



Production of Sodium Borohydride in Iceland

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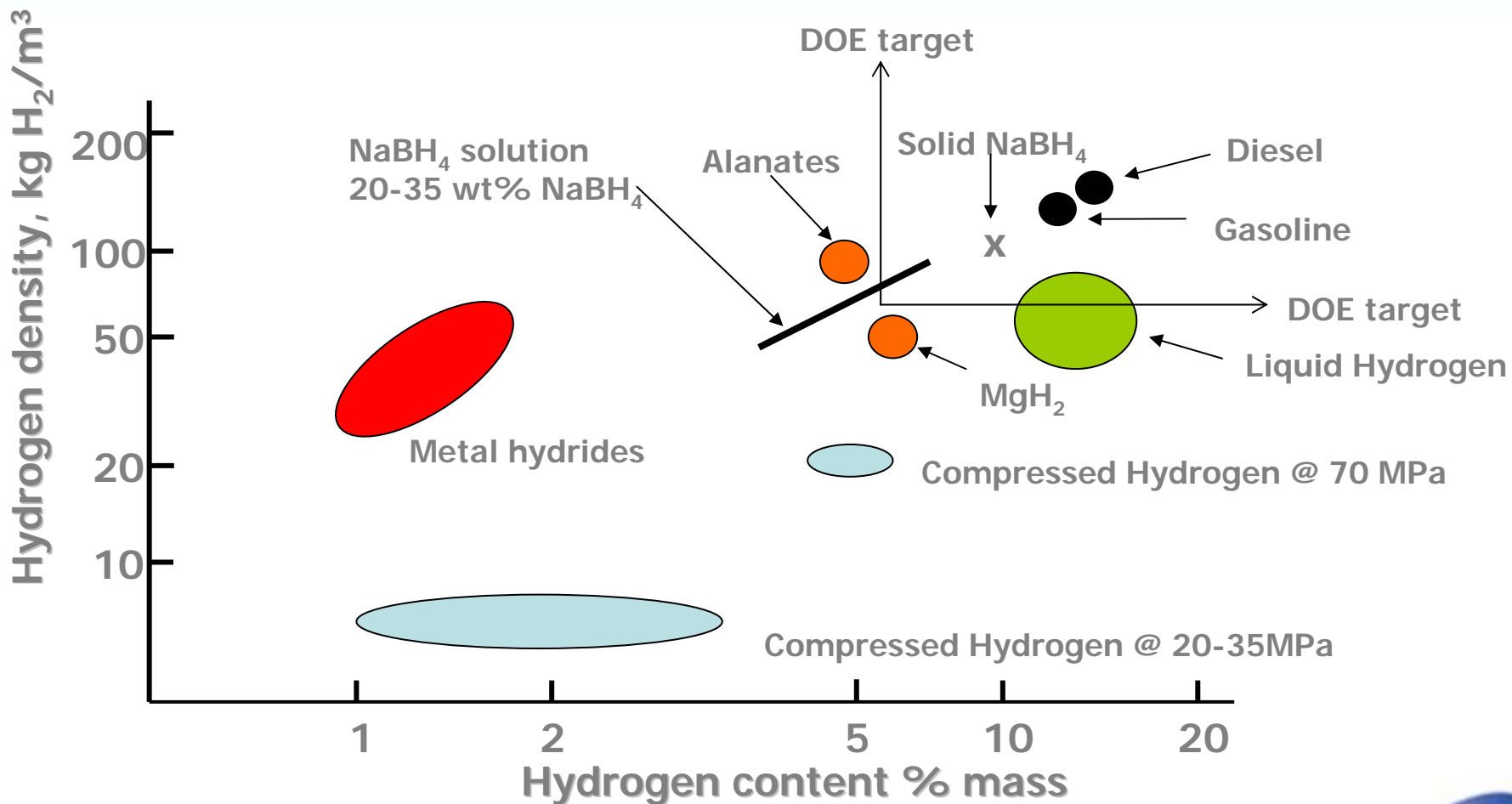
Outline

1. Overview
2. Sodium borohydride as a hydrogen fuel
3. The energy situation in Iceland
4. Initial feasibility analysis
5. Proposal for technical validation and IPHE project



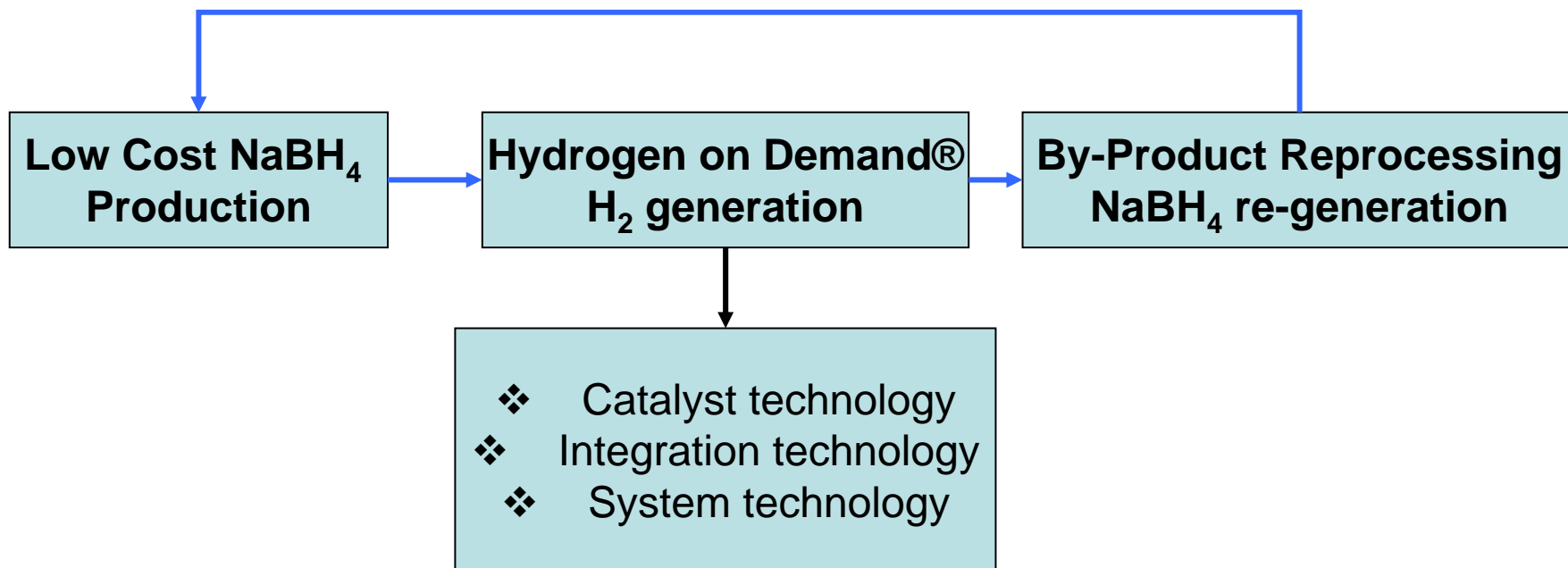


Hydrogen Storage Alternatives





NaBH₄ Technology Has Several Key Components



Millennium Cell is actively working in all these areas

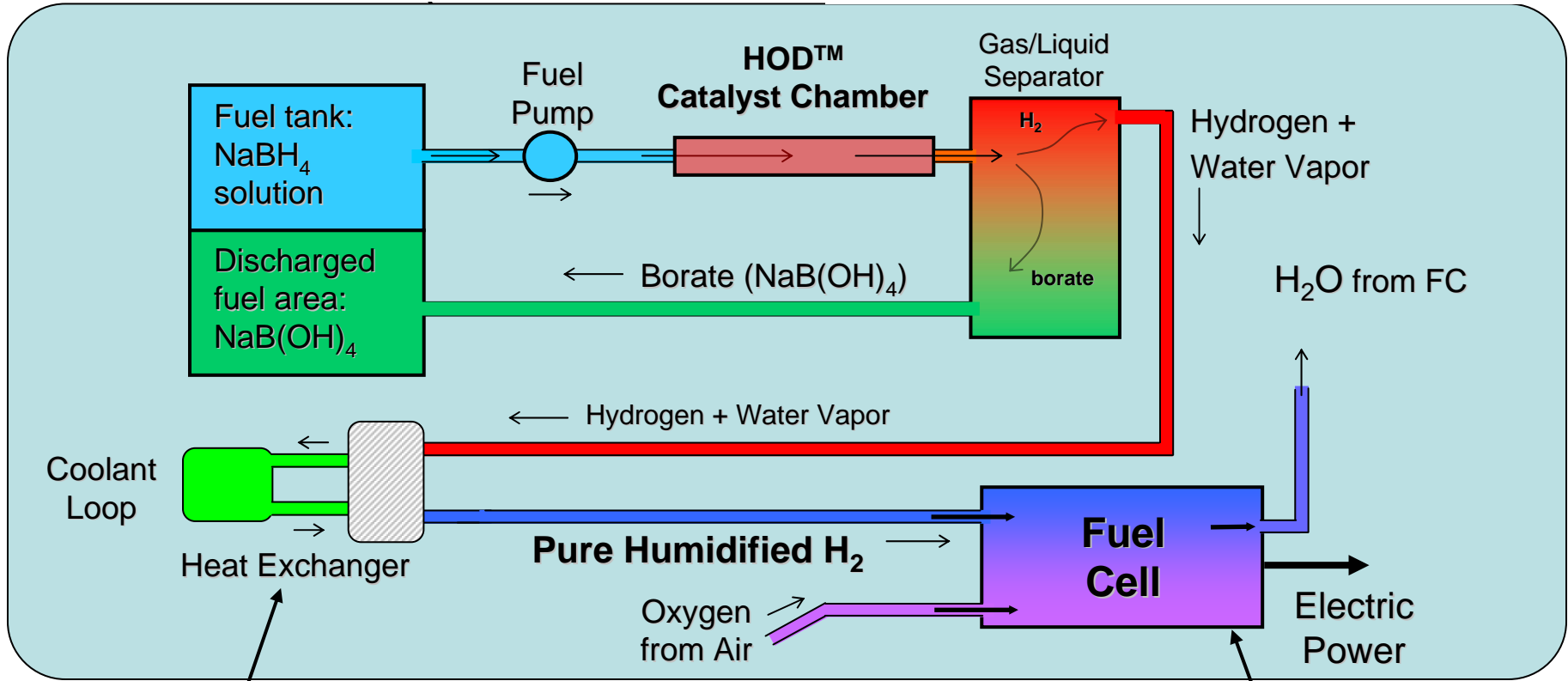


How Hydrogen on Demand® Works



1. Borohydride Fuel is moved from a tank through a chamber containing MCEL's proprietary catalyst.

2. The fuel is converted into pure hydrogen, water vapor, and borate (NaB(OH)_4).



3. The temperature and humidity of the hydrogen stream are adjustable.

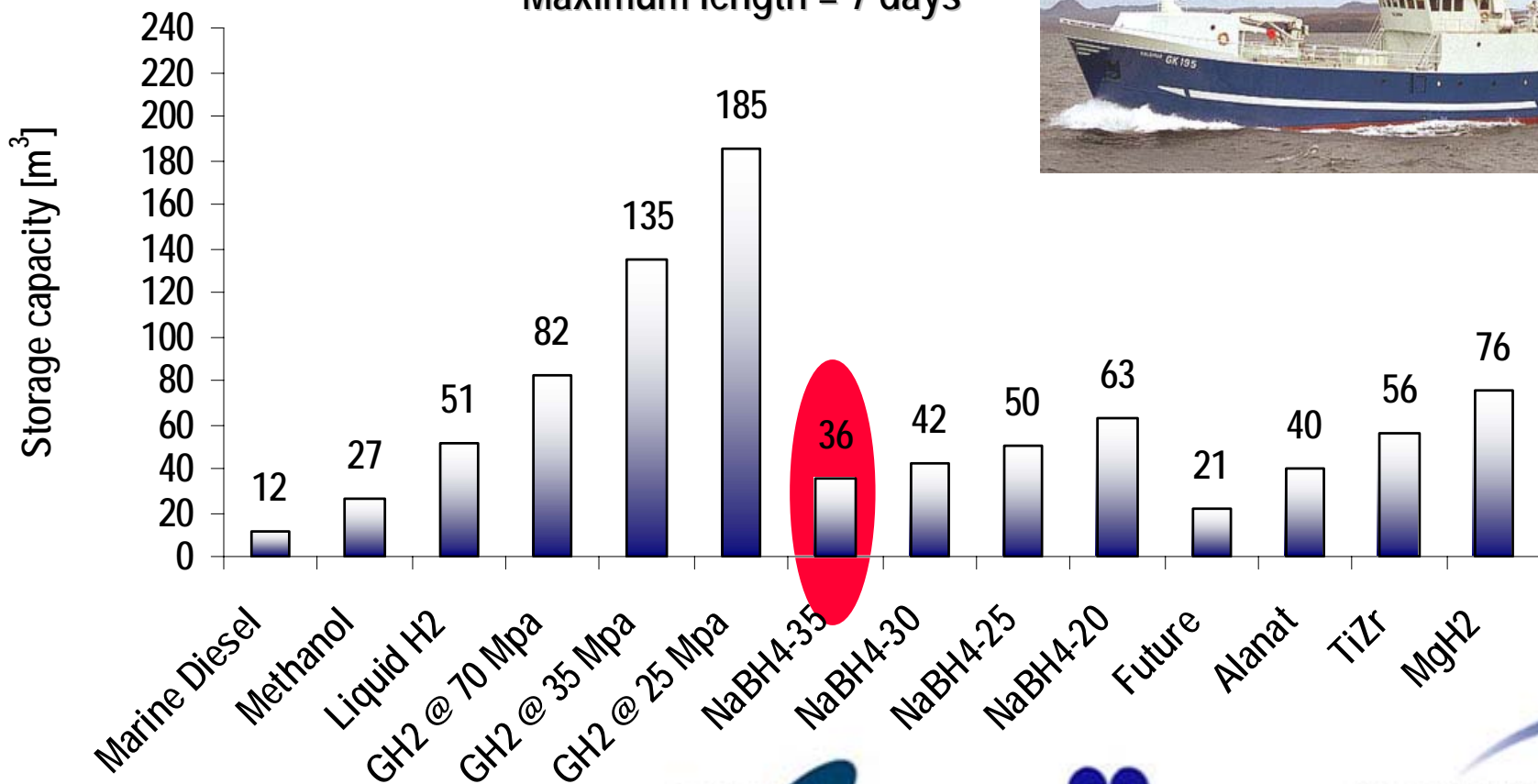
4. Water generated at the Fuel Cell can be recycled within the HOD system, improving storage efficiency.



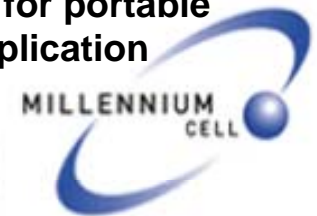
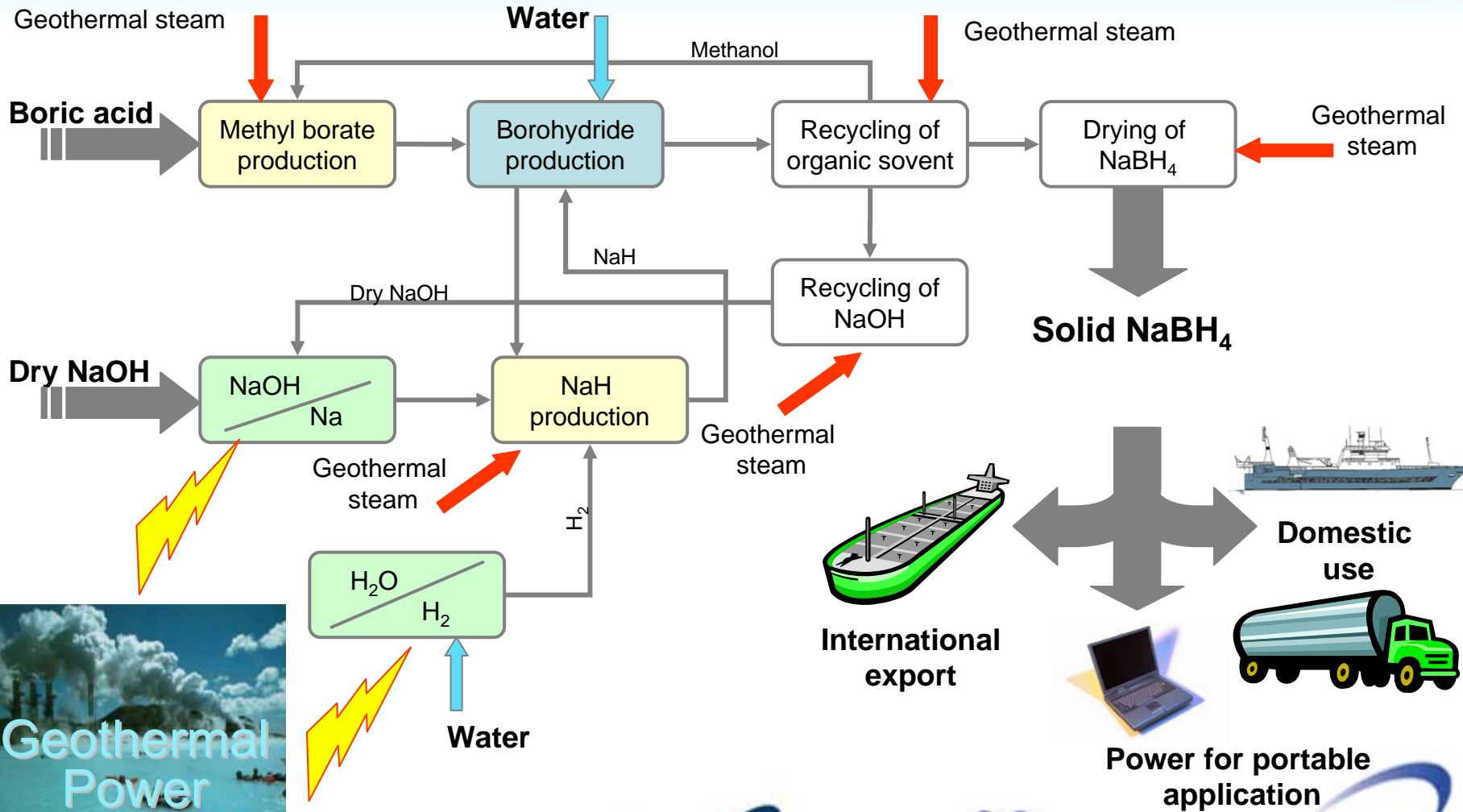
Comparison of Hydrogen Storage Onboard a Typical Fishing Vessel in Iceland.



Valdimar GK
Average fishing trip = 5 days,
Maximum length = 7 days



The NaBH₄ Production Concept

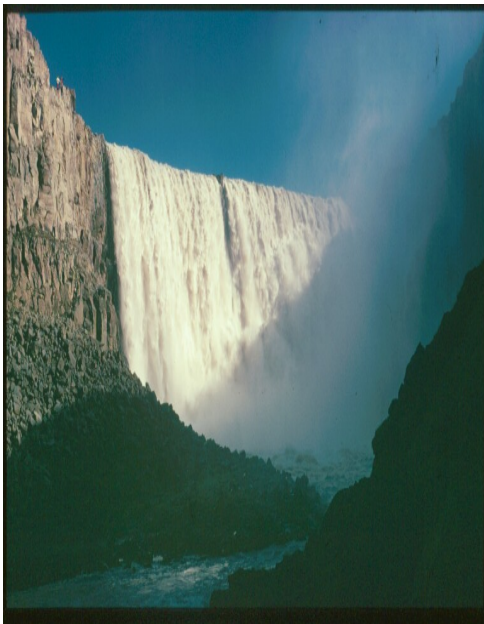




The NaBH₄ Production Concept – cont'd

In short, Production of NaBH₄ in Iceland takes advantage of clean and abundant natural resources unique to Iceland:

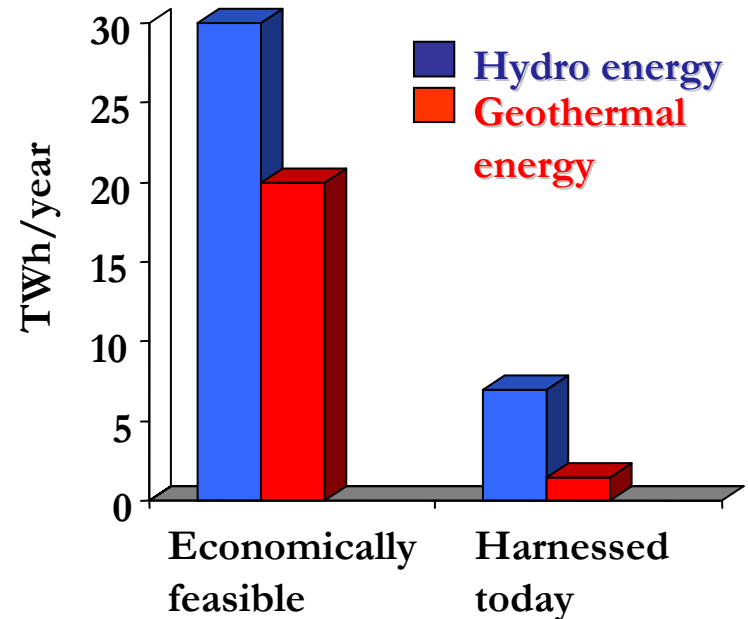
- » Geo-thermal Steam
- » Geo-thermal Power
- » Pure Water





Energy Potential in Iceland

1. Iceland is rich in renewable energy sources, especially hydro and geothermal energy
 - Total: 50 TWh/year
 - 8,5 TWh/year used to day, or about 17%
2. Iceland has the unique circumstances to produce a “hydrogen based fuel project” in a CO₂ neutral environment
3. Iceland has similar standards and industrial system as most other developed countries and therefore the results and the learning can easily be adapted elsewhere
4. Strong government support to transform Iceland into a hydrogen society in the near future





Methodology of Feasibility Study

- Establish process steps
- Develop process flow sheets
- Analyze energy flow and steam requirement
- Conduct process risk assessment






Results from Preliminary Feasibility Study

- Preliminary Energy and Cost Analysis:

	Steam t/t NaBH ₄		Electricity kWh/t NaBH ₄
	6 bar	20 bar	
Production of boric acid and sodium hydroxide	3.6		1300
Production of methyl borate	11.7		
Production of sodium metal			25036
Production of sodium hydride	0.9		
Production of sodium borohydride	1.0		
Production of solid NaOH		5.1	1000
Methanol recycling	1.4		
Isopropylamine recycling	2.5		
General electric energy use			2000
Sum	21.0	5.1	29336

Production cost of sodium borohydride using the “new Icelandic” process	World market price of sodium borohydride
\$6,39/kg_{NaBH₄} — \$5,39/kg_{NaBH₄}	\$51-\$55/kg_{NaBH₄}





Project PoSE: Production of Sodium via Electrolysis

- The preceding analysis was a pre-study on the feasibility of producing sodium borohydride in Iceland using specially developed process adapted for Icelandic energy sources.
- Need to carry out material focused research and development to address remaining technical uncertainties.
 - The main advantage of this new process is the reduced cost of sodium metal, which accounts for ~ 65% of production cost.
 - Based on producing sodium metal from sodium hydroxide, using β'' -alumina membrane in an electrolysis process;
 - Utilizes economic and renewable energy source in Iceland.





Brief Description of Next Steps

Main Objective

- The main objective of the next steps is to:
 - Leverage accomplishments made to date by MCEL on the improved Na process.
 - Verify and prove the durability of β "-alumina (BA) membrane, which is critically important for commercial feasibility
 - Other commercial applications of BA – Na/S Battery, Na recovery, etc.
 - Develop and test a production process based on this sodium metal production method using geothermal energy





Brief Project Description

General setup of the project

The project will be set up as a two phase project

- Phase I
 - Evaluate the long-term stability of membrane (BA) materials
 - Develop process conditions that optimize membrane stability.
- Phase II
 - Will be executed if phase I proves successful
 - Involvement of the industry to design and test a full process for commercial production of NaBH_4
 - Proposed IPHE project





What do the Partners Bring ?

- Millennium Cell
 - Patents, know-how, and experience on NaBH_4 reactions and application of Hydrogen on Demand® technology
- IceTec
 - Icelandic expertise in renewable energy sources and geothermal industrial processes
 - Electrochemical process expertise
- INE
 - International partnership experience
- Additional Partners?





Summary

- Sodium borohydride can serve a dual purpose of supplying hydrogen in Iceland's Hydrogen Economy and efficiently exporting Iceland's clean energy source
- The production cost of sodium borohydride can be dramatically lowered by incorporating geothermal energy in Iceland
- Electrochemical process adapted to Iceland situation appears feasible on initial analysis, but need additional technical validation

Acknowledgement

- Ionotec – for discussions on the properties of β'' -alumina.

