Sodium borohydride for solid-state green hydrogen export

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FUTURE ENERGY EXPORTS Cooperative Research Centre

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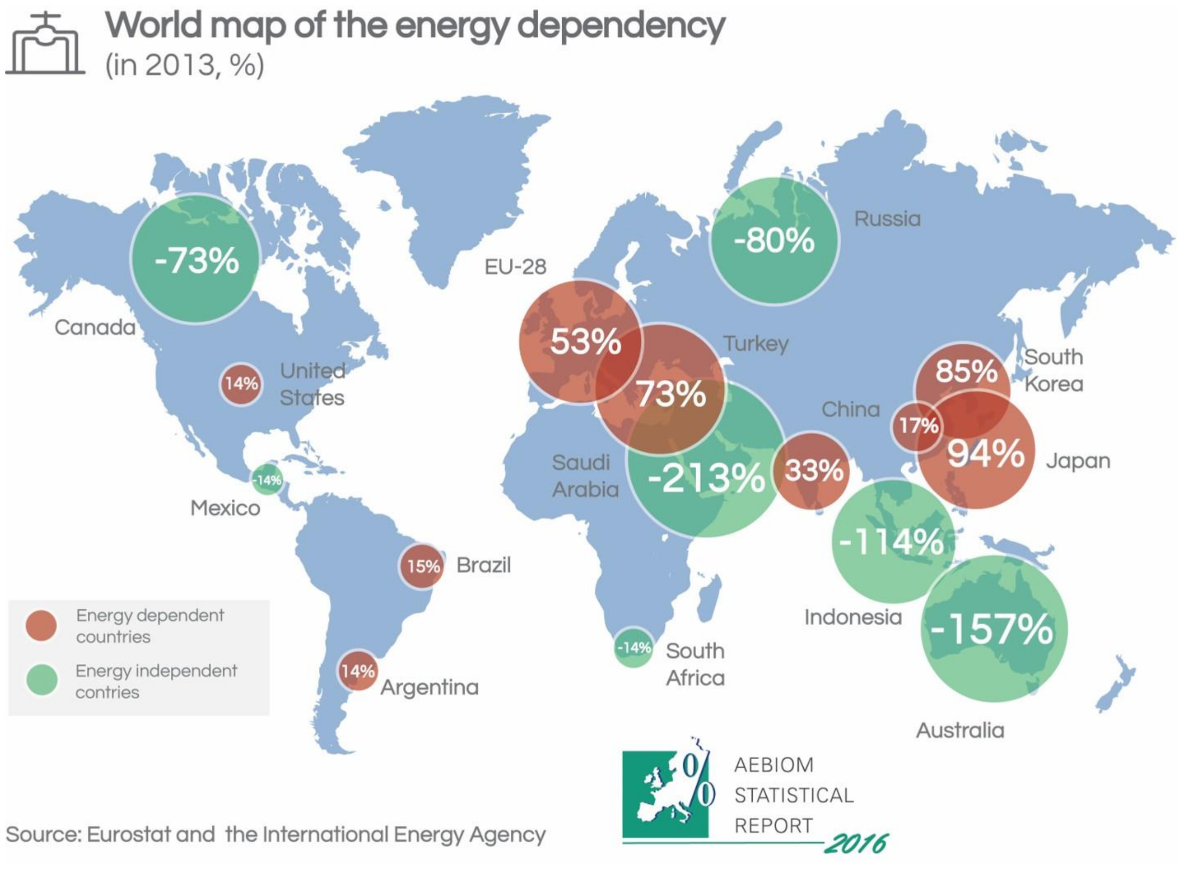
Kotai Energy

HSRG Hydrogen Storage Research Group

Curtin University

Hydrogen Energy Export



Why export hydrogen?

- Net zero by 2050
- Growing hydrogen economy
- Meet world energy demands

Global hydrogen demand from Australia:

- 2 - 9 million tonnes by 2030
- 20 – 230 million tonnes by 2050

Hydrogen Energy Storage

How is hydrogen stored?

- High pressures
- Cryogenic temperatures
- Physisorption
- Liquid organic hydrogen carriers
- Chemical or metal hydrides

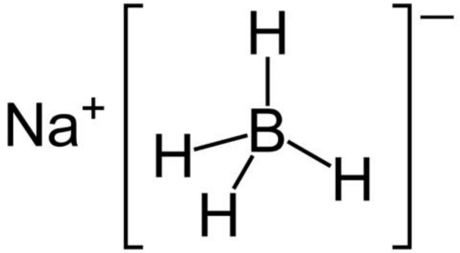
Table 1: Comparison of hydrogen export materials

Hydrogen carrier	**Export temperature (°C)**	**Export pressure (bar)**	**Volumetric density of H_2 (kg/m^3)**
H_2 (gas)	20	700	39.7
H_2 (liquid)	-253	1	71.1
NH_3 (liquid)	20	10	107
LOHC - methylcyclohexane (liquid)	20	1	47.4
$NaBH_4$ (solid)	20	N/A	69 - 137

Ibrahim, A., et al., *Chemical compression and transport of hydrogen using sodium borohydride.* Sustainable Energy Fuels, 2023. 7, p. 1196-1203.

Sodium borohydride ($NaBH_4$)

- Metal hydride
- White powder, solid state RTP
- High hydrogen content **≈ 10.7 wt%**
- Easy and safe to transport on regular ships
- No heat or energy input upon arrival at export destination
- Controlled hydrogen generation at RTP using metal catalyst
  - Effectively 21.4wt% H_2 by reaction with water



Transport:
115 kg H_2/m^3 $NaBH_4$

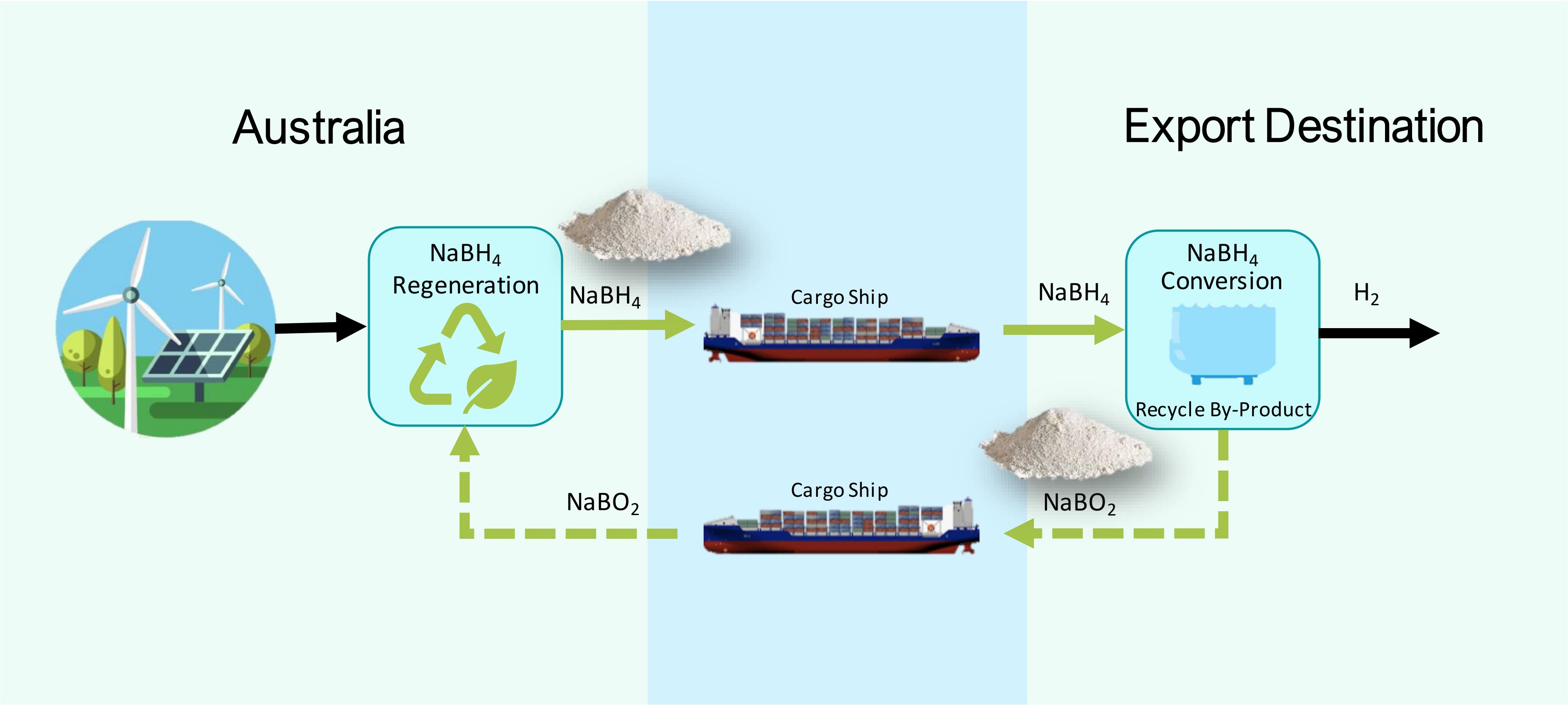
Actual output:
230 kg H_2/m^3 $NaBH_4$

$$NaBH_4 + 4H_2O \rightarrow NaBO_2.2H_2O + 4H_2$$

50%   50%

Half the hydrogen comes from
water at export destination!

$NaBH_4$ Hydrogen Export Cycle



How is $NaBH_4$ Regenerated?

Table 2: Comparison of existing $NaBH_4$ chemical regeneration methods

	Thermochemical [1-3]	Mechanochemical [4-7]	Electrochemical [8-12]
Temperature	500 – 650 °C	Ambient	Ambient
Pressure/ atmosphere	3-7 MPa H_2	1 atm Ar or 3-7 MPa H_2	N/A
Reductant or working electrode	Metal (Mg) or metal hydride (MgH_2)		Transition metals (Pd/Pt/Au/Ag/Zn)
$NaBO_2$ form	Dehydrated	Hydrated or dehydrated	Hydrated
Time	1-2 h	1 – 36h	0.5 - 48h
$NaBH_4$ yield	Up to 98%	60-90%	Up to 17%

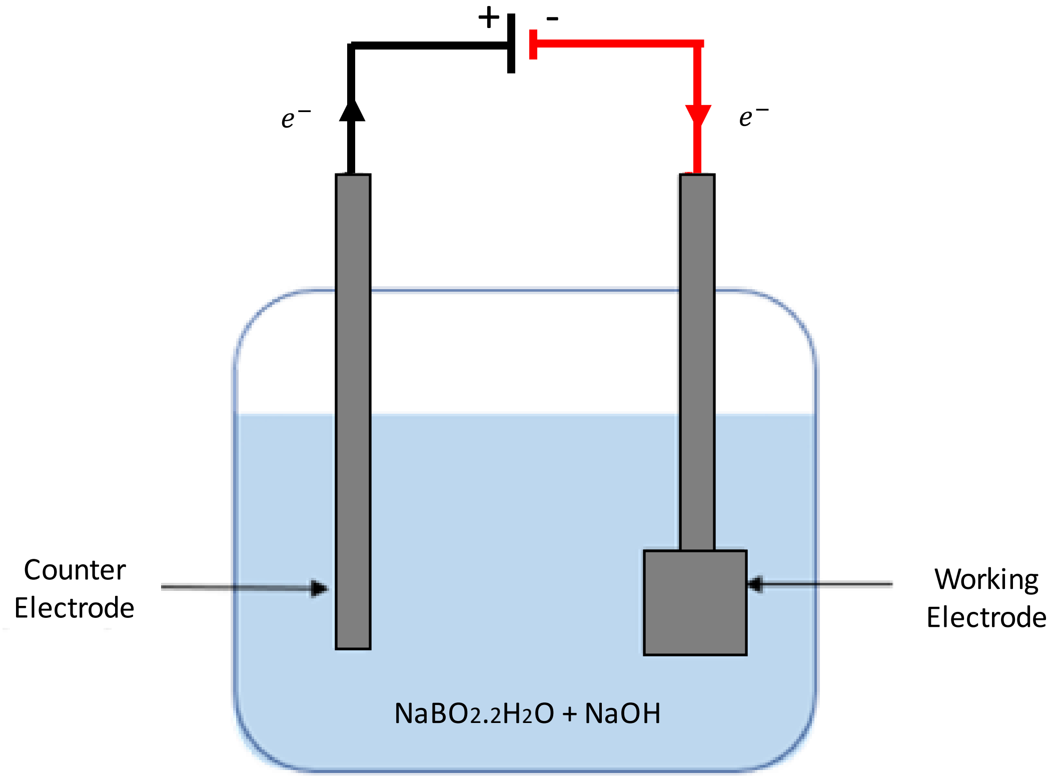
Current issues:

- $US 50/kg $NaBH_4$
- High energy or low yield
- Not commercially sustainable

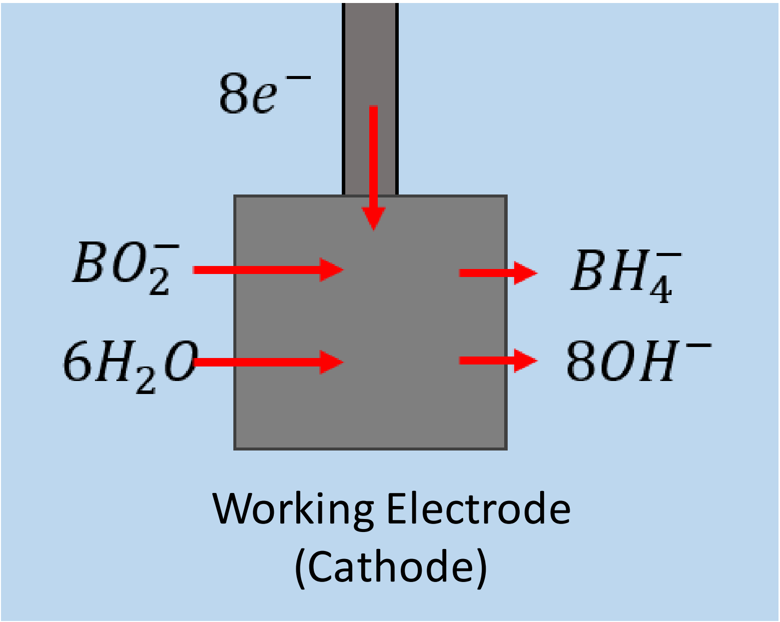
Project approach:

- Electrochemical Regeneration
- Hydrated by-product $NaBO_2.2H_2O$
- Electrodes reused
- Only input electricity

Electrochemical cell set up



- Applying a potential to regenerate $NaBH_4$ from $NaBO_2.H_2O$
  - Parameters include: voltage, time, electrolyte, electrodes, cell configuration
  - Enhance electron efficiency for desired reaction



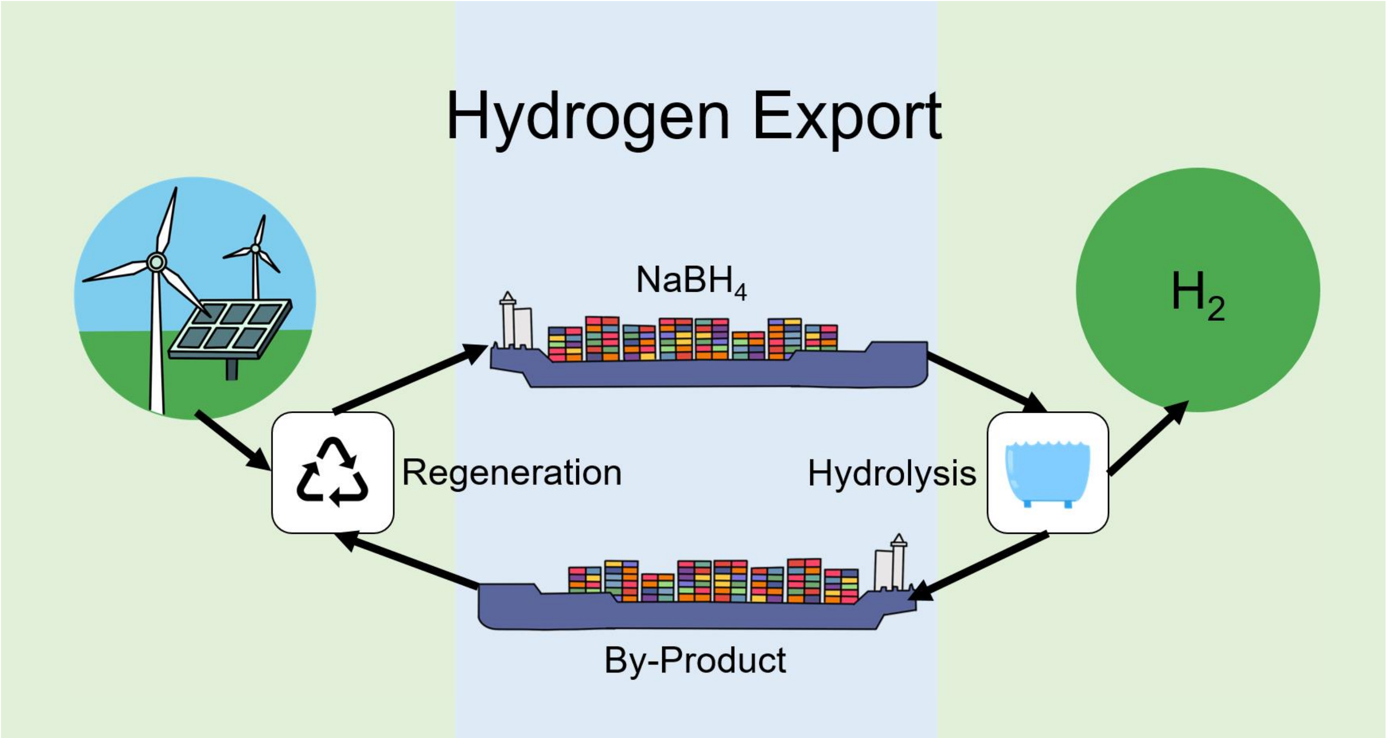
Oxidation:

$8OH^- \rightarrow 4H_2O + 2O_2 + 8e^-$

Reduction:

$BO_2^- + 6H_2O + 8e^- \rightarrow BH_4^- + 8OH^-$

Conclusion



- New hydrogen export material
- Reducing cost of regeneration
- Enhance electrochemical efficiency for desired regeneration reaction
- Powered by renewable energy
- Closed loop solid-state green hydrogen export cycle
- Potential cost as low as $USD 4/kg H_2

(Based on electricity cost of $0.0685 USD/kWh)

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