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Evaluating the Economic Potential for Green Ammonia Production in Australia

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ABSTRACT

Green ammonia has received much interest in Australia as a key carrier for international exports. Here we present a model to evaluate the impact of temporal operational flexibility of electrolysers and the Haber-Bosch process on the optimal design of the ammonia production system. We show green ammonia can be cost-competitive if the system is well-optimised to cope with renewables variability.

Keywords: renewable/green hydrogen, ammonia, energy systems for power generation, energy storage

NONMENCLATURE

Abbreviations	
HB	Haber-Bosch process
ASU	Air Separation Unit
BESS	Battery energy storage system

1. INTRODUCTION

In November 2019, the Australian federal government launched its National Hydrogen Strategy [1] which aims to position Australia as a major player in the global hydrogen market by 2030. Several other studies have also recognized Australia's potential competitive advantage in the emerging hydrogen economy (e.g. [2,6-8]). For long-distance delivery to international markets, hydrogen needs to be compressed, liquefied, or converted into an alternative energy carrier. Of the potential energy carriers available, ammonia is perhaps the most promising: shipping ammonia is commonplace today as it is one of the world's most widely used chemicals, most often as a feedstock for fertilizer production. The Asian Renewable Energy Hub proposed a 26 GW renewable generation system comprising wind and solar PV to supply 10 million tons of green ammonia per annum to the international market [9].

Although there has been much interest in green ammonia as a key carrier for international exports in Australia, to our best knowledge, there is no detailed temporal and spatial economic potential study available for the Australian context. To bridge this gap, we have developed a Mixed Integer Programming (MIP) model called "MUREIL-Ammonia". The model has the ability to evaluate the impact of temporal operational flexibility of electrolysers and the Haber-Bosch (HB) process with the support of various storage options on the optimal design of the ammonia production system using hourly wind and solar PV data for the whole of Australia.

2. MODEL DESCRIPTION AND INPUT ASSUMPTIONS

2.1 Schematic of the green ammonia production system

A schematic of the green ammonia production model is shown in Fig. 1.

The model assumes that electricity for powering PEM electrolysers, the Air Separation Unit (ASU) and the HB process for ammonia production can be supplied by the onsite wind, solar PV or a hybrid system. This system may be supported by a 2, 4 or 6-hour battery energy storage system (BESS) or 8-hour pumped hydrogen energy storage (PHES), as well as a hydrogen buffer tank. Cost-optimal designs are calculated among these generation and storage options to produce ammonia at an average output of 100 tons a day. The model also considers the possibility that electricity can also come from the grid directly or from the fuel cell system (which

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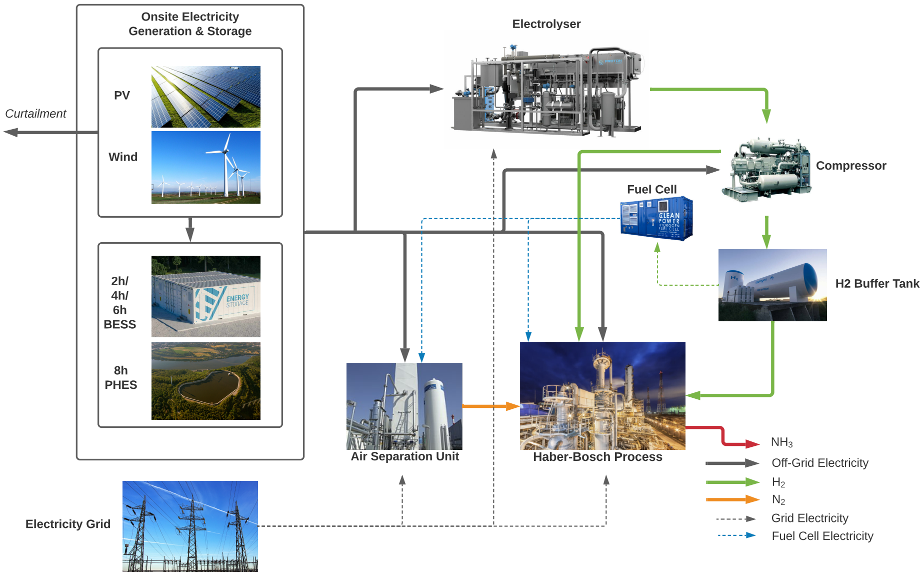


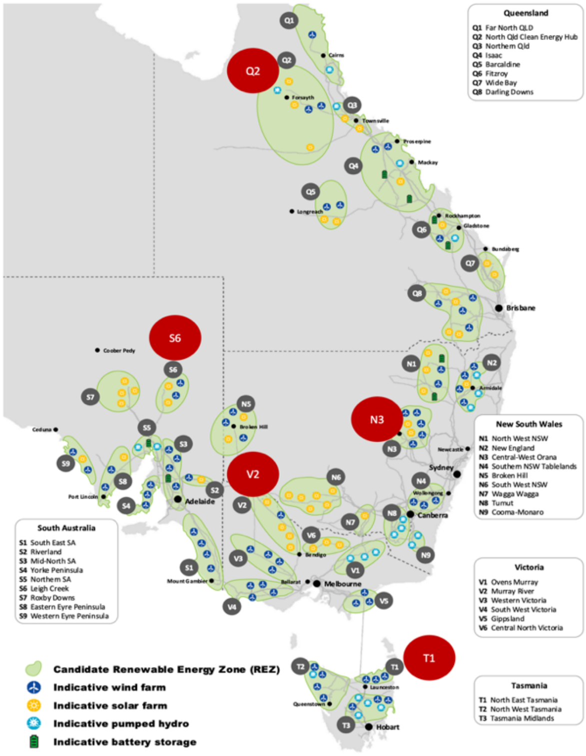
Fig. 1. Schematic of the green ammonia production system (pictures are for indicative purposes only)

consumes hydrogen stored in the hydrogen tank) to power the ASU-HB plant.

Optimisation results are presented for the off-grid system for five Renewable Energy Zones (REZs, i.e. Q2 North Qld Clean Energy Hub, N3 Central-West Orana, V2 Murray River, S6 Central North Victoria and T1 North East Tasmania), shown in Figure 2. Results of the grid-connected system will also be given in the final presentation. The average annual wind and solar capacity factors in 2014, which indicate renewable resources quality for these selected locations are shown in Figure 2; input weather data are taken from the AEMO ISP [3]. The WACC is assumed to be 5%. Most of the facilities are assumed to have an economic life of 25 years, whereas PEM stacks lifetime is assumed to be 80000 hours of operation. Other key technology CAPEX are mostly taken from the AEMO ISP 2022 [3] Inputs and Assumptions Workbook, and are summarised in Table I.

	2022 CAPEX ($/kW)	2030 CAPEX ($/kW)
PEM (70% eff.)	1796	700
Wind	1991	1848
Solar PV	1058	796
BESS 2h	902	548
BESS 4h	1377	759
BESS 6h	1800	1000
NH3_HB_plant	828	662
H2 tank	$20/kWh	$20/kWh

Table I. Key CAPEX assuptions[3,4]



	Q2	N3	V2	S6	T1
Wind	51.8%	40.3%	34.0%	44.5%	44.5%
PV	29.2%	28.1%	29.8%	31.8%	25.8%

Fig. 2. The five selected REZs [3] assessed for onsite ammonia production

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2.2 System Flexibility

A standard HB synthesis loop normally operates at high pressure and high temperature. Its operation is less flexible than PEM electrolysers, and HB synthesis loops are usually run on a constant power source [4]. An intermediate buffering system is, therefore, required to smooth out fluctuations in hydrogen production. We modelled pressurised gaseous steel tanks coupled with a compressor for this purpose. We also consider flexible HB plants (with 40% minimum partial load and 20% hourly ramp rates) to best reflect the recent development [5]. A more advanced HB (with 20% minimum partial load) is also studied in the 2030 scenario. This level of flexibility could be achieved by varying the H2:N2 ratio [4]. With these operation constraints, optimal sizing of the onsite wind, solar PV, electricity storage, hydrogen buffer and the HB system are simultaneously determined by the MIP model to meet the production goal of an average of 100t ammonia per day.

RESULTS AND DISCUSSION

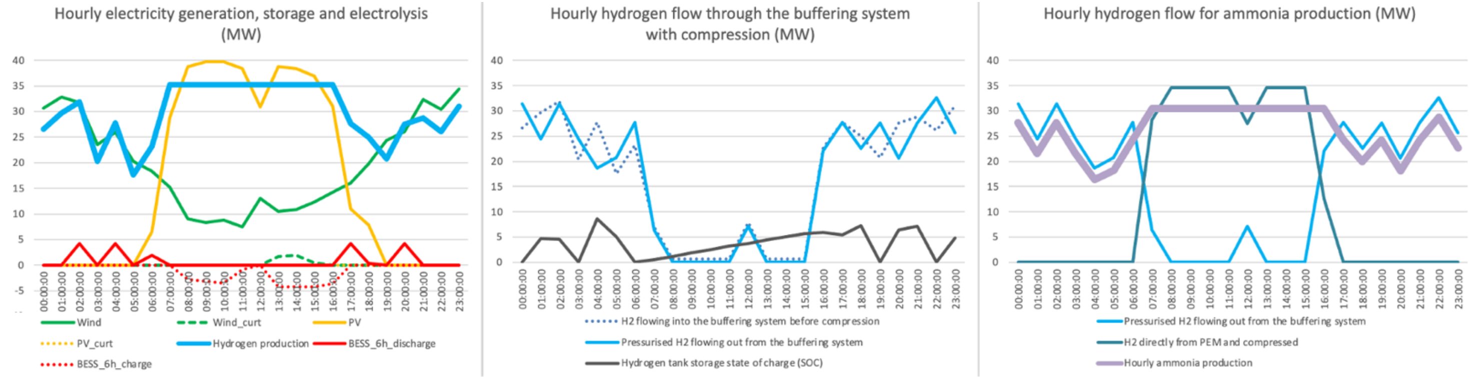

Fig.3 Optimised capacity and hourly operation of the onsite ammonia production system in South Australia for the combined solar PV, wind and BESS scenario

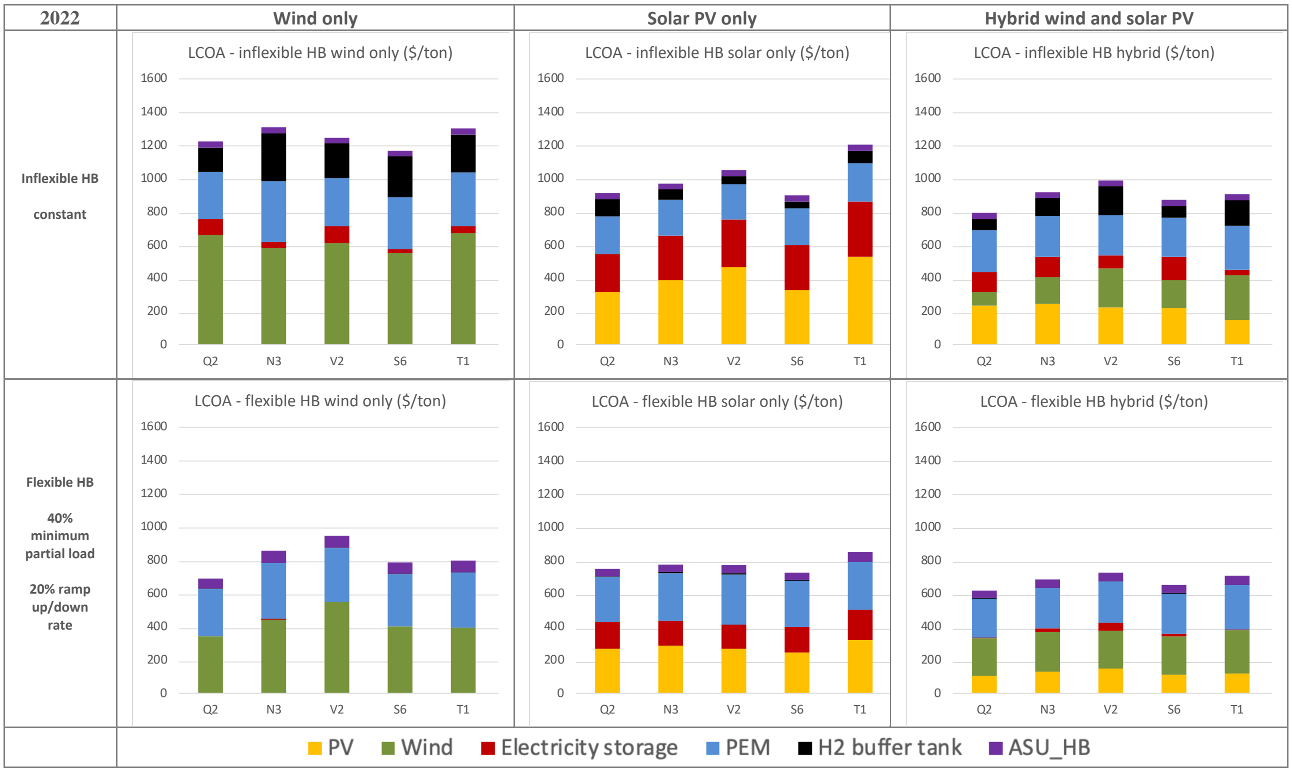

Fig. 4 Levelized costs of Ammonia (LCOA) using 2022 CAPEX assumptions for scenarios with wind only, solar PV only and a hybrid wind and solar system

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Here we compare the results from (i) wind only, (ii) solar PV only and (iii) hybrid wind-solar systems with flexible and inflexible HB processes.

Figure 3 shows the modelled hourly (on 29 January) interplay between the optimally sized onsite hybrid RE system, BESS, hydrogen buffer and the flexible HB plant at Leigh Creek (REZ S6) in South Australia.

From Figure 3, to produce an average of 100t green ammonia, the optimal onsite production system would comprise 44 MW wind, 45 MW solar PV, 51 MW PEM and 14 MWh hydrogen tank, 4.3 MW 6h BESS. The optimal curtailment rate of wind is around 15%. The LCOA of the system with the 2022 CAPEX assumptions are around $650 per ton.

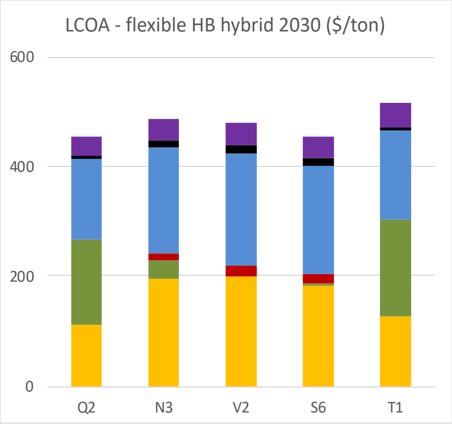

Fig. 5 LCOA with 2030 CAPEX

The LCOA for inflexible and flexible HB process with different generation options (i.e. wind only, solar only and the hybrid system) are presented in Figure 4. In general, the optimisation results indicate:

1. All the states can produce cost completive green ammonia if the system is flexible and optimally designed.
2. Flexibility is key to facilitate large-scale ammonia production; the use of h2 buffer tanks is very limited with flexible HB in all the RE electricity supply configurations.
3. Systems with inflexible HB are significantly more expensive due to rising RE curtailment and storage requirement; a system with solely solar PV needs BESS to store electricity to power the ACU-HB process at night, while a large H2 buffer tank is required for the wind-only system.
4. A well-mixed wind and solar PV could significantly improve electrolysis and HB capacity factor and reduce the need for battery and hydrogen buffer storage
5. Electricity generation and storage systems constitute the major component in the LCOA. With flexible HB, wind and solar PV alone can produce cost-completive green hydrogen. A well-mixed wind and solar can further reduce the LCOA.
6. The LCOA of the optimal hybrid wind-solar system in the 2030 scenario is shown in Figure 5. Ammonia in 2030 can match the costs of fossil fuel ammonia with a carbon price of $100/ton given the production of 1 tNH3 from natural gas currently involves emissions of 2.3 tCO2.

Future work will consider grid-connected ammonia and operation flexibility of alkaline electrolysers. Fuel-switching carbon prices, international shipping costs and domestic geospatial infrastructure mapping for ammonia delivery will also be included.

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