ASIA CLEAN ENERGY FORUM 2020
VISION 20/20: CROSS-SECTORAL INNOVATIONS FOR A SUSTAINABLE FUTURE

The prospect of hydropower to hydrogen in developing countries in Asia - the case of Nepal

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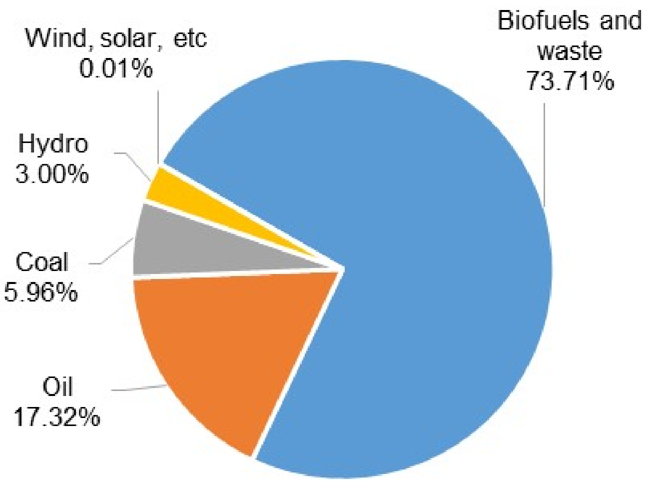
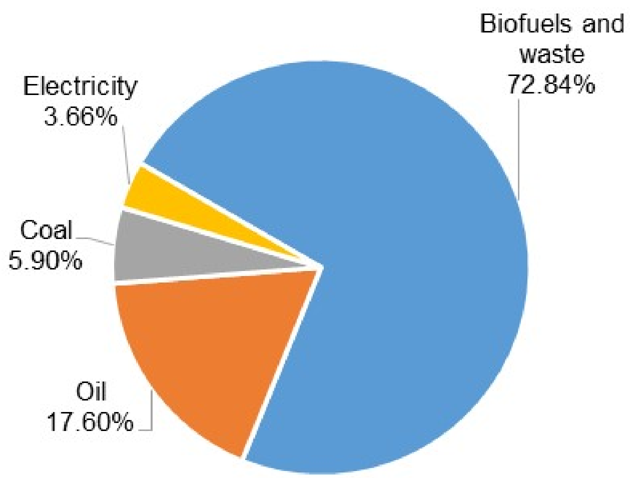
The prospect of hydropower to hydrogen in Nepal



Total primary energy supply



Total final consumption

- Nepal's energy mix is dominated by biofuels and waste and imported petroleum
- Share of electricity = 3.66%
- Hydropower potential 83GW, commercially exploitable potential 42GW
- Total installed capacity of hydropower 1.1 GW by FY2019
  - Inadequate planning and investment
  - Take-or-pay contract obligations
  - Delays in project development

Sources: ADB (2017) Nepal Energy Sector Assessment, Strategy and Road Map; IEA (2019) Data and statistics; Nepal Electricity Authority (2019) Annual Report 2018/19

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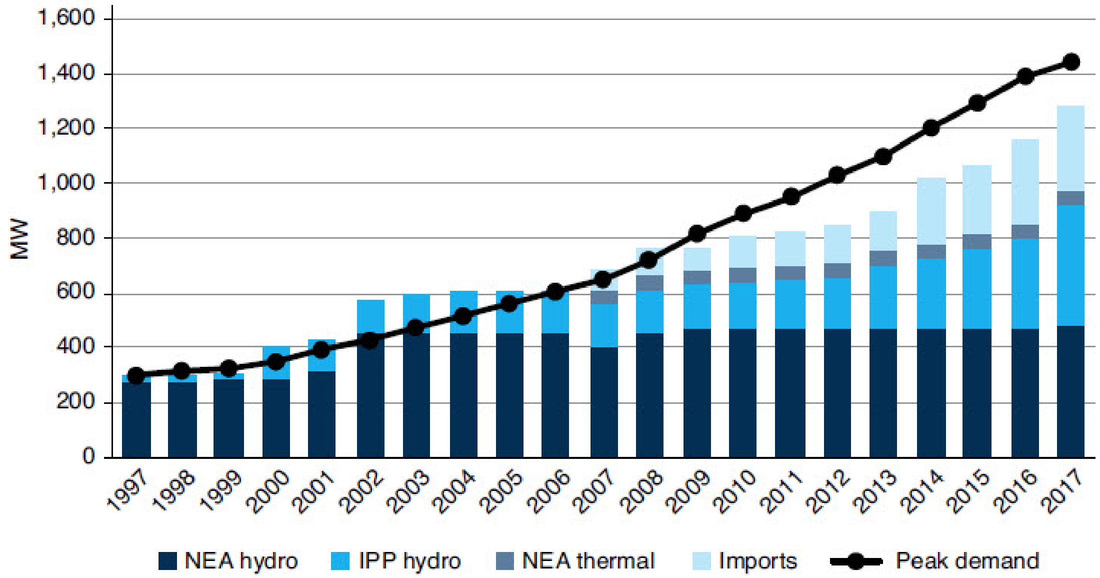

Peak demand versus installed capacity, 1997–2017 (World Bank, 2019)

- Installed capacity (NEA-owned and IPPs) not sufficient to meet peak demand - 1.1GW vs 1.5GW in FY2019
- High fluctuation and seasonality of electricity generation by run-of-the-river hydropower plants
- Critical shortfall in power capacity during dry winter season
- Rate of electrification has increased, but actual electricity consumption remains low
- Total electricity consumption very likely to remain low over the medium term
  - 2035 estimate: 0.9 Mtoe, 5.4% of total final energy demand
- 2017 per capita electricity consumption (kWh/year):
  - Nepal 197, Bangladesh 402, Sri Lanka 712, India 947, China 4,546, World average 3,152

Sources: ADB (2013) Energy Outlook for Asia and the Pacific; ADB (2017) Nepal Energy Sector Assessment, Strategy and Road Map; Nepal Electricity Authority (2019) Annual Report 2018/19; World Bank (2019) Nepal Energy Infrastructure Sector Assessment

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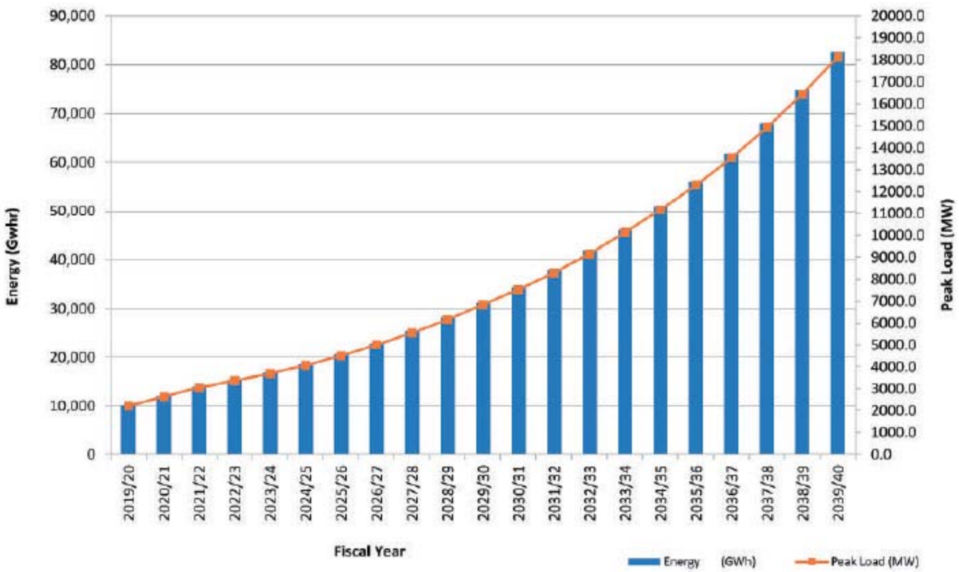

Load forecast from 2019 to 2040 (NEA, 2019)

- NEA-owned hydropower plants generated 2,548GWh in FY2019
- 340 PPAs were signed with IPPs in FY2019 for a combined capacity of 6GW
- Electricity import from India to bridge supply-demand gap:
  - Share of imported electricity increased from 18% in 2011 to 35% in 2016
  - FY2019 import from India was 2,813 GWh, 29% in total available electricity in NEA's system.

- White Paper on *Energy, Water Resources and Irrigation Sector's Status and Roadmap for the Future* issued in 2018 set ambitious targets:
  - total installed hydropower capacity to reach 3GW in 3 years, 5GW in 5 years and 15GW in 10 years
  - per capita electricity consumption to 1,500 kWh in 10 years

- NEA's peak demand forecast: 2.2 GW in 2020, 6.8 GW in 2030, 18 GW in 2040

Sources: Ministry of Energy Water Resources and Irrigation (2018) Energy, Water Resources and Irrigation Sector's Current Status and Roadmap for Future; Nepal Electricity Authority (2019) Annual Report 2018/19

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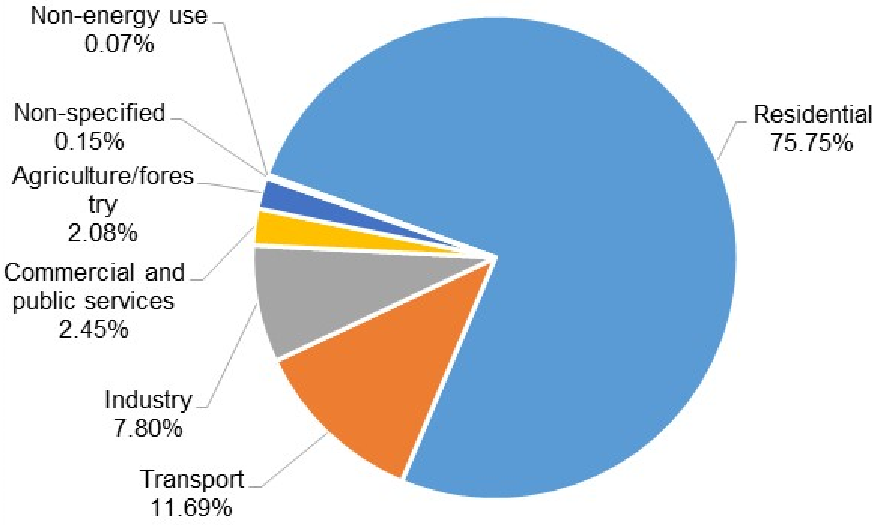
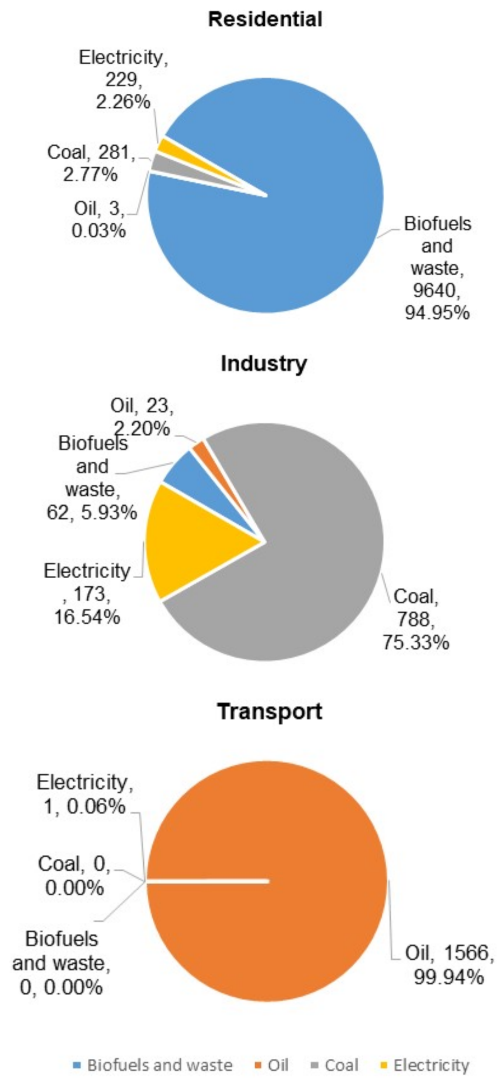


Total final energy consumption by sector, 2017



- Final energy consumption in 2017: residential sector 75.8%, transport sector (11.7%), industry sector (7.8%)
- Heavy dependence of transport and industry sectors on imported coal and oil products
- Low level of energy diversification of transport sector - share of oil nearly 100%

Sources: IEA (2019) Data and statistics

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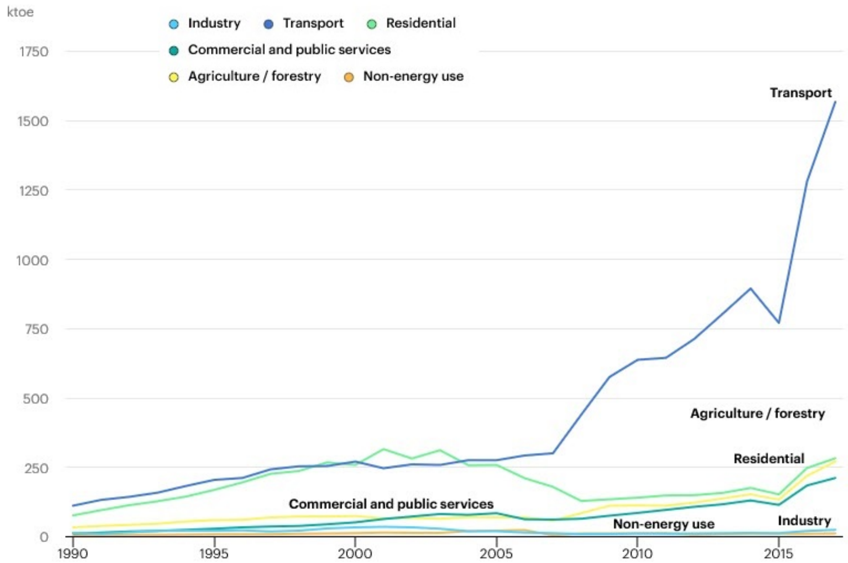
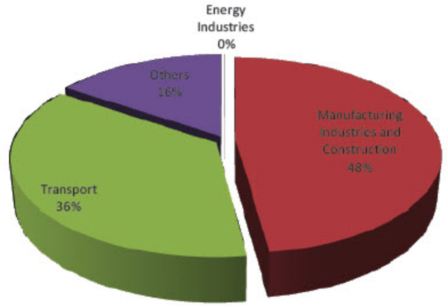
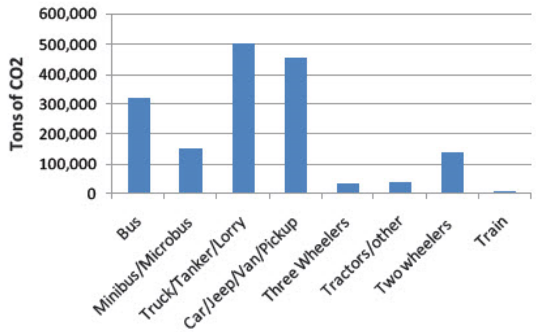


Oil products final consumption by sector 1990-2017



Share of CO2 emissions by sector (excluding CH4 and N2O)



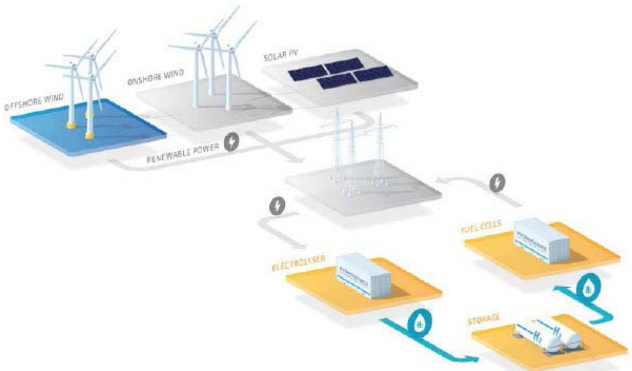
CO2 emissions from various land transport modes

- Share of transport sector in total oil products consumption increased from 49% in 2007 to 67% in 2017
- Transport sector accounted for 12% of total GHG emissions from Nepal's energy consumption in 2011.
- If CH_4 and N_2O emission are excluded, the share was 36.5% in 2011 and 45.4% in 2017.
- Major emitters are heavy commercial vehicle, passenger car, bus and minibus
- Promoting electric vehicles emphasised in Nepal's Environment-Friendly Vehicle and Transport Policy 2014, National Sustainable Transport Strategy for Nepal 2015-2040, Nationally Determined Contribution (NDC)
- NDC aims to reduce dependency on fossils in transport sector by 50% by 2050
- Electrification can improve energy supply diversification, ease increasing import, enhance energy security

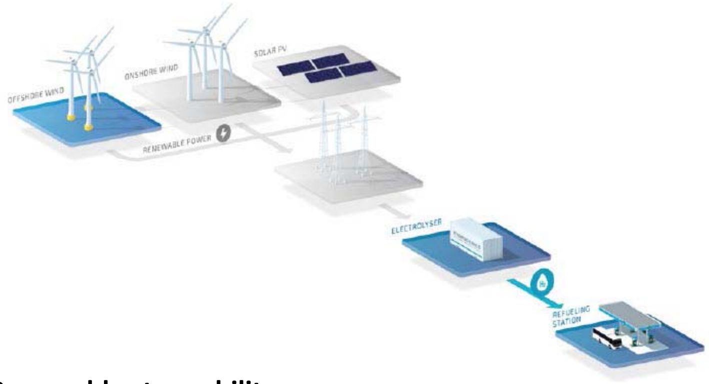
Sources: Ministry of Physical Infrastructure and Transport (2015) National Sustainable Transport Strategy for Nepal (2015-2040). Ministry of Population and Environment (2017) Nepal's GHG Inventory - For Third National Communication to the UNFCCC. Global Green Growth Institute (2018) National Action Plan for Electric Mobility: Accelerating Implementation of Nepal's Nationally Determined Contribution. IEA (2019) Data and statistics

The Prospect of Hydropower to Hydrogen in Nepal

- Situation: abundance of hydropower resources, seasonality of electricity generation, surplus during wet season and shortage during dry season
- Possible solution: store the otherwise-curtailed surplus electricity to mitigate shortage during dry season and decarbonise transport sector



Renewables to power



Renewables to mobility

- H2 produced through electrolysis using RE and stored with various modes can create short-term, seasonal, or long-term reserve for re-electrification and/or end-uses
- "Time shifting with hydrogen" avoids curtailment of variable RE and enhance supply security
- Electrolyser serve as a variable controllable load for frequency regulation and add demand-side flexibility to systems with large RE

- Fuel cell electric vehicles (FCEVs) provide a low-carbon mobility option
- Driving performance comparable to conventional vehicles.
- Advantage over batteries (weight, driving range, refuelling time) for medium o high duty cycle
- Currently costly with limited availability, but total cost of driving likely to drop quickly
- Possible cost parity with hybrid vehicles 2030-2040

Sources: Hydrogenics (2019) Renewable hydrogen solutions; IEA (2015) Technology Roadmap: Hydrogen and Fuel Cells; IEA (2017) Global Trends and Outlook for Hydrogen; IRENA (2018) Hydrogen From Renewable Power: Technology outlook for the energy transition; IRENA (2019a) Hydrogen: A renewable energy perspective; NREL (2016) Economic Assessment of Hydrogen Technologies Participating in California Electricity Markets

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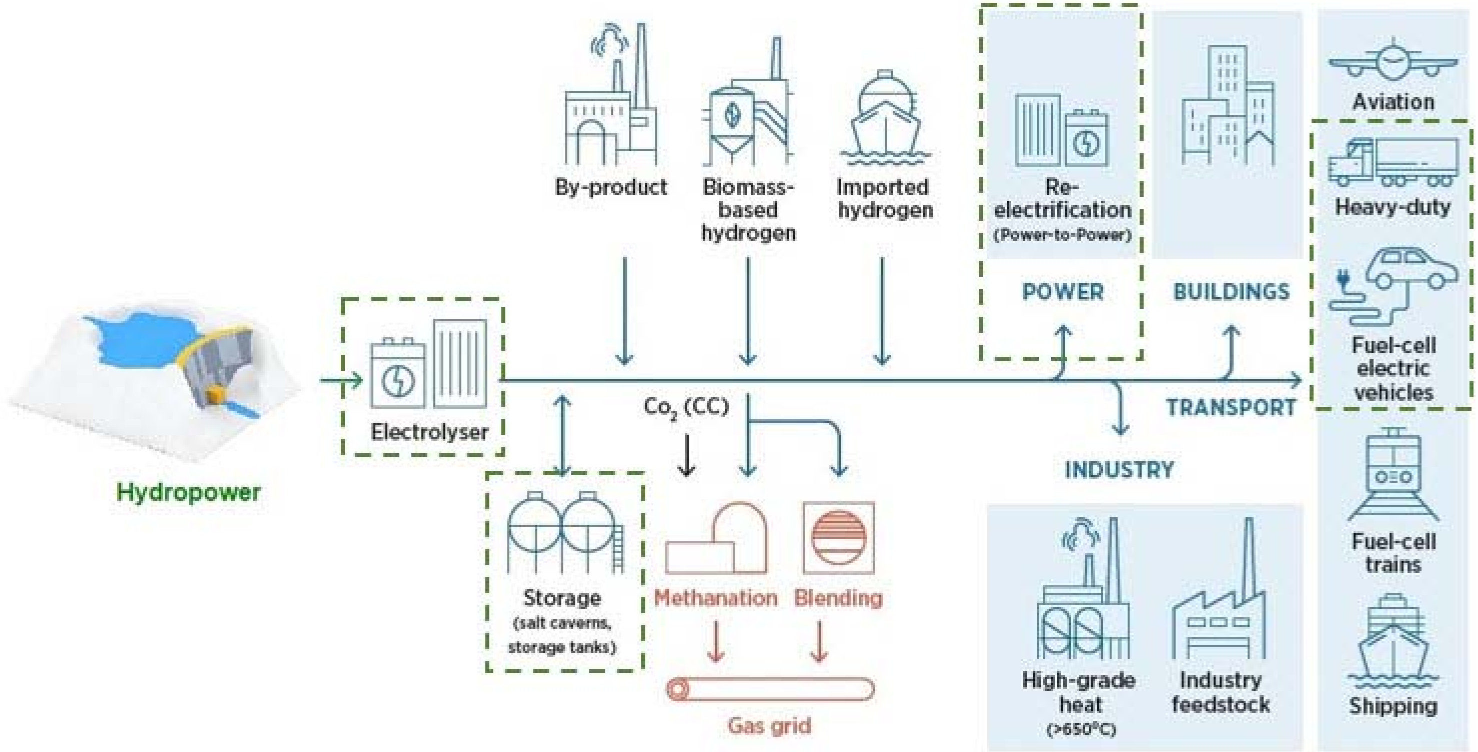
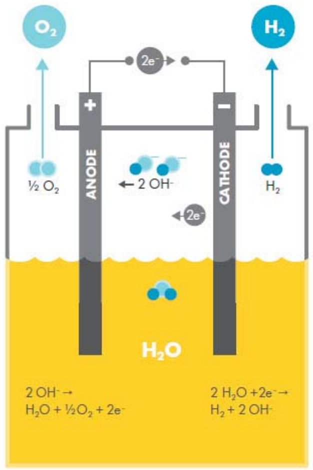


Possible hydrogen value chain in Nepal

Hydrogen production from surplus hydropower that otherwise would have been curtailed during wet season and using the stored hydrogen to generate power to meet demand during dry season ("hydropower-to-power") and/or to power FCEVs ("hydropower-to-mobility").

Sources: IRENA (2019) Innovation Landscape for a Renewable-Powered Future: Solutions to Integrate Variable Renewables; and Thyssenkrupp (2019) Hydrogen from Large-Scale Electrolysis: Efficient Solutions for Sustainable Chemicals and Energy Storage.

The Prospect of Hydropower to Hydrogen in Nepal



Principles of electrolysis

	ALK			PEM			SOEC		
	2019	2030	Long-Term	2019	2030	Long-Term	2019	2030	Long-Term
Electrical efficiency (%, LHV)	63–70	65–71	70–80	56–60	63–68	67–74	74–81	77–84	77–90
Operating pressure (bar)	1–30			30–80			1		
Operating temperature (°C)	60–80			50–80			650–1,000		
Stack lifetime (operating hours)	60,000–90,000	90,000–100,000	100,000–1,500,000	30,000–90,000	60,000–90,000	100,000–1,500,000	10,000–30,000	40,000–60,000	75,000–10,000
Load range (%, relative to nominal load)	10–110			0–160			20–100		
CAPEX (USD/kW)	500–1,400	400–850	200–700	1,100–1,800	650–1,500	200–900	2,800–5,600	800–2,800	500–1,000

Techno-economic characteristics of ALK, PEM and SOEC

- Currently, electrolysis plays a minor role in global hydrogen production, mainly as a byproduct of chlorine
- Dedicated hydrogen production via water electrolysis is much less - 0.1% of global total

- 3 main technologies: alkaline (ALK), proton exchange membrane (PEM), and solid oxide electrolysis cells (SOEC).

  - ALK: fully mature and commercial, relatively low capital costs compared to other technologies, accounting for most of the installed capacity
  - PEM: emerging technology, overcome some operational drawbacks of ALK, higher costs, shorter lifetime
  - SOEC: least mature technology, not yet commercialized, lower material costs than ALK and PEM, reverse mode as a fuel cell

Sources: IEA (2015) Technology Roadmap: Hydrogen and Fuel Cells; IEA (2019) The Future of Hydrogen: Seizing Today's Opportunities. IRENA (2018) Hydrogen From Renewable Power: Technology outlook for the energy transition; Shell (2017) Shell Hydrogen Study: Energy of the Future? Sustainable Mobility through Fuel Cells and H2.

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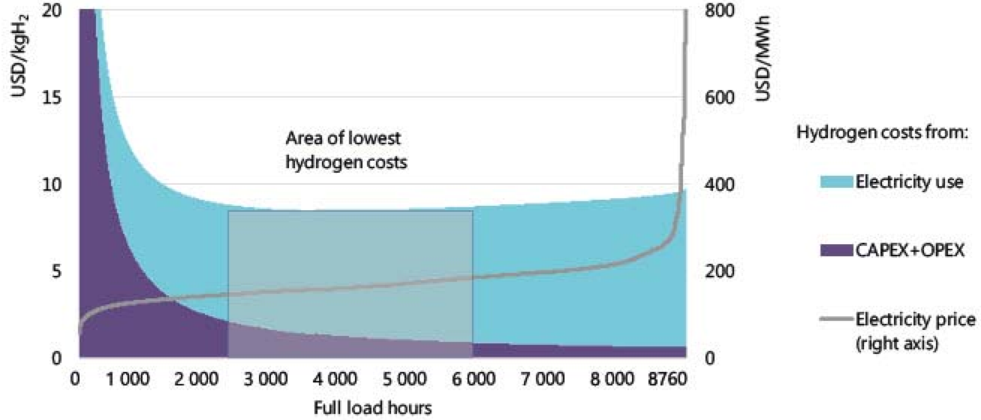
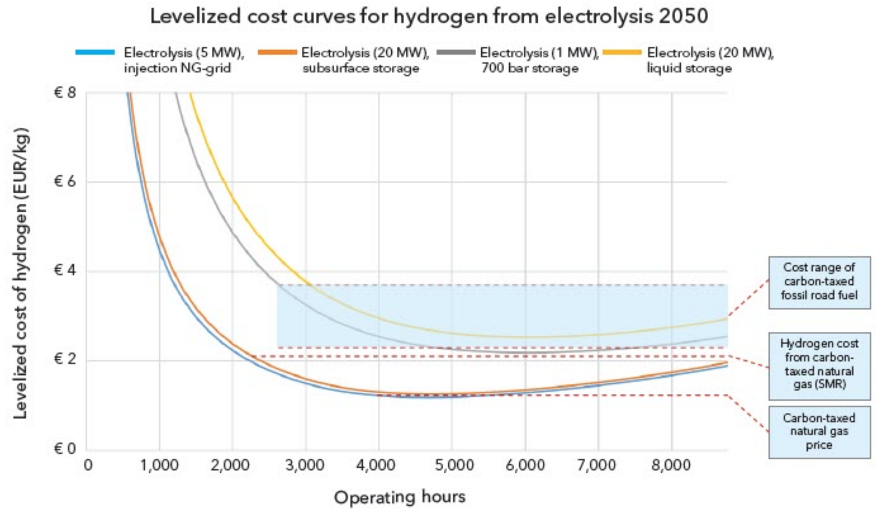


Notes: CAPEX = USD 800/kWe; efficiency (LHV) = 64%; discount rate = 8%.

Dynamic impact of electrolyser load factor and electricity cost on LCOH



LCOH of electrolysis using surplus electricity compared to alternatives in 2050

- Low utilisation of electrolyser leads to high LCOH
- Increase of load factor increases electricity cost but also decrease cost of unit production of hydrogen
- The combined effect is a nearly flat LCOH at load factor range of 40%-80%
- At high load factor, the effect of higher electricity cost during peak hours lead to higher LCOH

- With surplus renewable electricity with near-zero cost (otherwise-curtailed), the effect of CAPEX and OPEX of electrolysers is substantially dominant at low to mid load factors
- With zero-cost surplus electricity available for 3,000 hours, hydrogen production can be viable if the operating hours are above 2,100 - its LCOH is comparable with SMR

Sources: IEA (2019) The Future of Hydrogen: Seizing Today's Opportunities. DNV GL (2019) Hydrogen in the electricity value chain.

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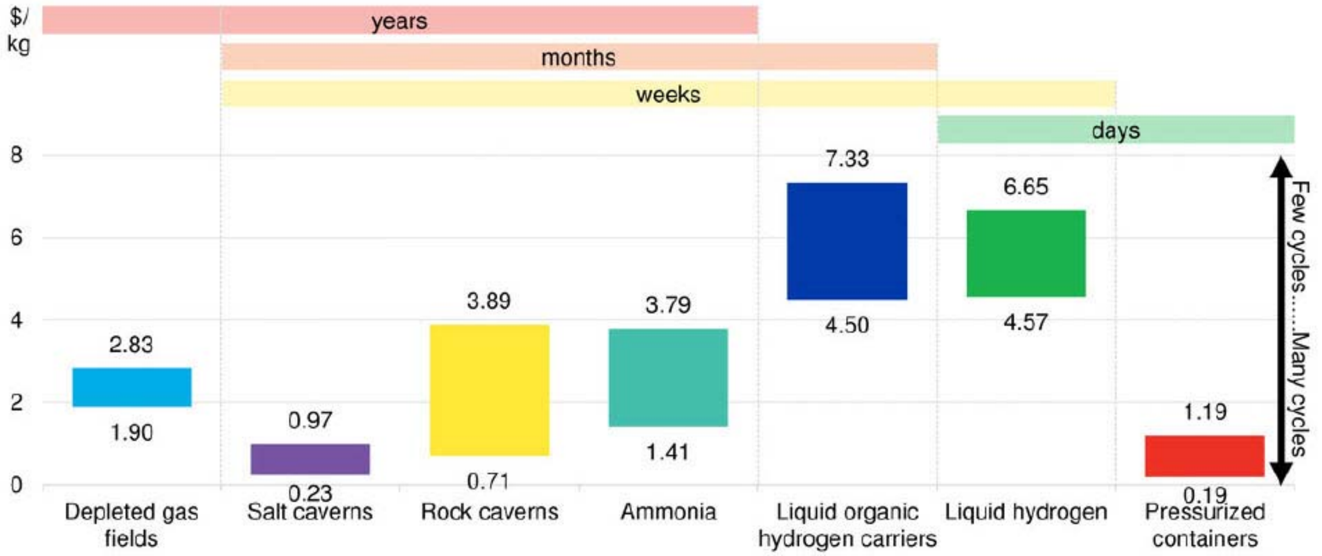

Levelised cost of hydrogen storage and typical storage duration (Source: BloombergNEF)

Storage for "hydropower-to-mobility“:

- Pressurised containers is a most common option for small-scale mobile and stationary application
- High discharge rates and efficiencies of 99%, appropriate for local stocks that need to be readily available, e.g. refuelling stations
- Levelised cost ranges from 0.09 to 1.19 USD/kgH2

Storage for "hydropower-to-power”:

- Subsurface storage of compressed gaseous hydrogen subject to geological availability
- Chemical storage through converting hydrogen to ammonia tends to be a cost competitive option
- Levelised cost of ammonia storage ranges from 1.41 to 3.79 USD/kgH2

Sources: BloombergNEF (2019) Hydrogen: The Economics of Storage - Storing clean molecules at scale.

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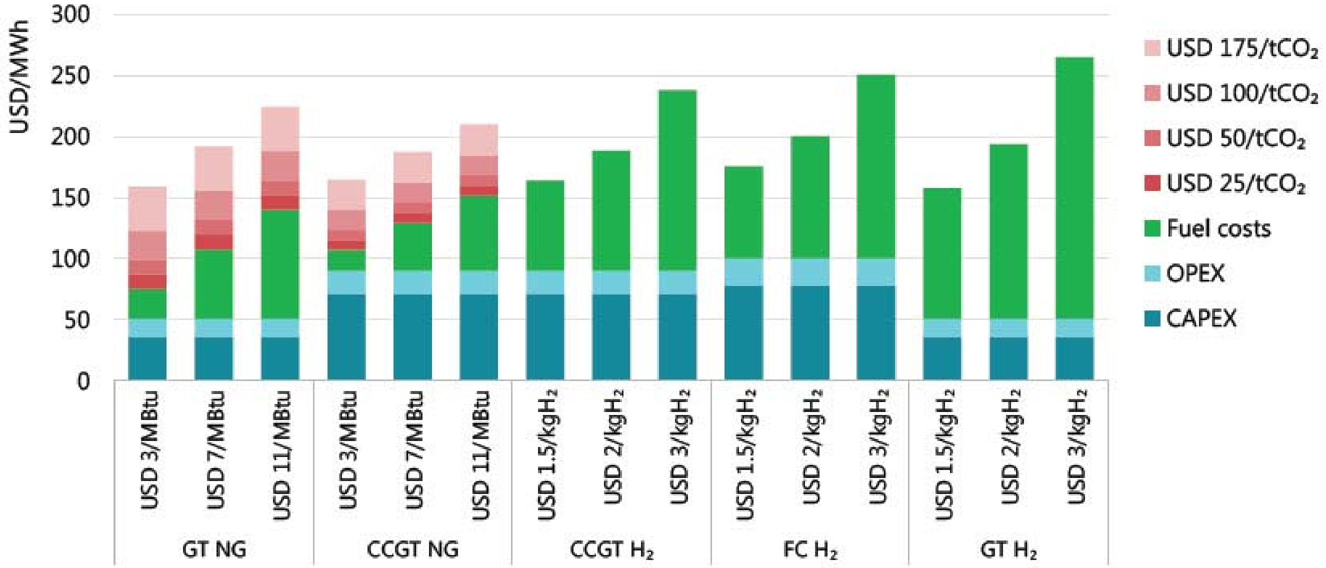

Notes: GT = gas turbine; CCGT = combined-cycle gas turbine; FC = fuel cell; NG = natural gas. CAPEX = USD 500/kW GT, USD 1 000/kW CCGT without CCS and hydrogen-fired CCGT, USD 1 000/kW FC. Gross efficiencies (LHV) = 42% GT, 61% CCGT without CCS and hydrogen-fired CCGT, 55% FC. Economic lifetime = 25 years for GT and CCGT, 20 years for FC. Capacity factor = 15%. More information on the assumptions is available at www.iea.org/hydrogen2019.

Source: IEA 2019.

Levelised electricity generation costs for load balancing from natural gas and hydrogen (Source: IEA 2019)

The competitiveness of hydrogen-fired power plants with natural gas-fired power generation for load balancing and peak load generation depends on the hydrogen price, natural gas price and the potential level of CO2 prices

Sources: IEA (2019) The Future of Hydrogen: Seizing Today's Opportunities.

The Prospect of Hydropower to Hydrogen in Nepal

Assumptions on estimating hydropower-to-X in Nepal

- Hydropower capacity targets discounted based on White Paper
  - White Paper (2018): 3 GW in 3 years, 5 GW in 5 years and 15 GW in 10 years
  - discounted: 3GW by 2025, 8GW by 2030
- A simplified approach to estimate possible surplus hydropower
  - Capacity factor with no curtailment: 60%
  - Curtailment scenarios: 20%, 30%, 40%
- Hydrogen production efficiency:
  - IEA: 52 kWh/kgH_2 on average
  - IRENA: 52 kWh/kgH_2 in 2017 and 49 kWh/kgH_2 in 2025 for ALK; 58 kWh/kgH_2 in 2017 and 52 kWh/kgH_2 in 2025 for PEM

	Variable	2025	2026	2027	2028	2029	2030
A	Total installed capacity (GW)	3	4	5	6	7	8
B	Capacity factor without curtailment (%)	60%					
C1	Curtailment - Scenario 1	20%					
C2	Curtailment - Scenario 2	30%					
C3	Curtailment - Scenario 3	40%					
D	Hydrogen production efficiency (kWh/kgH_2)	50					
E1	Hydrogen production - Scenario 1 (MtH_2)	0.063	0.084	0.105	0.126	0.147	0.168
E2	Hydrogen production - Scenario 2 (MtH_2)	0.095	0.126	0.158	0.189	0.221	0.252
E3	Hydrogen production - Scenario 3 (MtH_2)	0.126	0.168	0.210	0.252	0.294	0.336

Sources: Ale, B. B. and Bade Shrestha, S. O. (2008) 'Hydrogen energy potential of Nepal', International Journal of Hydrogen Energy; Mcbennett, B., Rose, A., Hurlbut, D., Palchak, D., Cochran, J., Mcbennett, B., Rose, A., Hurlbut, D., Palchak, D. and Cochran, J. (2019) Cross-Border Energy Trade between Nepal and India: Assessment of Trading Opportunities

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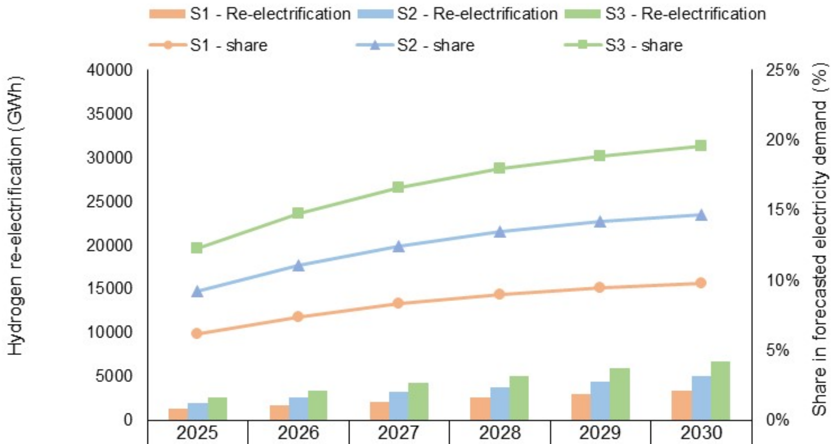

	2025	2026	2027	2028	2029	2030
S1 - Re-electrification	1261	1682	2102	2523	2943	3364
S2 - Re-electrification	1892	2523	3154	3784	4415	5046
S3 - Re-electrification	2523	3364	4205	5046	5887	6728
S1 - share	6.1%	7.4%	8.3%	9.0%	9.4%	9.8%
S2 - share	9.2%	11.1%	12.4%	13.5%	14.2%	14.7%
S3 - share	12.3%	14.7%	16.6%	17.9%	18.9%	19.6%

- The “hydropower-to-power” pathway:
  - A considerable quantity of electricity through re-electrification of stored hydrogen may be produced
  - Planned expansion of installed capacity, from 3GW by 2025 to 8GW by 2030, leads to a generally ascending trend of the ratio of re-electrification to total forecasted electricity demand of Nepal

- The “hydropower-to-mobility” pathway:
  - Fuel economies for FCEVs are 0.01kgH2/km for car and 0.08kgH2/km for bus
  - Official statistics: 154,433 cars (and jeeps and vans) and 12,617 buses in Nepal by end of FY2018
  - Electrification target: 20% of cars and buses
  - Demand for hydrogen: 8% to 17% of total available hydrogen in 2025 under scenario 1 and scenario 3

Sources: Nepal Electricity Authority (2019) Annual Report 2018/19; Hydrogenics (2019) Renewable hydrogen solutions; Department of Transport Management (2019) Registered Vehicles till fiscal year 2017/18

Further studies

- More holistic and in-depth studies to evaluate the technical feasibility and economic viability of developing a hydrogen value chain in Nepal

- Developing an enhanced understanding of current cost levels and future cost-reduction potential of different types of electrolysers

- Estimating potential quantity of the otherwise-curtailed surplus hydropower during wet season that may potentially be utilized for electrolysis in the context of Nepal

- Developing an enhanced understanding of the energy system benefits of hydrogen production from electrolysis, in particular:
    - economics of seasonal storage of hydrogen for re-electrification during dry season
    - electrolysers providing ancillary services such as adding demand-side flexibility to power system

- Taking stock of existing vehicles, e.g. registration number, age distribution, fuel economy and annual driving distance, forecasting future transport demand, updating the estimate of hydrogen value chain potential in transport sector

- Identifying the opportunities and assessing potentials of other pathways potentially relevant to Nepal’s economy, e.g. “hydropower-to-fuel” and “hydropower-to-industry”

Thank You

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