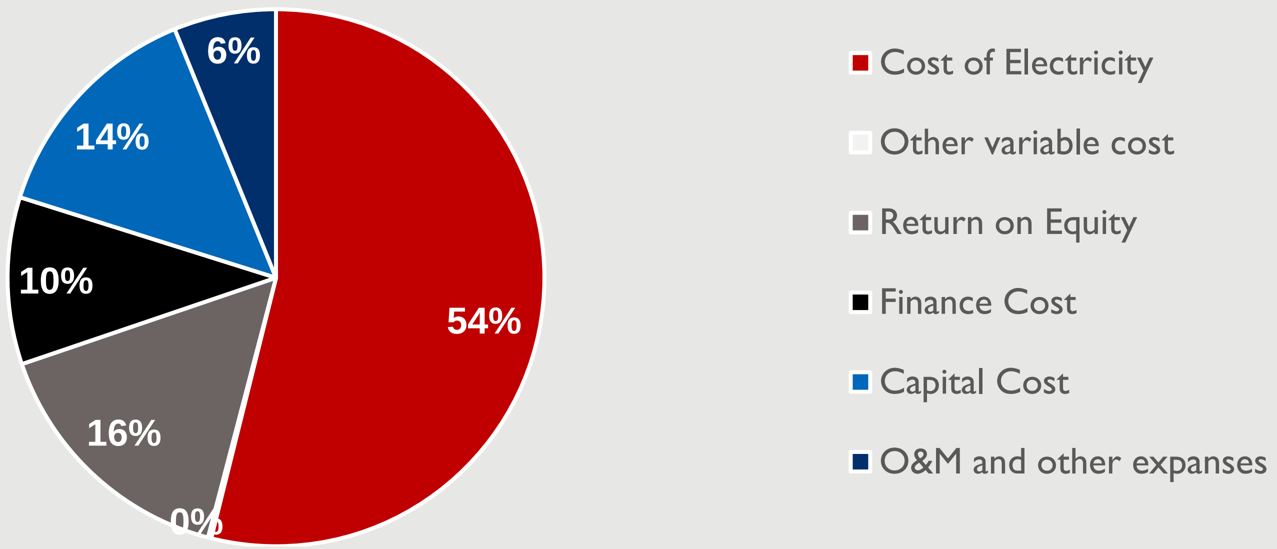


*** *70% RTC profile PEM electrolyzer*

*** Only hard capex included without I&C, insurance , duty , tax , capital cost . Green Ammonia generation consists of ammonia equipment and material cost (20% total cost)*

Source: SAREP Analysis

Electricity is the major (54%) contributor to LCOA



Key Assumptions –
Electricity cost*- RTC tariff For 70% - INR 4.27/kWh , 75% - INR 4.82/kWh , 80% - INR 5.34/kWh , 85% - INR 5.81/kWh , 90% - INR 6.24/kWh ; Open access surcharge = INR 0.5/kWh ; * As per data shared by NTPC-REL
Other Variable cost is too small to be visible on pie chart.

Source: SAREP Analysis

Underground H2 Storage Technologies

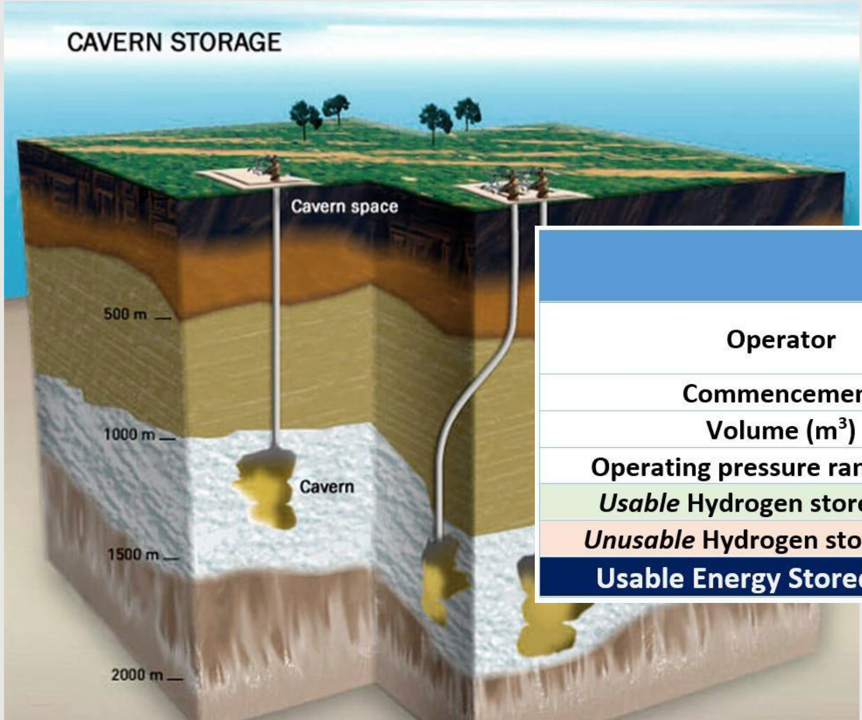
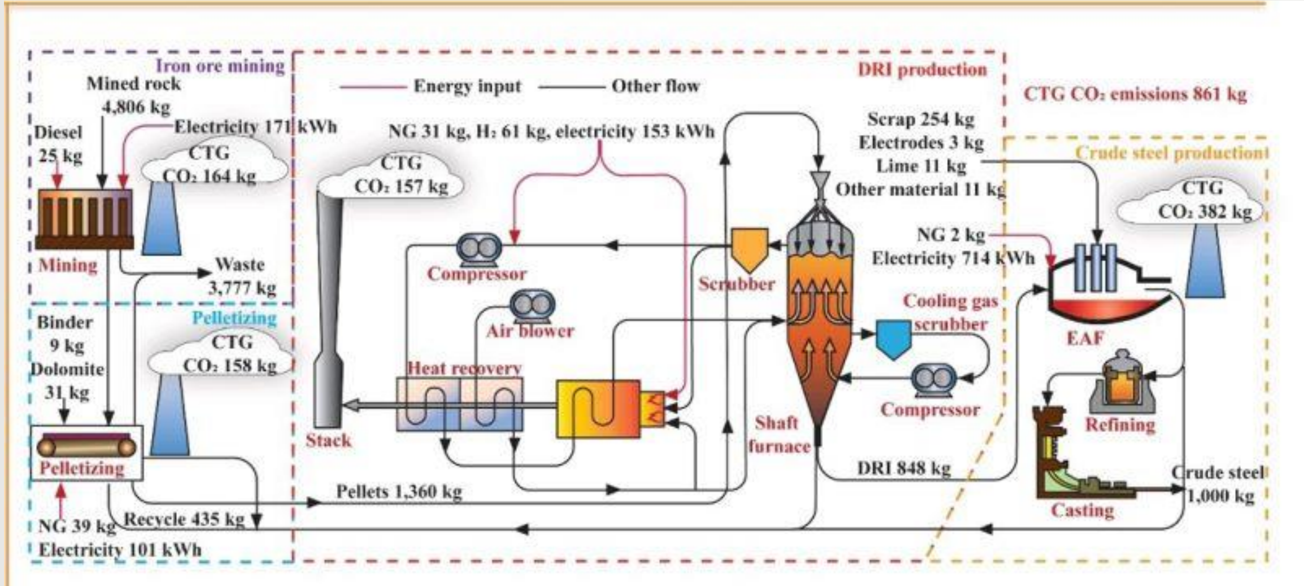


Image source: Northern gas networks, 2016

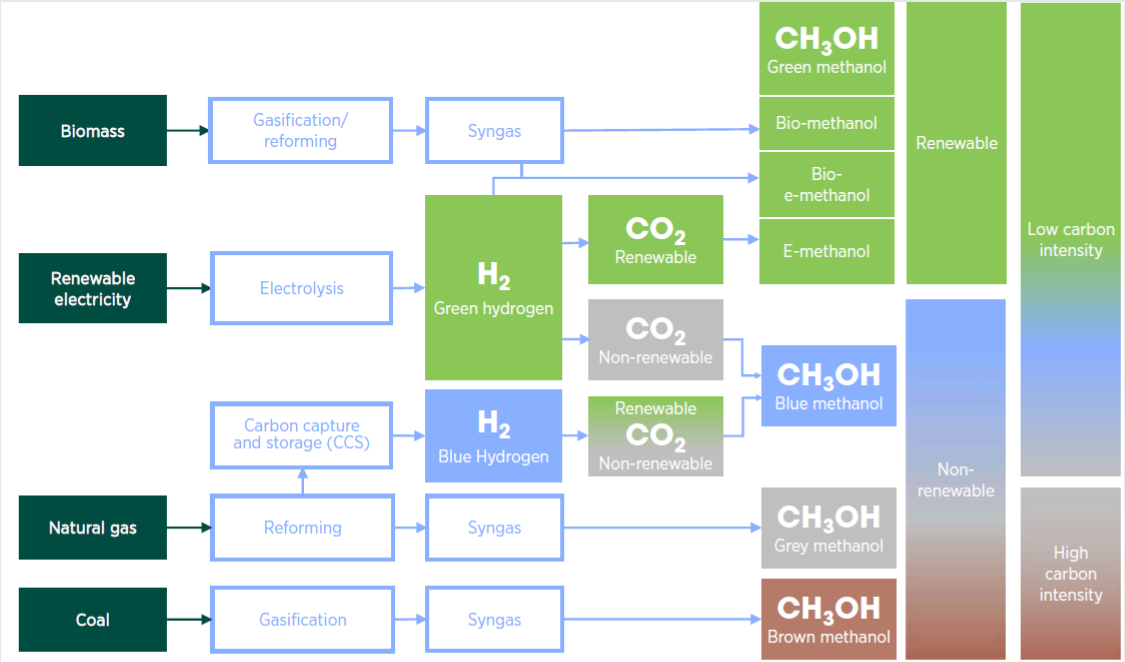
	Clemens Dome (US)	Moss Bluff (US)	Spindletop (US)	Teeside (UK)
Operator	Conoco Philips	Praxair	Air Liquide	Sabic
Commencement	1983	2007	2014	1972
Volume (m^3)	580,000	556,000	906,000	210,000
Operating pressure range (bars)	70-135	55-152	62 - 200	45 – 100
***Usable* Hydrogen stored (tons)**	3000	2900	4800	1100
***Unusable* Hydrogen stored (tons)**	3300	3200	3300	1200
Usable Energy Stored (GWh)	100	96	274	36

Green Steel : DRI – EAF – H2 for 75% Ore and 25% scrap



Process scheme of DRI-EAF-H2 by using 75% ore and 25% scrap

Classification of Green Energy Carriers



Graph in a report from IRENA. As per this graph, the methanol is labelled as green only if the CO2 comes from either of the following two sources:

1. Biological process (fermentation, biogas production, etc)
2. Direct air capture (DAC)

Thank You

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