Electronic Supplementary Material (ESI) for Energy & Environmental Science.

1 Supplementary information

Supplementary table 1 – Model parameters

Parameter	Specification
Battery round trip efficiency	90%
Electrolyser efficiency	55 kWh kg^{-1} H_2
Electrolyser turndown	95%
Hydrogen production	36,500 tonnes H_2 yr^{-1}
Electrolyser capacities tested	400 to 900 MW at 20 MW intervals

Supplementary table 2 - Production model decision rules

Condition	Result		Notes
	Solar-battery scenario	Solar-grid scenario	
IF SOLAR > ELECTROLYSER CAPACITY	Send surplus to battery	Export surplus to grid	Surplus solar fed to battery or grid. Electrolyser runs at full capacity.
ELSE IF SOLAR > MIN. ELECTROLYSER CAPACITY	No battery flows	No grid flows	Electrolyser load follows solar.
ELSE IF SOLAR < MIN. ELECTROLYSER CAPACITY	Discharge battery if sufficiently charged	Import difference from grid	Electrolyser runs at min. load. Battery or grid supplies difference. If battery not charged, register as not-run.

Supplementary table 3 – Solar farm specifications

Parameter	Specification
Solar modules	Tier 1, 340 watt
Capacity	Solar-battery baseline 1,010 MW-dc Solar-grid baseline 940 MW-dc
Tracking	single axis, north-south orientation of rotating axis
Solar cell type	multi-crystalline silicon
Panel efficiency	16.8% [63]
Component lifetime	solar modules 30 years inverters 10 years structure 60 years
Site area	1,890 hectares based on 20 m^2 kW-dc^{-1}, based on Australian sites, e.g. Tailem Bend 16 m^2 kW^{-1}, Limondale 26 m^2 kW^{-1}
Solar module shipping	Volume-based estimate for 340 watt panel, 1956×992×40 mm, 572 panels per 40’ HQ container [104]
Solar balance-of-plant shipping	Mass-based estimate assuming 20 tonne load per 40’ HQ unit.

Supplementary table 4 – Battery specifications

Parameter	Specification
Battery chemistry	Li-ion, nickel manganese cobalt (NMC)
Round trip efficiency	assume 90% based on reported values of 85-95% [70]
Lifetime	10 years
Maximum depth-of-discharge	80%
Design storage capacity	scaled by 1.2 to account for capacity fade of 20% [70]
Design power capacity	set to 4 hour charge or discharge (i.e. 400 MWh gives 100 MW)
Battery cooling system	100 kW cooling capacity per MW [69], assume chiller COP of 3
Site area	45 m^2 MWh^{-1}, estimated from Hornsdale South Australia battery 194 MWh using online mapping.
Battery mass	9.5 t MWh^{-1} [74] of which 60% of the mass is due to battery cells.
Battery shipping	Mass-based estimate assuming 20 tonne load per 40' HQ ISO container, equal to 2.1 MWh per container.

Supplementary table 5 – Electrolyser specifications

Parameter	Specification
Type	Alkaline electrolyser (AE)
Electrical system power per stack	3.9 MW-e
Hydrogen output per stack	760 Nm^3 hr^{-1} (68 kg hr^{-1})
Electrolyser efficiency	55 kWh kg^{-1} H_2 with respect to AC power input, including pumps, chillers, and AC to DC rectifier losses to power the electrolyser stack
Electrolyte	25% potassium hydroxide (KOH) solution. 720 kg of 90% KOH is required per MW of capacity
Cells per stack	139
Cell diameter	1.6 metres
Operating pressure	30 bar
Hydrogen output temperature	40°C, dry hydrogen
Potassium hydroxide (90%) mass and lifetime	2,800 kg, replaced after 10 years
Site area – electrolyser building	27,500 m^2 based on 50 m^2 MW^{-1} for 550 MW
Site area – transformer & rectifier	5,500 m^2 based on 10 m^2 MW^{-1} for 550 MW
Electrolyser component shipping	Mass-based estimate assuming 20 tonne load per 40' HQ unit.

Supplementary table 6 – Pressure vessel specifications

Parameter	Specification
Type	Steel, cylindrical, ellipsoidal heads
Steel grade	304 stainless [81]
Pressure vessel dimensions	2.4 diameter x 20 metres long, 100 mm wall thickness
Pressure vessel mass	126 tonnes
Pressure vessel capacity	Each vessel 82 m^3, 527 kg H_2 @ 80 bar, 298 K
Number of vessels	380 vessels to store 200 tonnes H_2
Site area	30,000 m^2, based on 0.15 $m^2 kg^{-1}$ H_2, estimated from Energiepark Mainz plant in Germany,

Supplementary table 7 – Electrical transmission specifications

Parameter	Specification
Type	Overhead
Conductor material	Aluminium alloy, galvanised steel conductors
Voltage	275/330 kV AC, 3 phase
Distance	20 km baseline, 100/300 km sensitivity
Easement width	40 metres

Supplementary table 8 – Transmission distance sensitivity

		Transmission distance		
	units	**20 km**	**100 km**	**300 km**
Voltage	kV AC	275	275	330
Phases		3	3	3
Real power at solar farm	MW	1,010	1,032	1,054
Power factor		0.9	0.9	0.9
Maximum current	amps	2,356	2,407	2,049
Transformer losses (x 2)	%	2	2	2
Line losses	%	2	4	6
Real power at destination	MW	951	951	951
Mass of aluminium in conductors	tonnes	89	1,085	4,601
Mass of steel in conductors	tonnes	138	1,680	7,126

Supplementary table 9 – Water system specifications

Parameter	Specification
Type	Reverse osmosis
Feedwater demand	329 ML yr^{-1} based on 9 litres per kg H_2
Plant efficiency	3.8 kWh kL^{-1} [105]
Seawater extraction and brine discharge location	Hamersley Channel, off the coast of Karratha
Brine discharge	Hamersley Channel, off the coast of Karratha
Dried sludge	89 kg per day, 10wt% solids [105]
Site area	4,000 m^2 based on 0.01 m^2 kL^{-1} yr^{-1}

Supplementary table 10 – Electricity emission factors

Region	Electricity GHG emission intensity (g CO_2-e kWh^{-1})	References
China, national average	840	Li et al. [52]
World average	520	Ang & Su [53]
World average, projected in 2030 for IEA Sustainable Development Scenario	237	IEA [54]
Pilbara grid, North West Interconnected System (NWIS) average	620	Australian Government [56]

Supplementary table 11 – Power density for solar farm and electrolyser system

System component	**Solar panel plus frame and hardware**	**Electrolyser (AE)**
Energy conversion device	Solar module, support frame and hardware	Electrolyser stack
Mass of device [M]	20 kg solar module plus 20 kg support frame and hardware	32,600 kg
Maximum power flow per device (i.e. rated capacity) [P_r]	0.34 kW	3,900 kW
Average power flow over full year [P_a = P_r x capacity factor]	0.08 kW	1,170 kW
Average specific power [P_a x 1000 / M]	2.0 watts kg^{-1}	35.9 watts kg^{-1}
Average annual power flow across device per unit area	0.03 to 0.06 kW m^{-2} module in a plane normal to solar cell	6 to 20 kW m^{-2} in a plane normal to electrolyser cell
Site area for entire system	20.2 million m^2 for 1,010 MW solar farm	33,000 m^2 for electrolyser and rectifier building (550 MW)