[1]

HYDROPOWER TO HYDROGEN

GOVERNMENT PRIORITIES FOR SUSTAINABLE HYDROPOWER DEVELOPMENT AND ROLE OF NEA

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PRESENTED BY

HITENDRA DEV SHAKYA, *Managing Director*

[1] Atena, "Atena," Atena, [Online]. Available: https://www.atenaweb.com/2x40-gw-green-hydrogen-initiative/. [Accessed 03 09 2020].

SLIDE GUIDELINES

- Existing Energy Scenario in Nepal
- Capacity Balance in Integrated Nepal Power System
- Energy Balance in Integrated Nepal Power System
- Energy Storage Systems - Prime need for Sustainability
- Hydrogen, Nitrogen, Ammonia and Urea Production
- Role of Nepal Electricity Authority (NEA)

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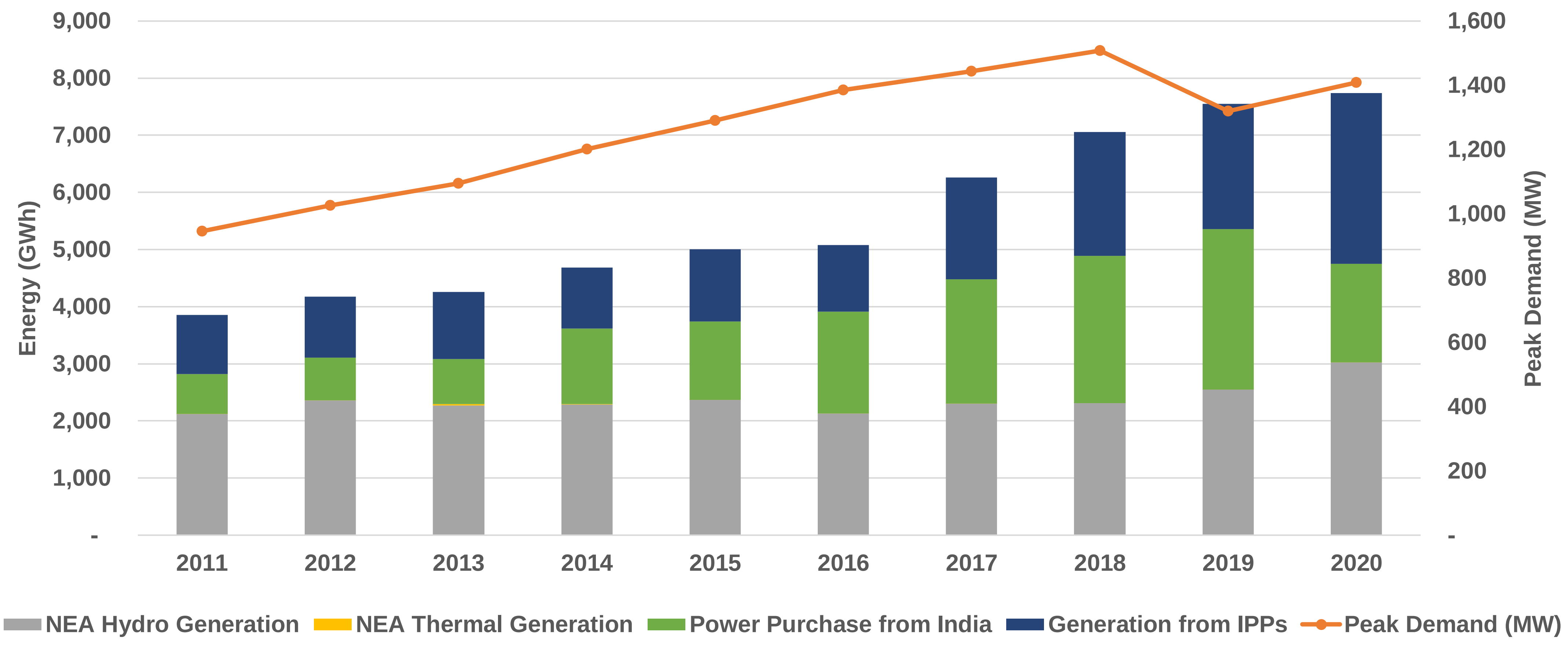
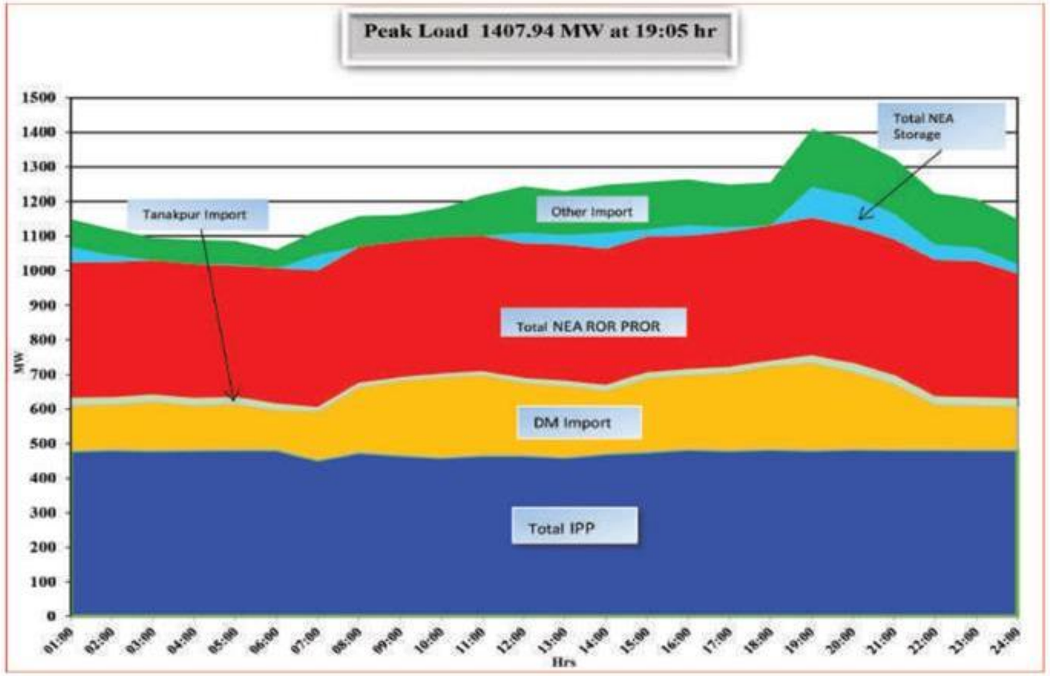
Peak Demand & Available Energy in Integrated Nepal Power System



Load Curve for Integrated Nepal Power System

System Load Curve (Maximum Demand) Bhadra 23, 2076
(Sep 9, 2019) Monday



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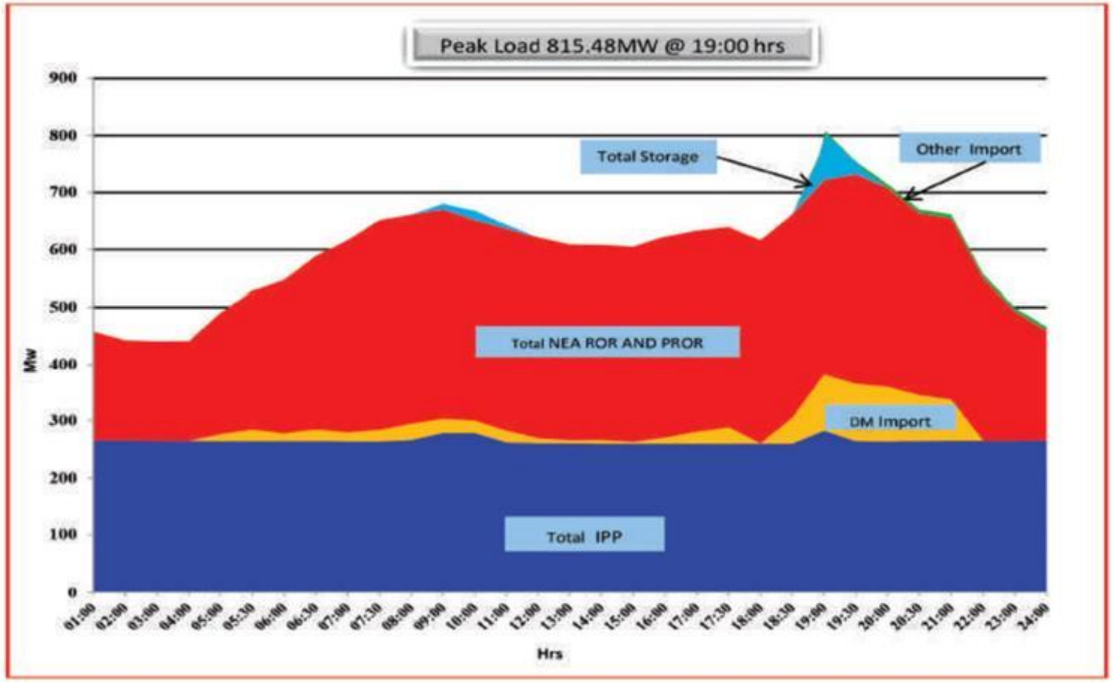
System Load Curve (Minimum Demand) Baishakh, 11, 2077
(23 APR,2020), Thursday



[1]

[1] N. E. Authority, "A Year in Review Fiscal Year - 2019/2020," Nepal Electricity Authority, Kathmandu, 2020.

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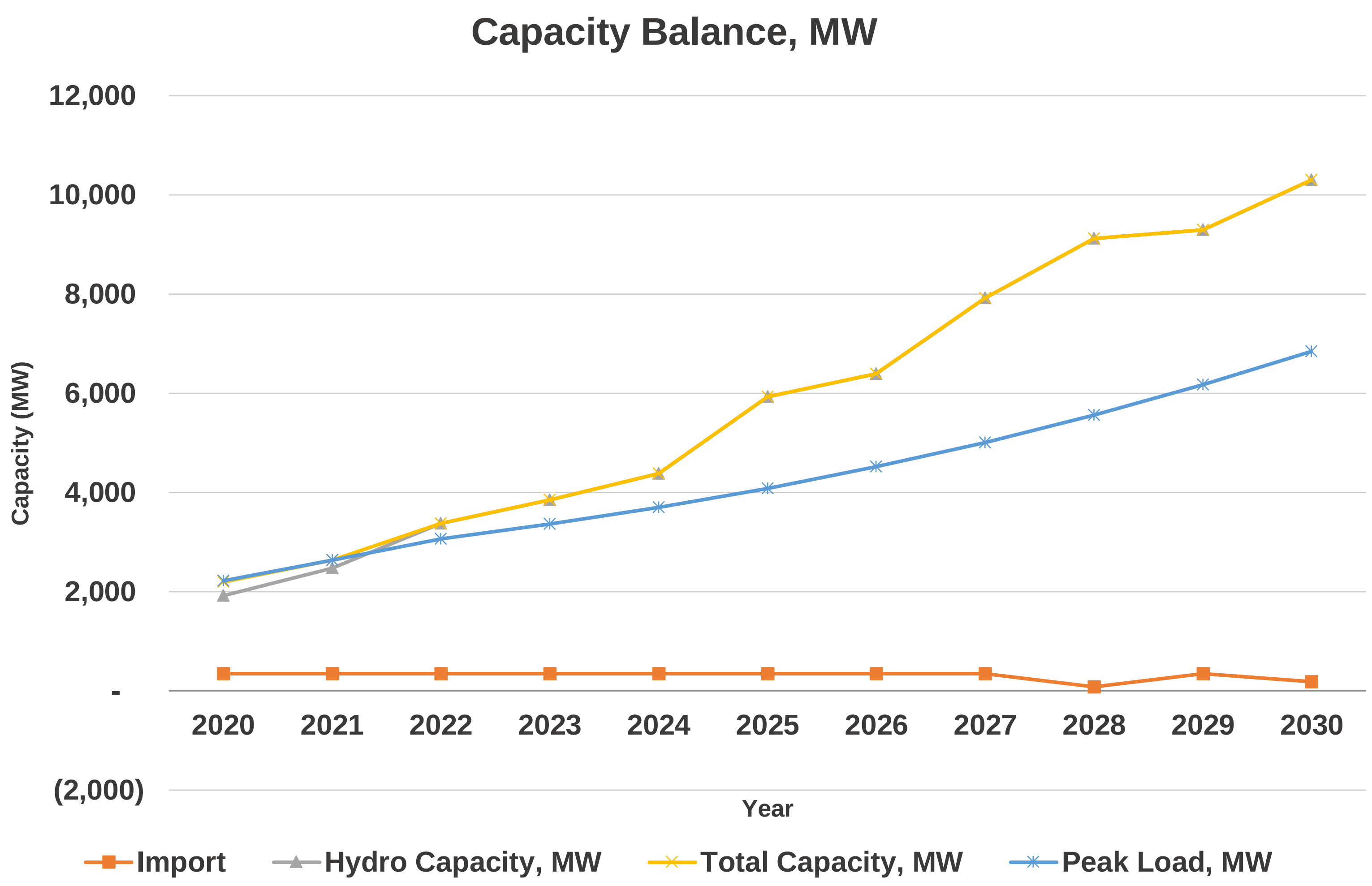
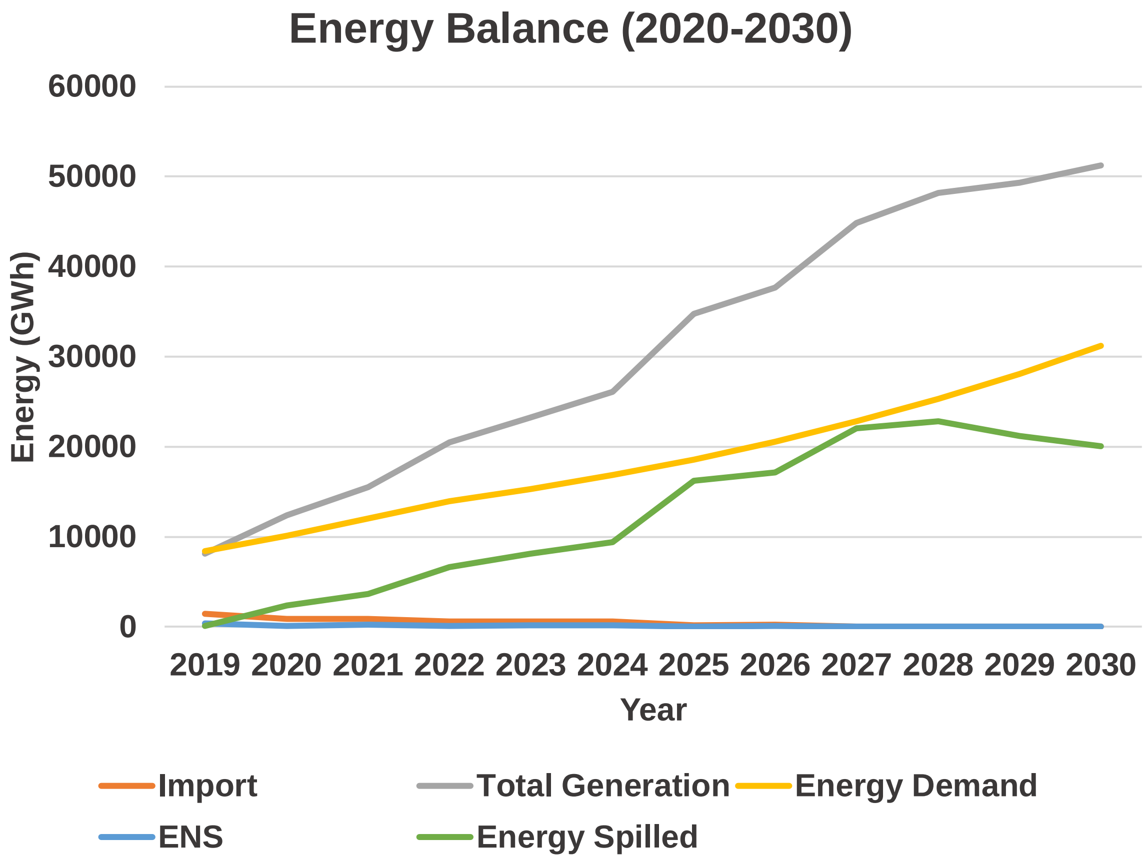
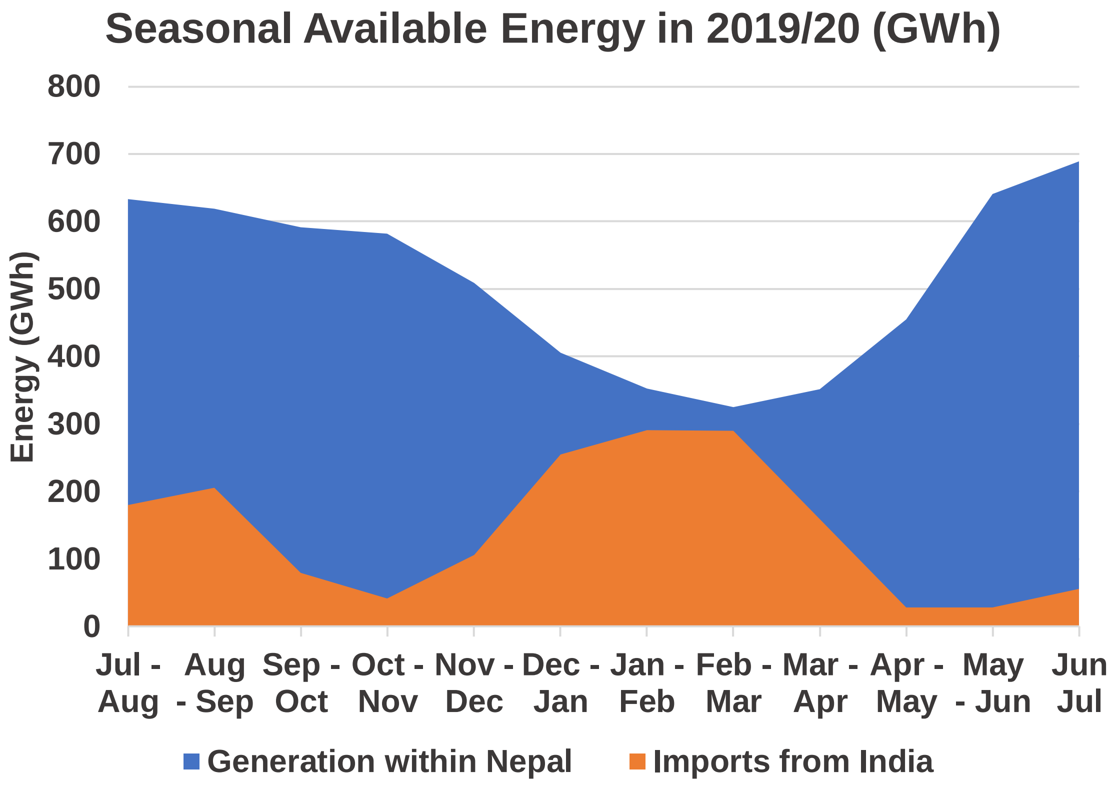
Capacity Balance (2019-2030)



Energy Balance (2019-2030) and Seasonal Energy Variation





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Overview of Energy Storage Systems

	Max Power Rating (MW)	Discharge Time	Max cycles or Lifetime	Energy density (Watt-hour per liter)	Efficiency
Pumped Hydro	3,000	4 – 16 hours	30 – 60 years	0.2 - 2	70 – 85%
Compressed Air	1,000	2 – 30 hours	20 – 40 years	2 – 6	40 – 70%
Molten Salt (Thermal)	150	hours	30 years	70 – 210	80 – 90%
Li-ion battery	100	1 min – 8 h	1,000 – 10,000	200 – 400	85 – 95%
Lead Acid Battery	100	1 min – 8 h	6 – 40 years	50 – 80	80 – 90%
Flow Battery	100	hours	12,000 – 14,000	20 – 70	60 – 85%
Hydrogen	100	mins - week	5 – 30 years	600 (at 200 bar)	25 – 45%
Flywheel	20	secs - mins	20,000 – 100,000	20 - 80	70 – 95%

Storage of energy is essential for sustainability of Nepal hydro. [1]

[1] The World Energy Council

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Fuel Cell and Its Selection

Fuel Cell Type	Typical Stack Size	Electrical Efficiency	Applications	Advantages	Challenges
Polymer Electrolyte Membrane (PEM)	<1 kW - 100 kW	60% direct H_2; 40% reformed fuel	• Backup power • Portable power • Distributed generation • Transportation • Specialty vehicles	• Solid electrolyte reduces corrosion & electrolyte management problems • Low temperature • Quick start-up and load following	• Expensive catalysts • Sensitive to fuel impurities
Alkaline (AFC)	1 - 100 kW	60%	• Military • Space • Backup power • Transportation	• Wider range of stable materials allows lower cost components • Low temperature • Quick start-up	• Sensitive to CO_2 in fuel and air • Electrolyte management (aqueous) • Electrolyte conductivity (polymer)
Phosphoric Acid (PAFC)	5 - 400 kW, 100 kW module (liquid PAFC); <10 kW (polymer membrane)	40%	• Distributed generation	• Suitable for CHP • Increased tolerance to fuel impurities	• Expensive catalysts • Long start-up time • Sulfur sensitivity
Molten Carbonate (MCFC)	300 kW - 3 MW, 300 kW module	50%	• Electric utility • Distributed generation	• High efficiency • Fuel flexibility • Suitable for CHP • Hybrid/gas turbine cycle	• High temperature corrosion and breakdown of cell components • Long start-up time • Low power density
Solid Oxide (SOFC)	1 kW - 2 MW	60%	• Auxiliary power • Electric utility • Distributed generation	• High efficiency • Fuel flexibility • Solid electrolyte • Suitable for CHP • Hybrid/gas turbine cycle	• High temperature corrosion and breakdown of cell components • Long start-up time • Limited number of shutdowns

[1]

[1] https://scientistmohamed.wordpress.com/2017/04/24/deep-water-technique-dwt-for-producing-hydrogen-purified-water-a-unique-electricity/

Hydrogen Generation Flexibility

S.N.	Basis	Alkaline Electrolyser	PEM Electrolyser
1	Flow range	15 - 100 % *Reference: https://nelhydrogen.com*	10 - 100 % *Reference: https://nelhydrogen.com*
2	Start time	Warm start time = 0 - 1 hr Cool start time = 4 hr	Start up procedure = 10 min Cool start = 30 min
3	Cost	NRs. 75 lakhs for 50 kW system.	Expensive than Alkaline Electrolyser
4	Electricity consumption	4.5 kWh/ Nm^3 H_2 *From quotation from supplier*	4.54 kWh/ Nm^3 H_2 *Reference: https://nelhydrogen.com*

For 500 kW hydrogen electrolyser:
Lowest electricity consumption = 1,500 units in a day = 150 kg ammonia/day
Highest electricity consumption = 10,000 unit in a day = 1 tons ammonia/day
Production:
Lowest production = 27 kg hydrogen/day = 150 kg ammonia/day
Highest production = 180 kg hydrogen/day = 1 tons ammonia /day

Normal cubic meter (Nm3) -
Temperature: 0 °C,
Pressure: 1.01325 barA

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Hydrogen Production

- Electrolyser consists of anode and cathode separated by electrolyte.
- Upon the flow of electricity, hydroxide ion is transported to anode through the electrolyte.
- For the production of Hydrogen, water with resistivity of 10 μS/cm is required. However, the typical water conductivity of drinking water is about 200 to 800 μS/cm.

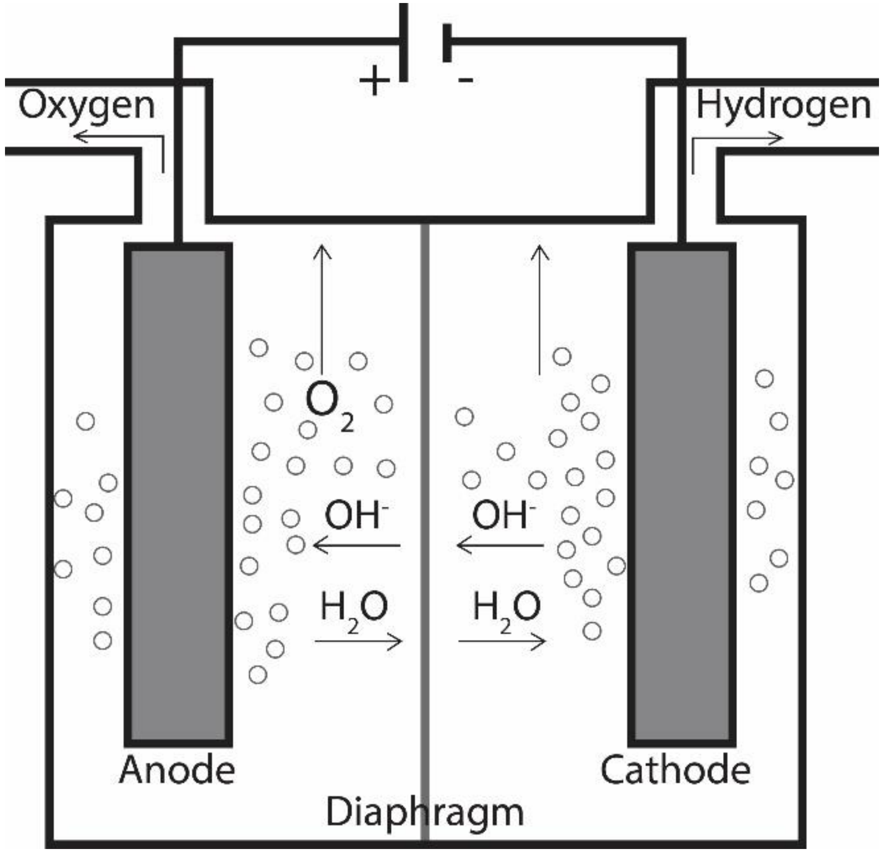

Figure: Water Electrolysis for H_2 generation

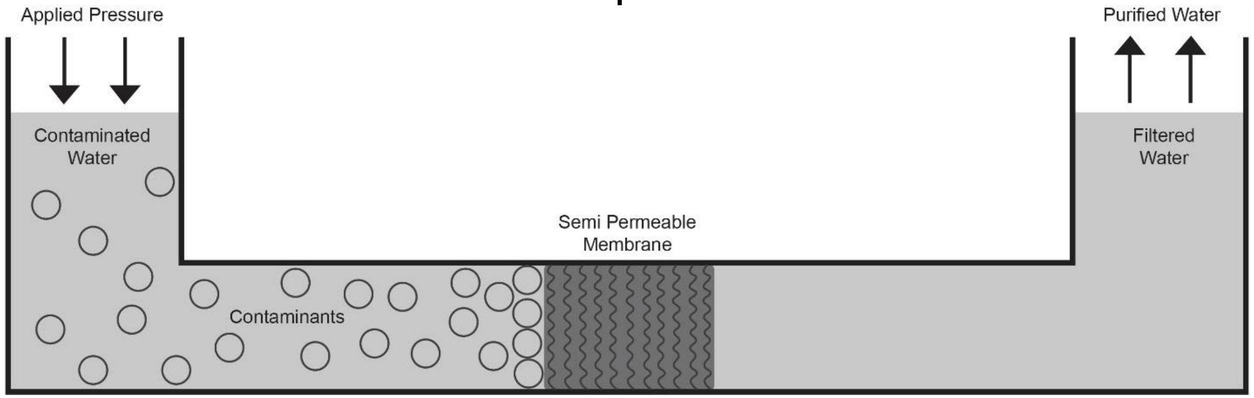

Figure: Reverse Osmosis for water treatment

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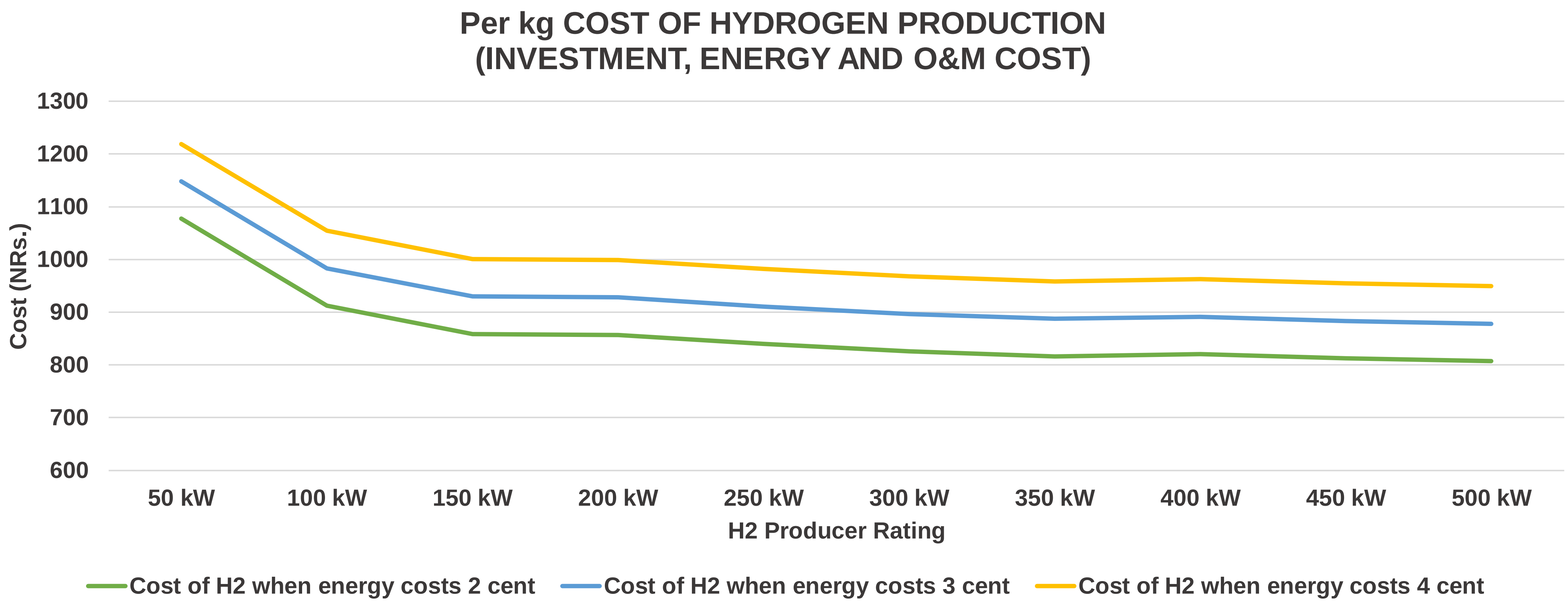
Cost of Hydrogen Production



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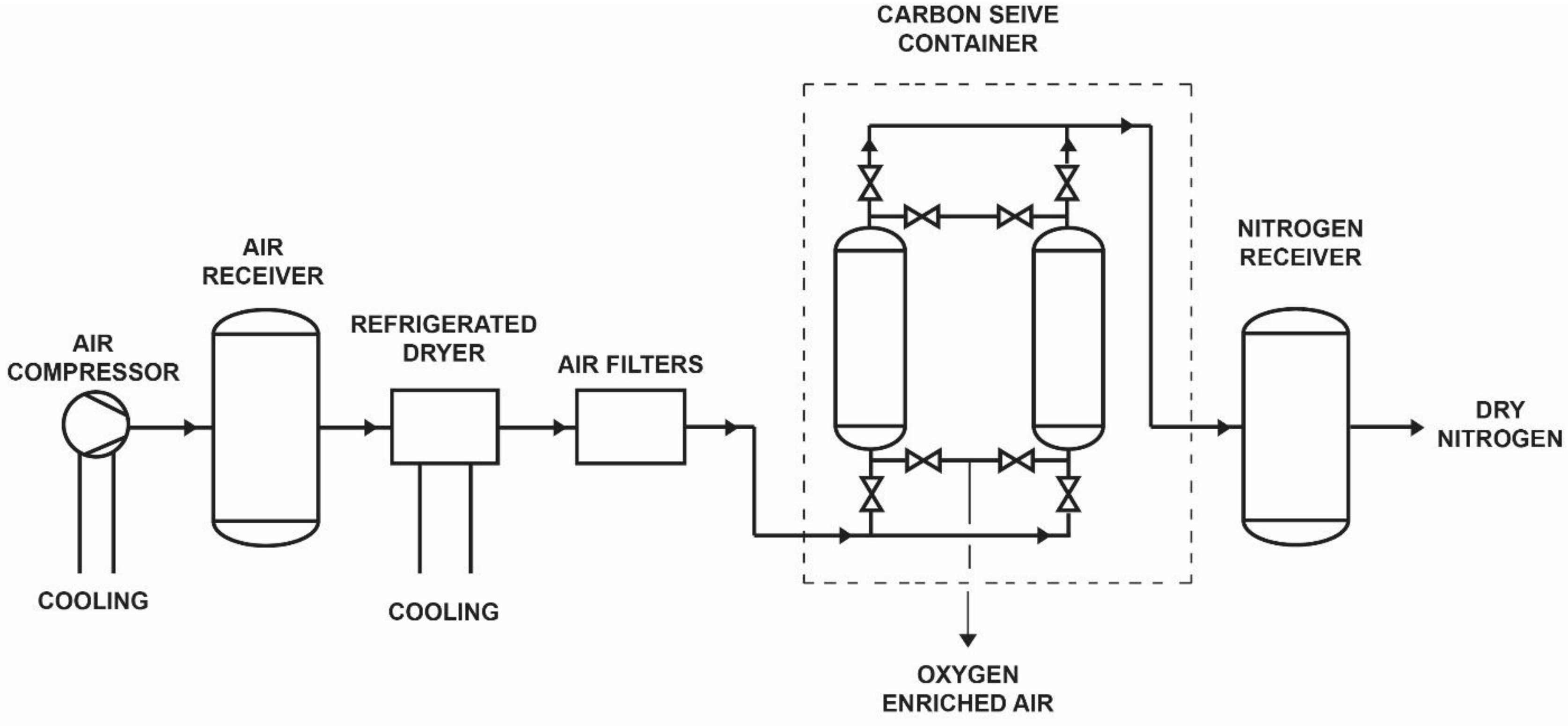
Nitrogen Production



- Firstly, the air is compressed, cooled and dried
- The air filter to remove impurities and oil
- After absorption and deabsorption, the nitrogen is stored and the oxygen is released form the double towers
- Obtained nitrogen is 99.95% pure

Figure: Nitrogen generation through Pressure Swing Absorption process

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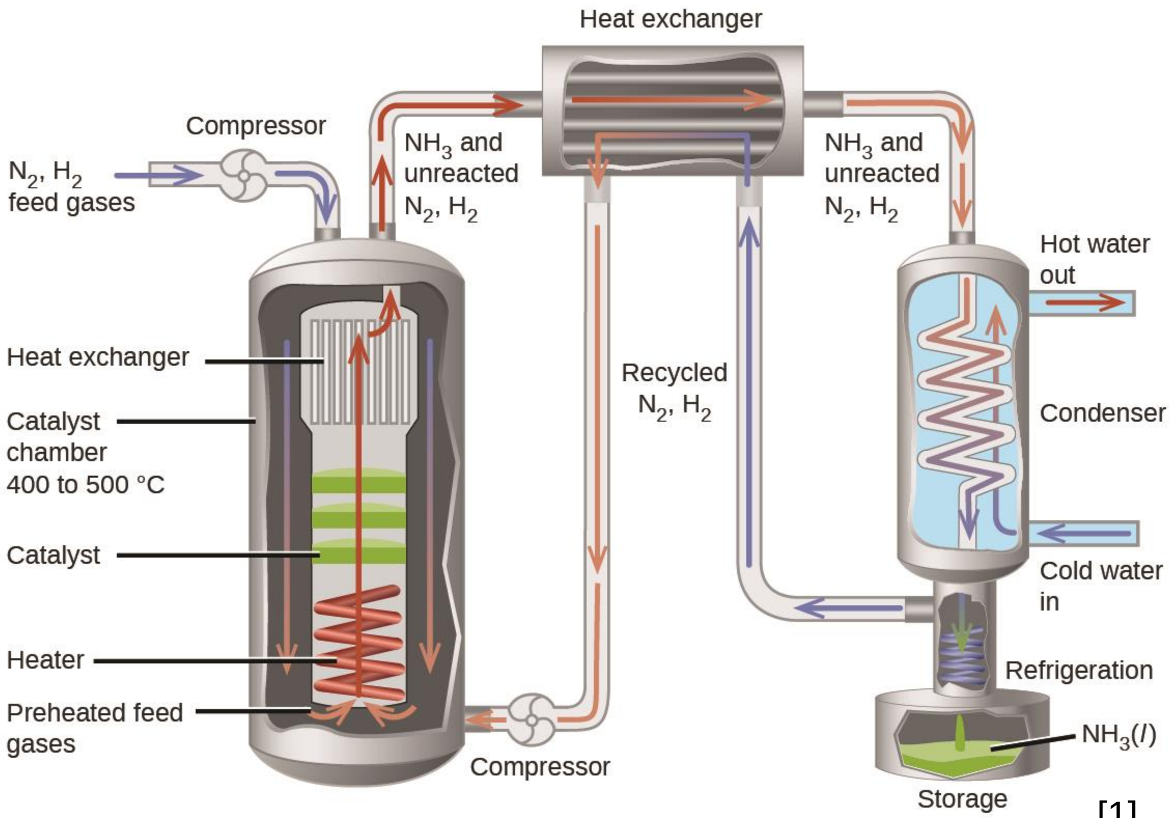
Ammonia Production



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- Hydrogen from electrolysis
- Nitrogen from air separation
- Ammonia production according to Haber-Bosch process

$$3H_2 \quad + \quad N_2 \qquad \rightleftharpoons \quad 2NH_3, \ \Delta\text{H = -92 kJ/mol}$$
$$(1kg) \ + (4.67kg) \ \ \rightarrow \ \ (5.67kg)$$

[1] OpenStaxCollege, "pressbooks-dev.oer.hawaii," [Online]. Available: http://pressbooks-dev.oer.hawaii.edu/chemistry/chapter/shifting-equilibria-le-chateliers-principle/. [Accessed 02 09 2020].

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Urea Production

- Ammonia from ammonia plant
- Carbon dioxide from carbon dioxide generation/ recovery plant
- Chemical Reaction involved in Urea production :

$$NH_3 \quad + \quad CO_2 \quad \rightleftharpoons \quad NH_2COONH_4$$
$$(5.67kg) + (7.33kg) \quad \rightarrow \quad (13kg)$$

$$NH_2COONH_4 \quad \rightleftharpoons NH_2 - CO - NH_2 + \quad H_2O$$
$$(13kg) \quad \rightarrow \quad (10kg) \quad + \quad (3kg)$$

- Normally urea is manufactured using Bosch-Meiser process

[1]

[1] K. S. Tarabar, "Kala Sepid Tarabar," Kala Sepid Tarabar, [Online]. Available: https://kst-transportation.com/urea-supplier/. [Accessed 02 09 2020].

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Historical Perspective : JICA Study on Urea

- Study in 1984 with commencement target of 1991

Technical Parameters

Size: 275 tonne per day

Site Area: 500 m * 200 m

Location: Hetauda

Electric power: 76.1 MW

Coal: 76.8 tonne per day

Hydrogen: Electrolysis

Carbon dioxide: Cement plant flue gas

Power plant considered: Sapta Gandaki (225 MW)

Financial Parameters

Total Investment: 144.79 Million USD

Foreign Currency: 82.8%

Local Currency: 17.2%

Loan/equity: 70% / 30%

ERR: 8.2%

Financially Viable: After 40% decrease in tariff price

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Case: Production of 1.8 Metric Ton Urea/Day

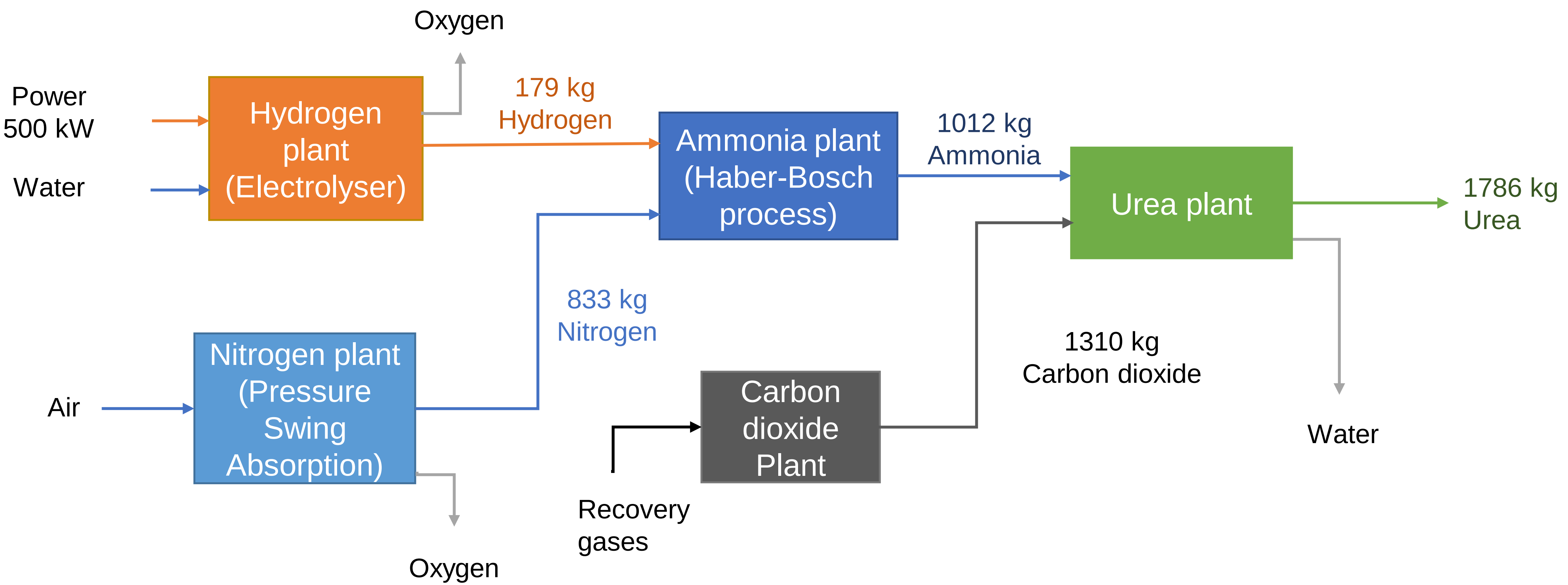

Figure: Process flow diagram of Urea Production

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Capital Cost for 1 MT/ day Ammonia Production

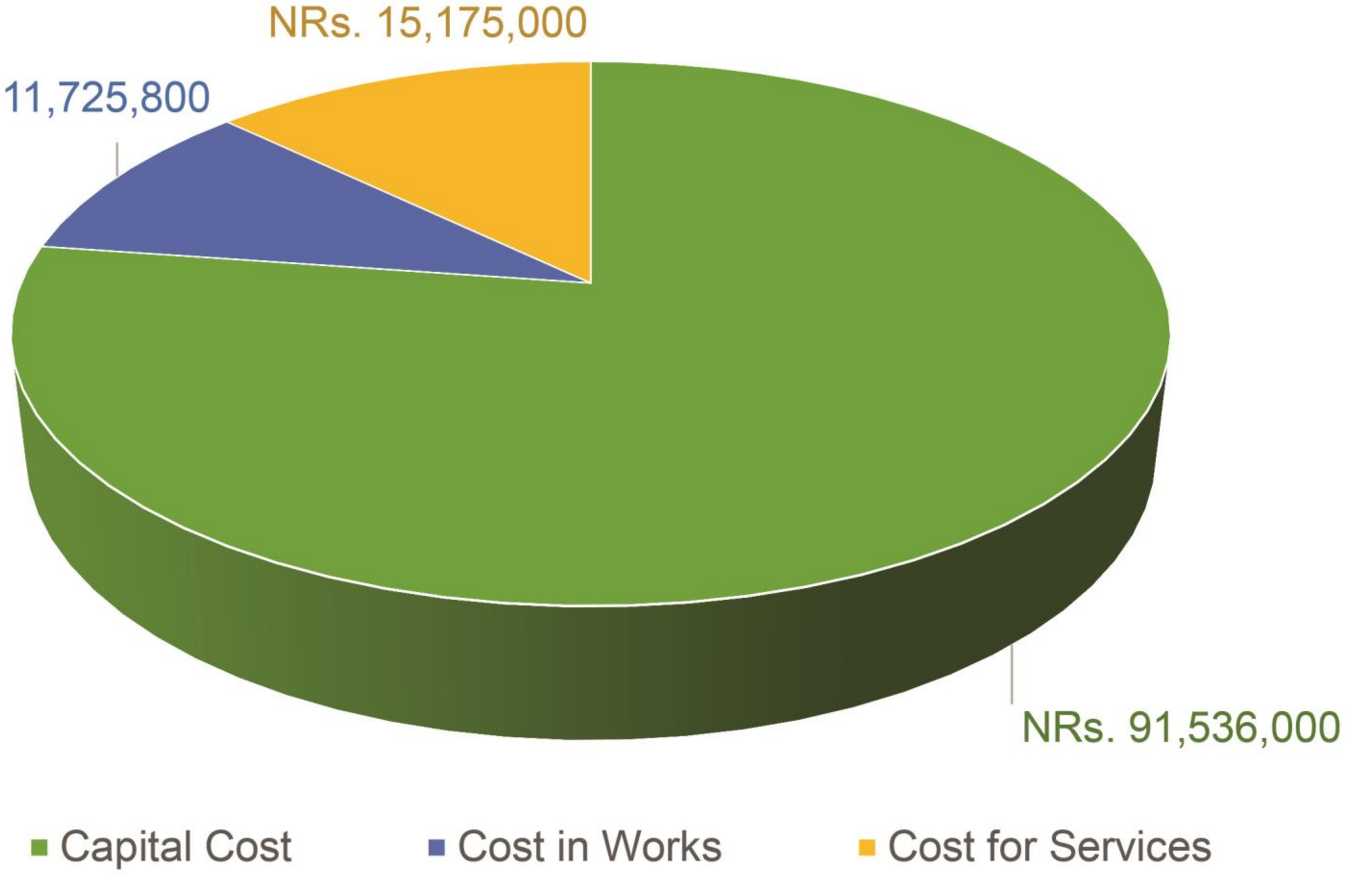

Figure: Price breakdown for 1 MT/ day ammonia production

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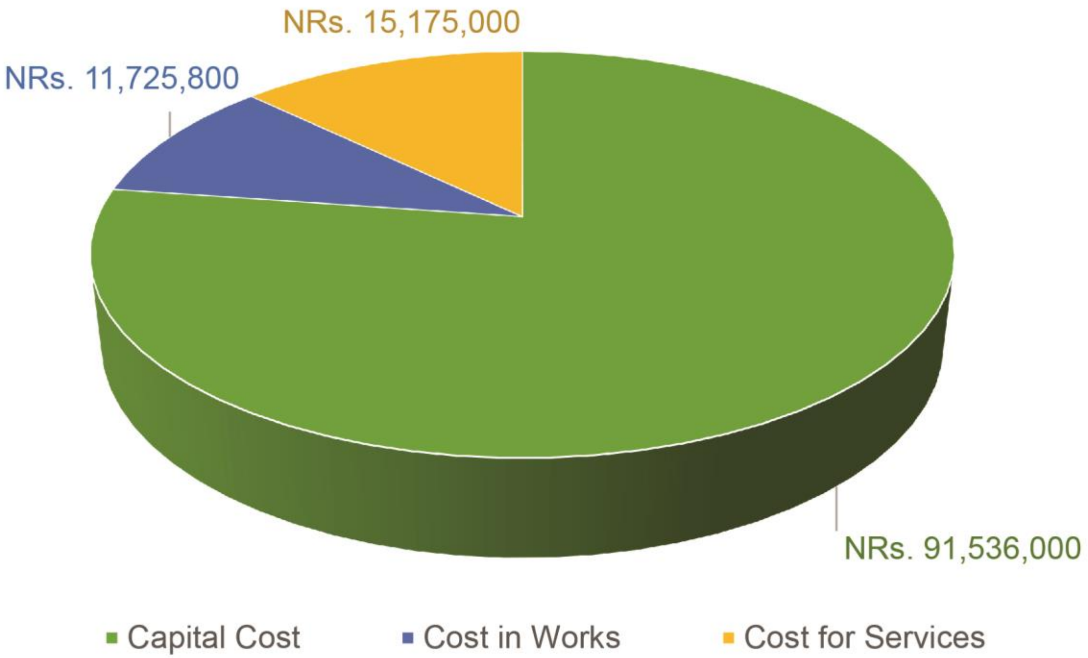
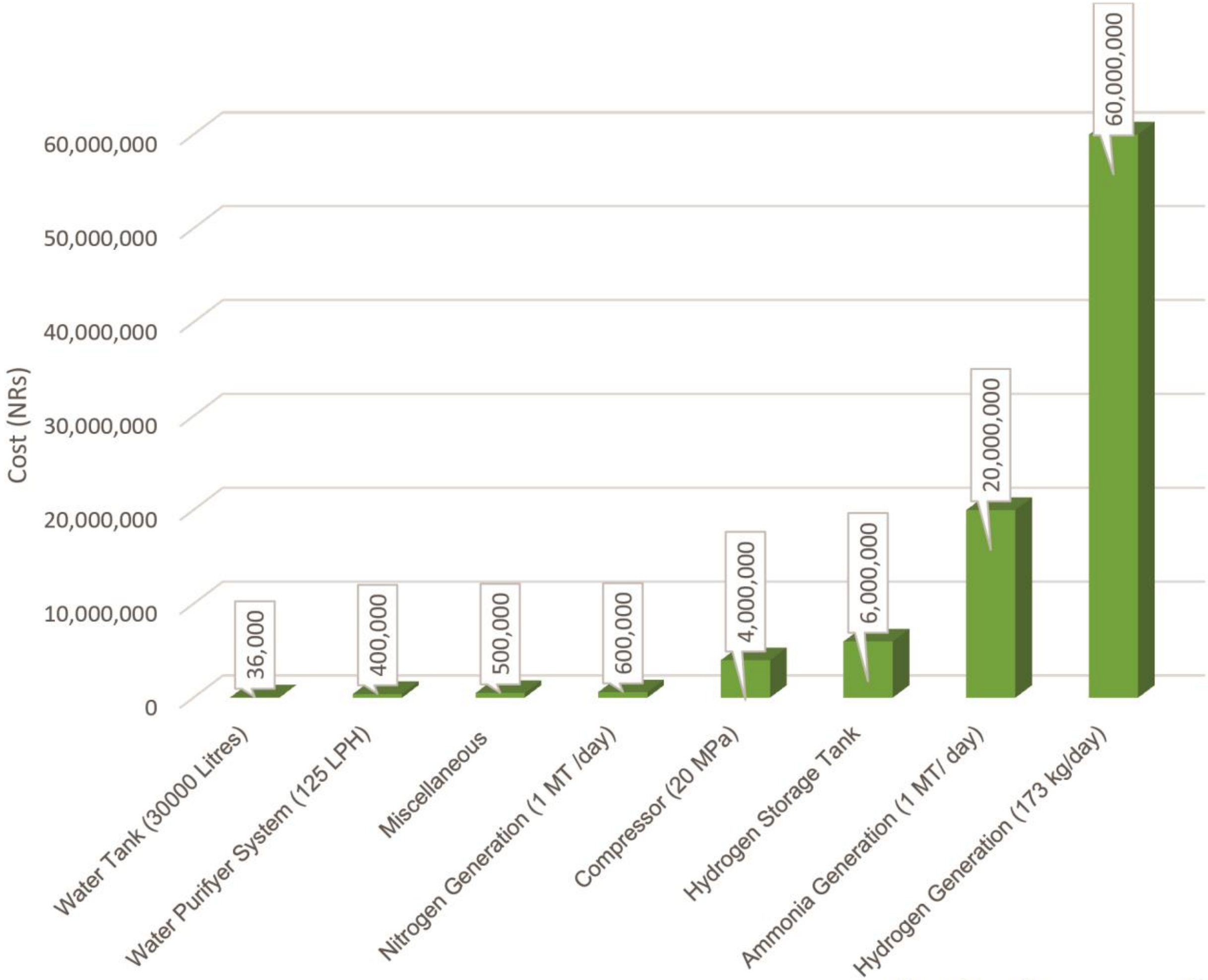
Capital Cost for 1 MT/ day Ammonia Production





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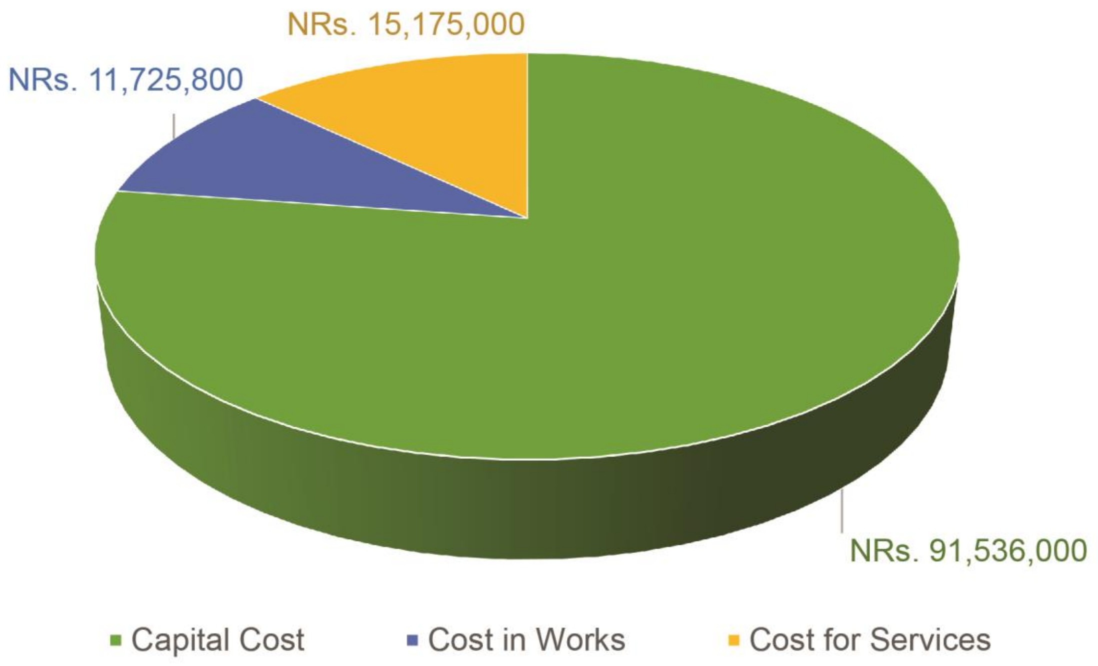
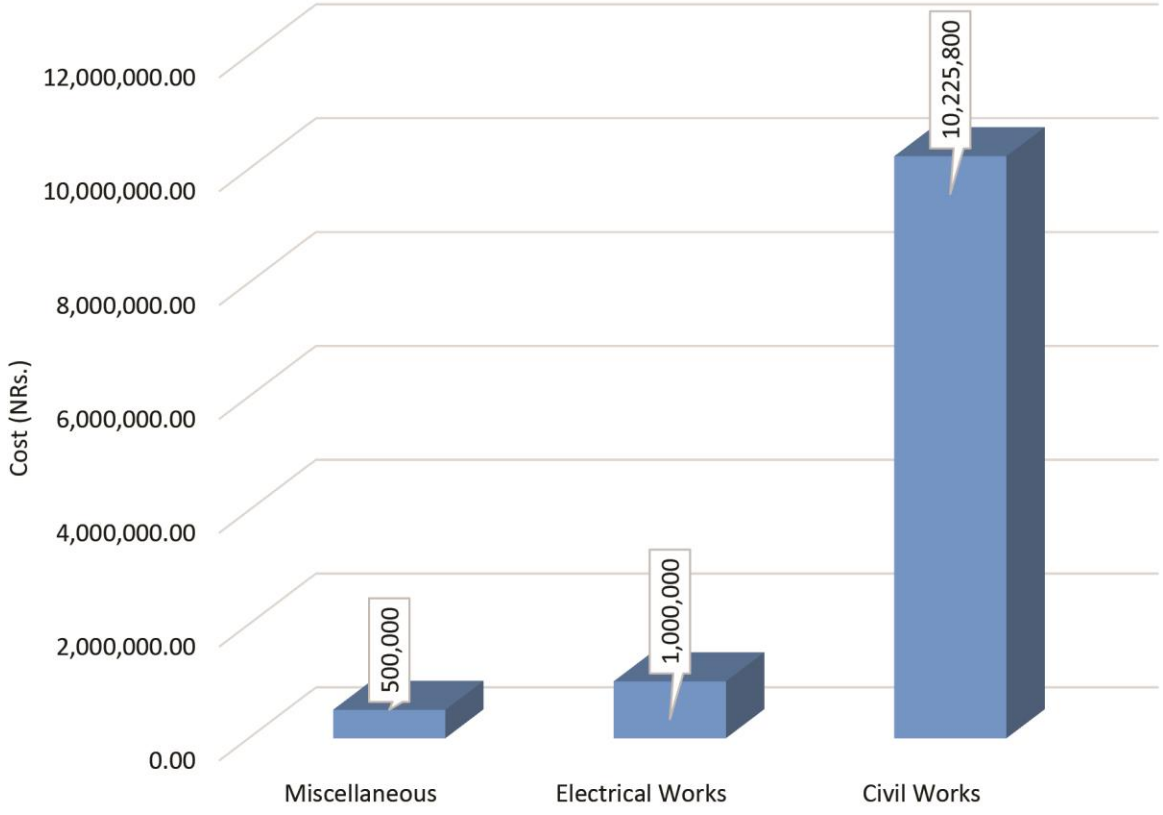
Capital Cost for 1 MT/ day Ammonia Production





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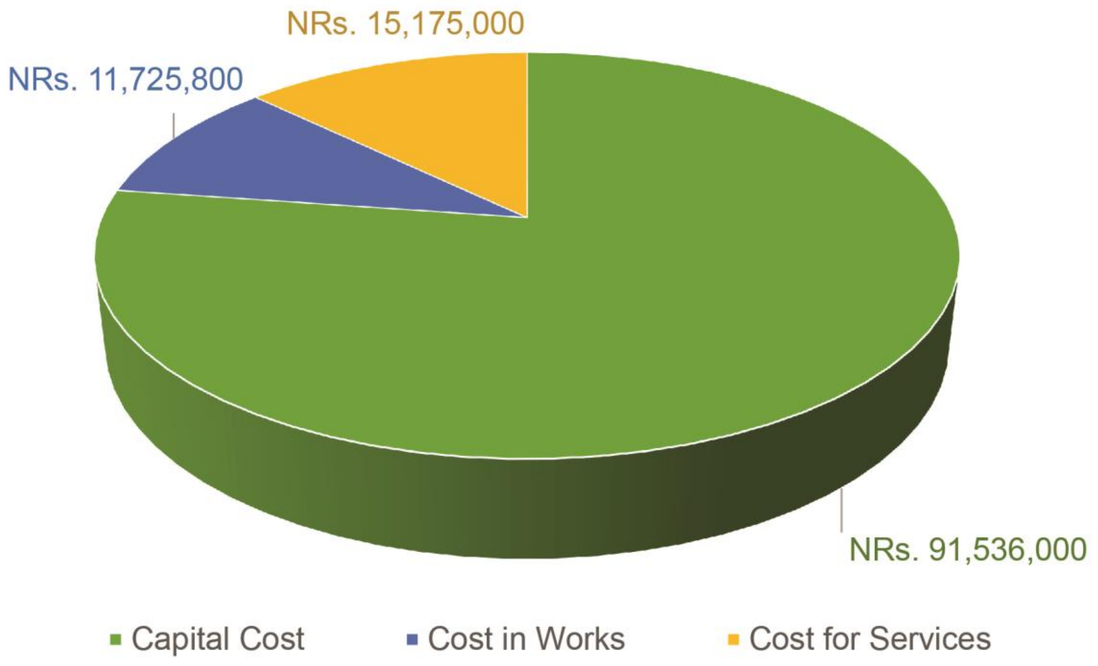
Capital Cost for 1 MT/ day Ammonia Production



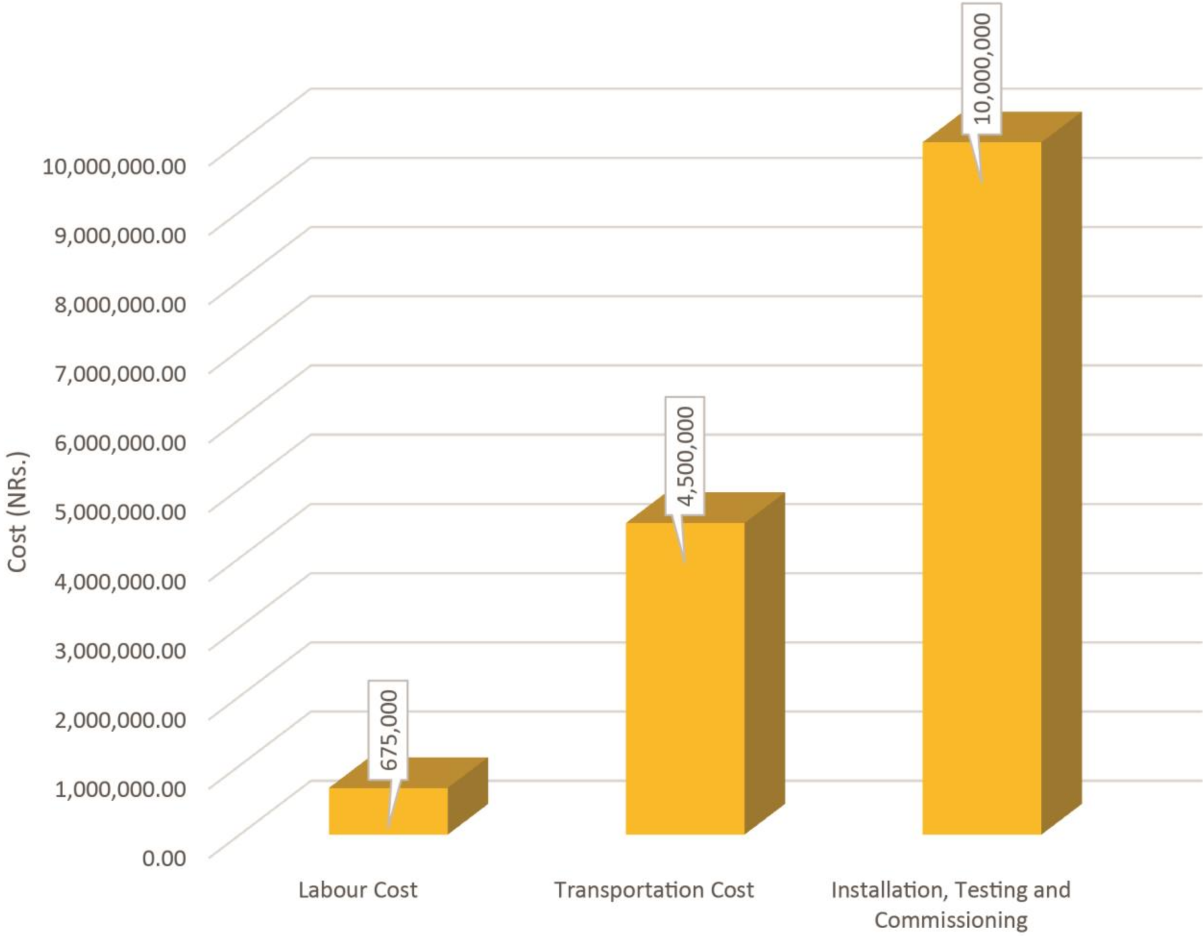


Figure: Price breakdown for 1 MT/ day ammonia production

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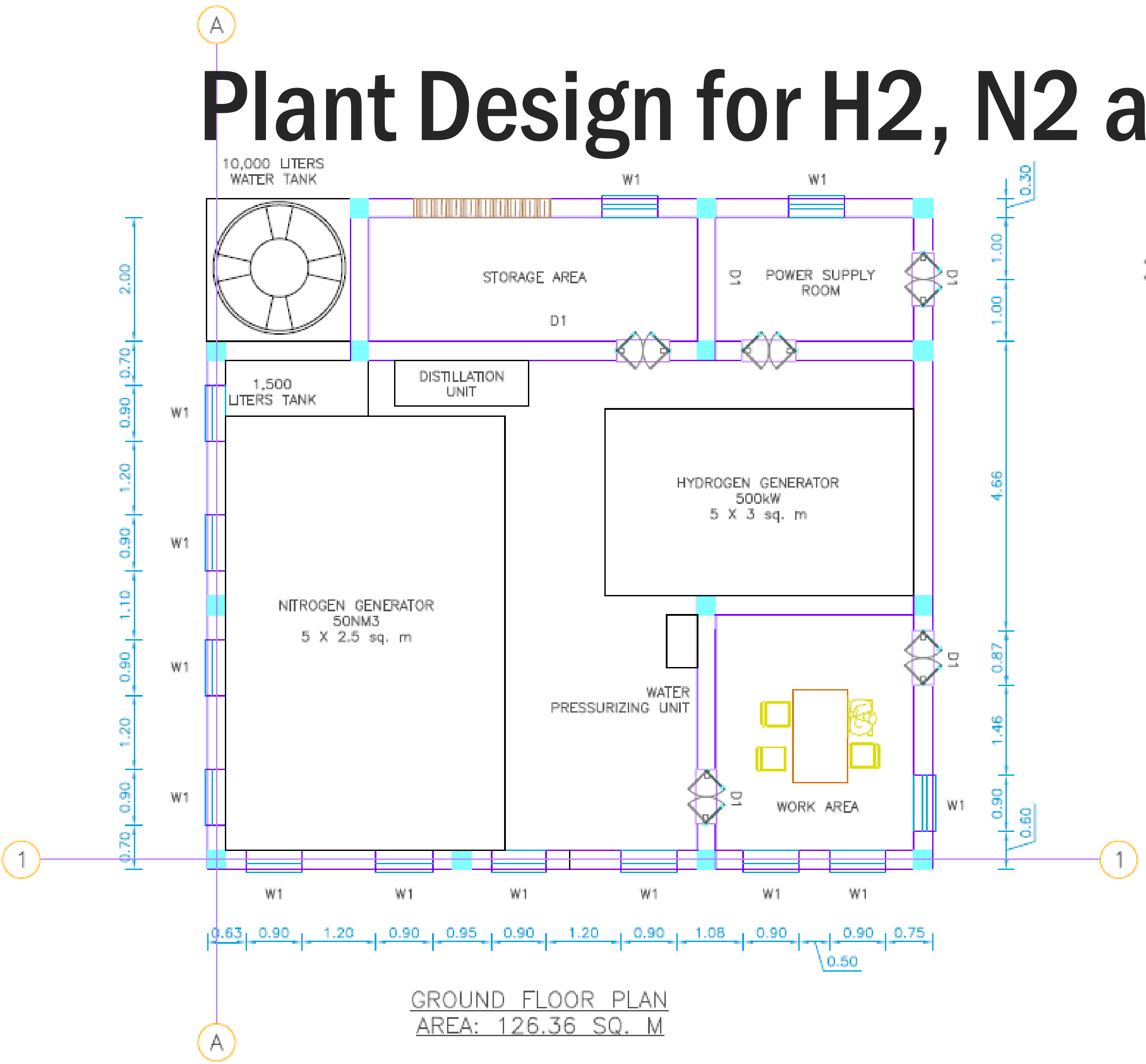
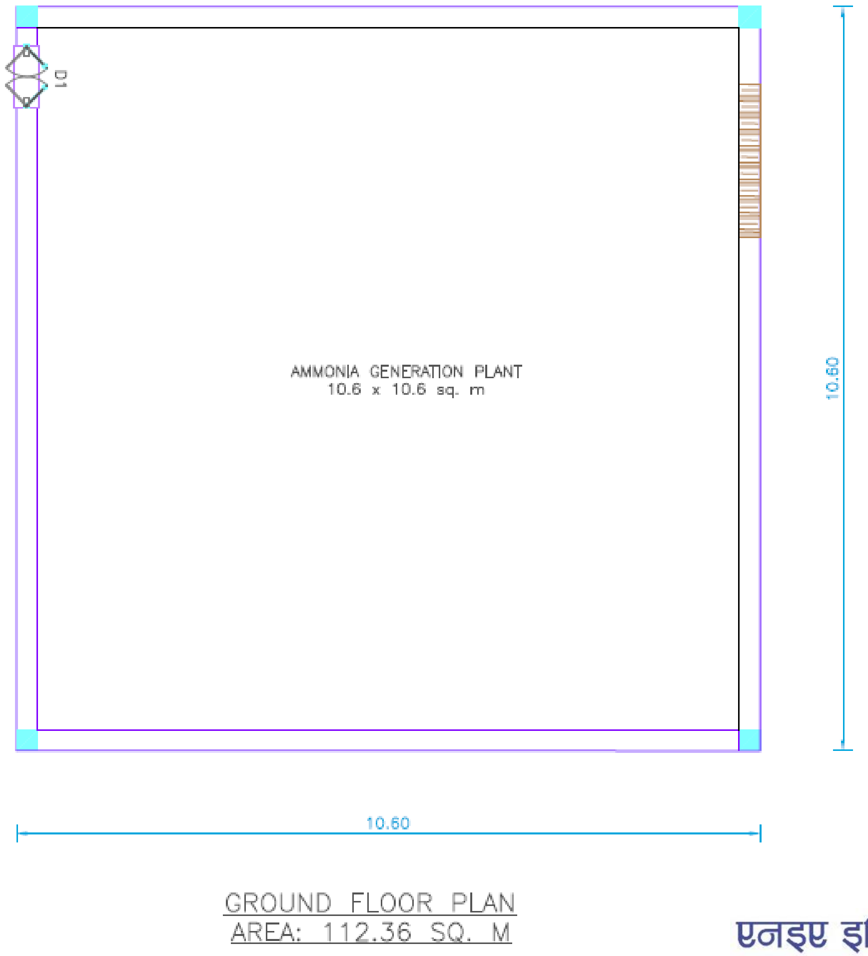
Plant Design for H2, N2 and Ammonia Production





Total Area:
238.72 sq. m

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Role of Nepal Electricity Authority (NEA)

- Hydropower is seasonal, and there is a mismatch in load and generation
- Storage hydro is expensive and does not pay by itself only for energy, multiple benefits must be extracted
- Power trade and use of foreign market as buffer or storage is risky, energy security is required
- Technologies for use of surplus **Seasonal** energy will stimulate **Seasonal Demand**
- Demand will encourage hydro-power development
- NEA is active in demand stimulation in industries, agriculture and domestic areas

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Role of Nepal Electricity Authority (NEA)

- Seasonal demand is the best fit. NEA and NEA Engineering Company Ltd are looking for research and development in this area
- Hydrogen generation using **seasonal surplus** (20 hours a day) is one solution
- If hydrogen generation helps urea production, it solves two problems of the nation with one stroke
- Similar demand industries such as Public EV charging and battery storage, controllable loads such as Cold Store and Irrigation pumps are interesting
- With better fuel cell efficiencies, hydrogen generation can be another Double Goal with hydrogen trucks and buses replacing petroleum and reducing pollution

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Thank You!

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