MINISTRY OF NEW AND RENEWABLE ENERGY
GOVERNMENT OF INDIA

MINISTRY OF PETROLEUM AND NATURAL GAS
GOVERNMENT OF INDIA

OFFICE OF THE PRINCIPAL SCIENTIFIC ADVISER TO THE GOVERNMENT OF INDIA

Confederation of Indian Industry

A Dassault Systemes 3DS Accelerator Company

Session 1C:
Hydrogen Energy Ecosystems & Assessment

International Conference on Green Hydrogen 2023
5-7 July 2023 I Vigyan Bhawan, New Delhi

Unleashing the Ecosystem
with
SOLID Hydrogen Logistics

James Khong
CO-Founder & COO, Galaxy FCT
5 July 2023

www.galaxyfct.com

Presentation Overview

Part 1: Introducing Solid H2 Logistics

Part 2: "Prime Site" Hyper-Scaled Production

Part 3: Leveraging for ECOSYSTEM Level Benefits

Solid H2 Logistics

Making H_2 …

"Cheap to Store"

"Easy to Move"

"Safe to Handle"

&

Infrastructure LIGHT across the supply chain

Solid H2 Logistics ("Solid Logistics")

Introducing the CONCEPT

CLICK HERE to See Full Article on Solid H2 Logistics in CHT Technical Journal May 2023 (Published my Ministry of Petroleum India)

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CONCEPT Overview: H_2 in SOLID

Production of Green Energy and H2 in the most productive Locations globally

"Packaging" of H2 into the form of Solid H2 (Sodium Borohydride/NaBH4)

All Storage/Logistics carried out in the form of Solid H2

H2 Gas is released at user location "on demand" only when required.

Bypassing the need to "fight the physics" of H2 Gas throughout the length of the supply chain

Galaxy FCT:
Patented Process for rapid and efficient H2 Release from SOLID

Sodium Borohydride ($NaBH_4$) Properties

- High Energy Density (126 kg H2/m3)
- Non-Flammable & Non-Explosive
- Ambient Temperature & No Pressure

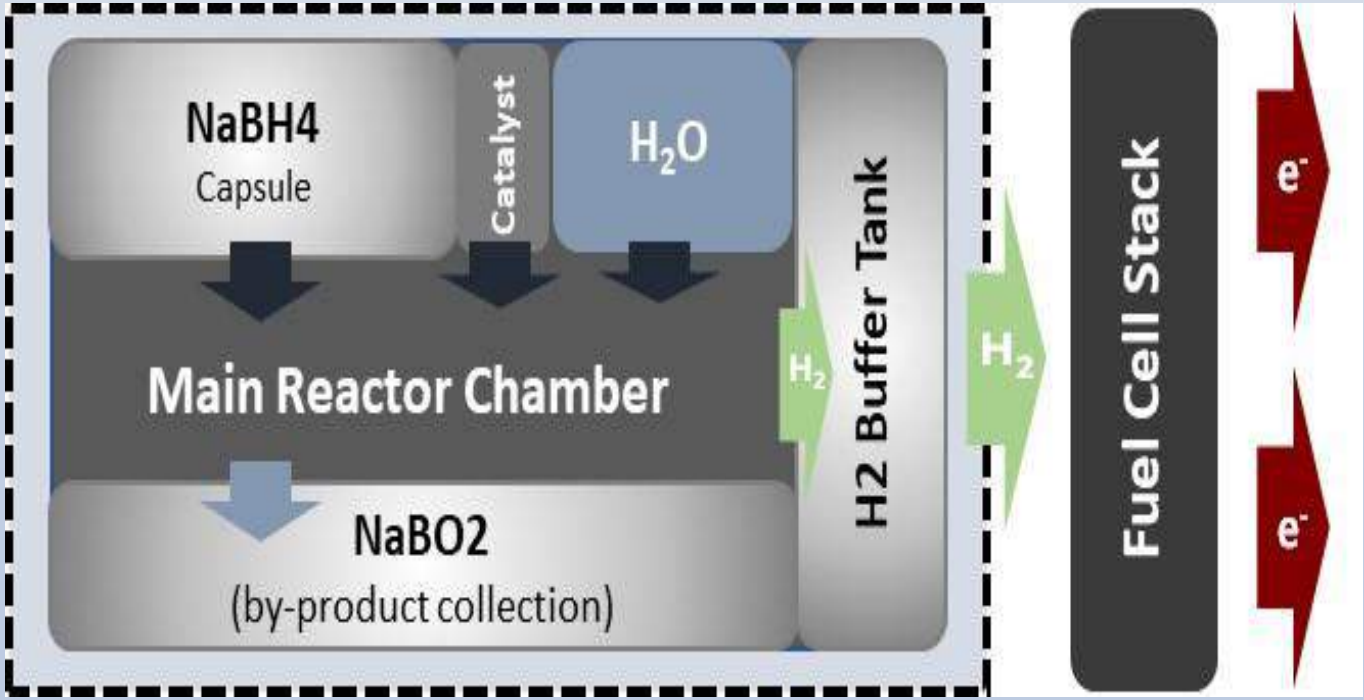
Safe, Simple and Efficient Logistics

Exothermic Reaction – External energy input NOT required at "last mile"

Compressed Gas @ 700 bar	42 kg H_2/m3
Liquid Organic H2 Carrier (LOHC)	57 kg H_2/m3
Liquid Hydrogen (-253C)	71 kg H_2/m3
Sodium Borohydride (NaBH4)	126 kg H_2/m3

Galaxy FCT & Solid H2 Logistics

Patented Process which provides a Foundation for the Emerging Ecosystem

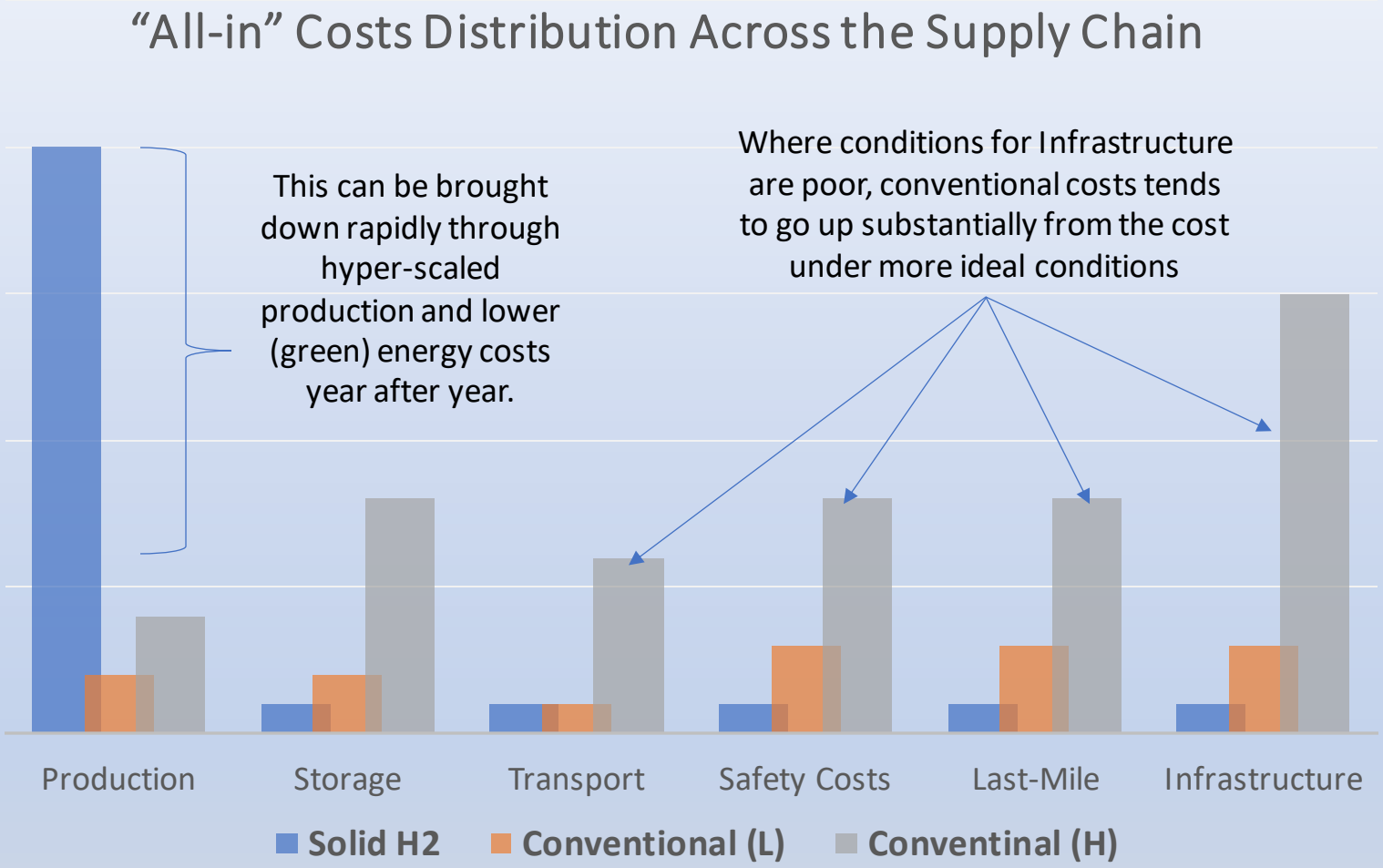


RAPID and EFFICIENT release of H2 gas "on-demand" from solid feedstock provides the foundation for the Solid H2 Logistics Ecosystem

Galaxy FCT is a Hydrogen Technology Company with a patented process which has resolved the technical difficulties with RAPID and EFFICIENT release of H2 gas from solid chemical feedstock (NaBH4).

Patents Issued in United States of America, **India (October 2022)**, China, Japan, South Korea, Africa (ARIPO), South Africa, Nigeria, Indonesia, Saudi Arabia, Chile, Malaysia and with worldwide pending.

The “Strategic Exchange” Underpinning Solid H2 Logistics



The Strategic “Exchange” underpinning Solid H2 Logistics essentially accepts high production costs today (mostly energy/ process) in EXCHANGE for much lower costs across the entire supply chain (which are harder to bring down significantly). Its about strategically selecting the more “winnable” battle in the future.

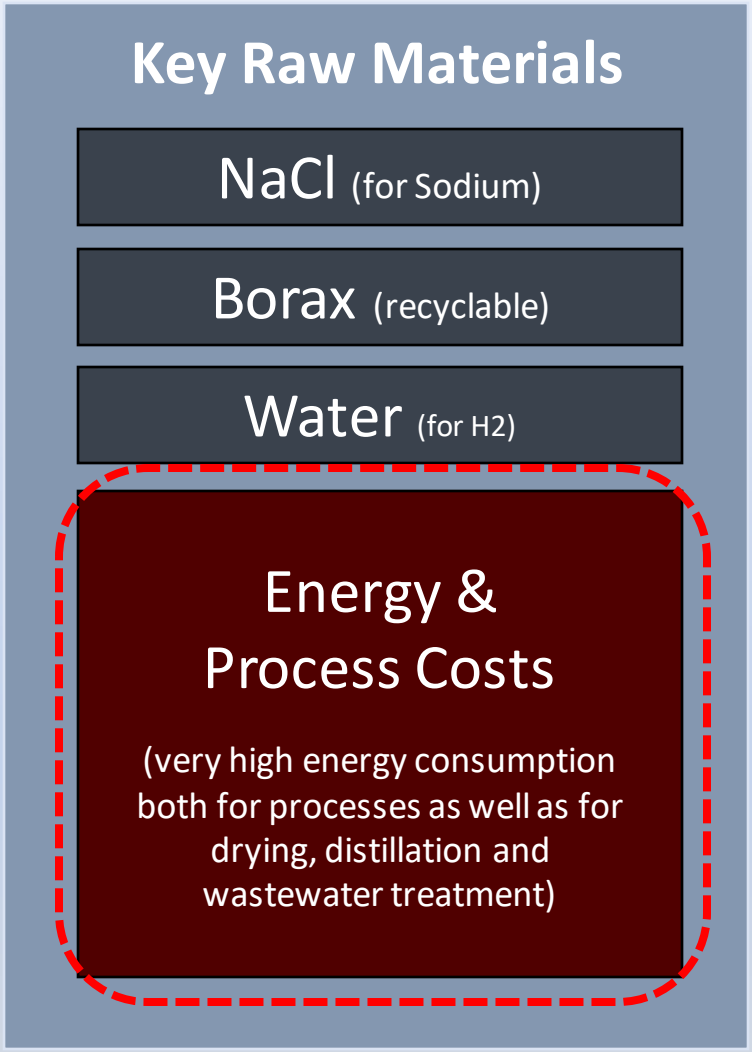
Given the global trends in RE … we believe the tipping point for Solid H2 Logistics is near

Commoditizing Global NaBH4 Production

Moving it from "Specialty Chemical" to Mass Produced Energy Commodity

- NaBH4 Currently produced as a Specialty Chemical at relatively low annual volume (miniscule when considered from a global energy perspective). However, as the Brown-Schlesinger/Down Process has been used in large scale produced since 1950s, we do not expect any issues that prevent effective "scaling up".
- All key basic raw materials are either inexpensive or recyclable … and the biggest cost component is energy and process costs which can be mitigated by leveraging lowest-cost renewables and integrated production at massive scale.
- Wright's Law – Every doubling of aggregate installed capacity will result in between 30% to 40% reduction in price per unit of energy produced.

With currently around 6.5% of global energy produced from Solar PV today, there is significant scope for much more future price reductions with every "Doubling". "HyperScaling" Prime Sites will make this happen sooner.



Hyper-Scaled Prime Site Production

Think of it as “Sunlight Refineries” in the Desert

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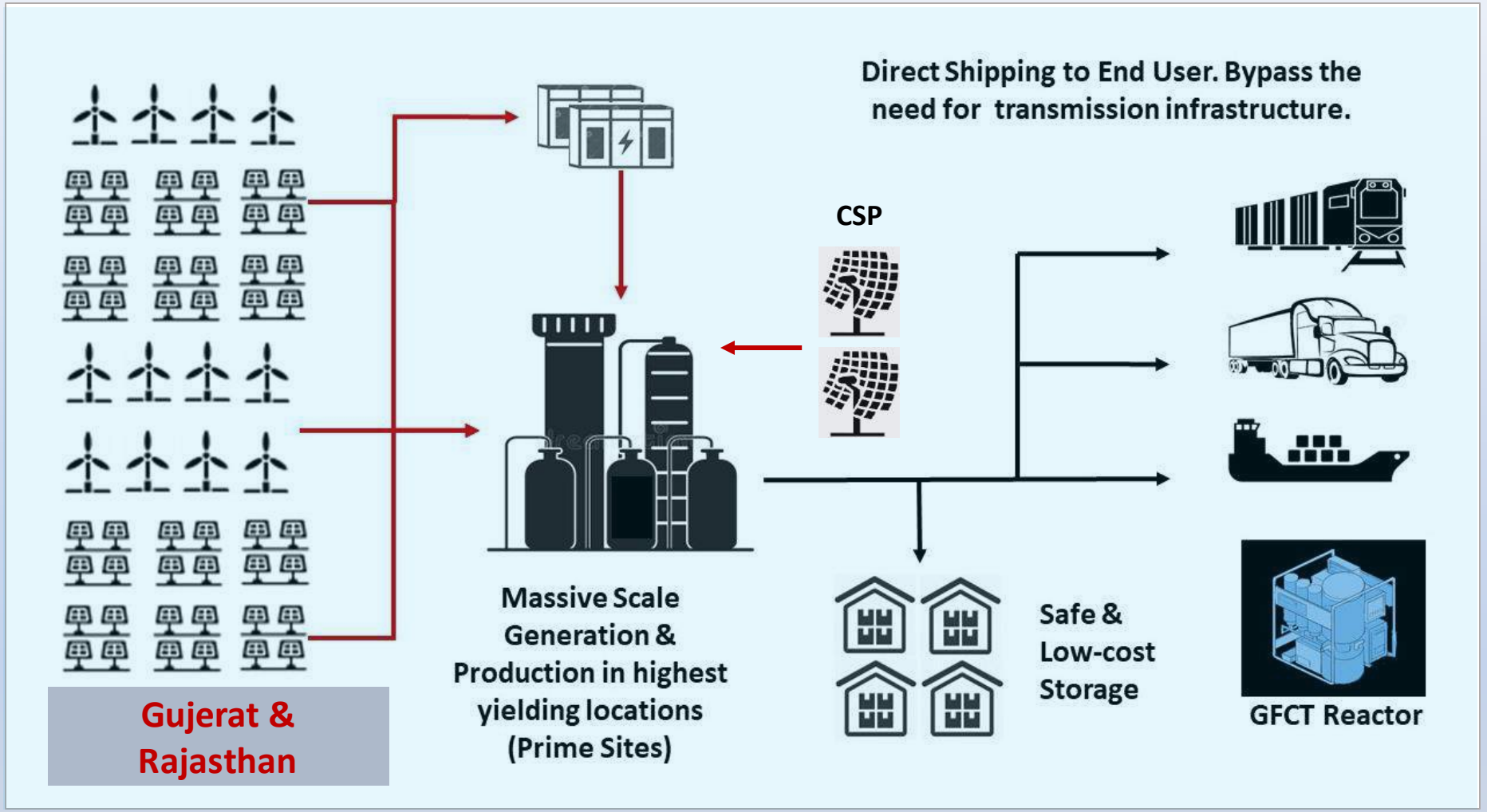
“Hyper-Scaling” Integrated NaBH4 Production in INDIA

Leveraging the most productive Renewable Energy locations (the “PRIME SITEs”) in Gujerat/Rajasthan



Same CAPEX
Deployed here produces much more Energy

Abundance of Land with No Competing Usage

No Transmission Infrastructure Required

“Unlimited” SCALE & “Shovel Ready” … Off-take not required

A HyperScaled Sunlight Refinery in INDIA to “collect” SOLID H2 to provide Long Term Energy Security …

Latest Studies show Promising Pathways for Future Cost Reduction

Sustainable Energy & Fuels

ROYAL SOCIETY OF CHEMISTRY

Received 27th September 2022
Accepted 30th January 2023

Chemical compression and transport of hydrogen using sodium borohydride

Ainee Ibrahim, Mark Paskevicius * and Craig E. Buckley

Web-Link

Conclusions

"The potential of NaBH4 as a hydrogen carrier opens up new avenues for the production, storage and compression of green hydrogen. The ability to compress hydrogen using the hydrolysis and methanolysis of NaBH4 to over 1000 bar can be utilised at hydrogen refuelling stations to compress hydrogen on-site. Cost predictions for the electrochemical production of NaBH4 could enable hydrogen to be exported at a cost of **$4.44 USD per kg H2**, at costs much lower than competing technologies, especially if electricity costs are lowered in the future using renewable energy. However, to make NaBH4 competitive for hydrogen storage and export, green methods of regeneration must be proven at scale and optimised. This could ultimately change the future of the global hydrogen economy"

Techno-economic assessment of green hydrogen supply with sodium borohydride as solid carrier

Student: João Miguel Pinheiro Petraglia Margutti
Supervisor TUM: Prof. Dr.-Ing. Kai-Olaf Hinrichsen
Supervisor External: Prof. Nilay Shah FREng
Date of Submission: May 27, 2022

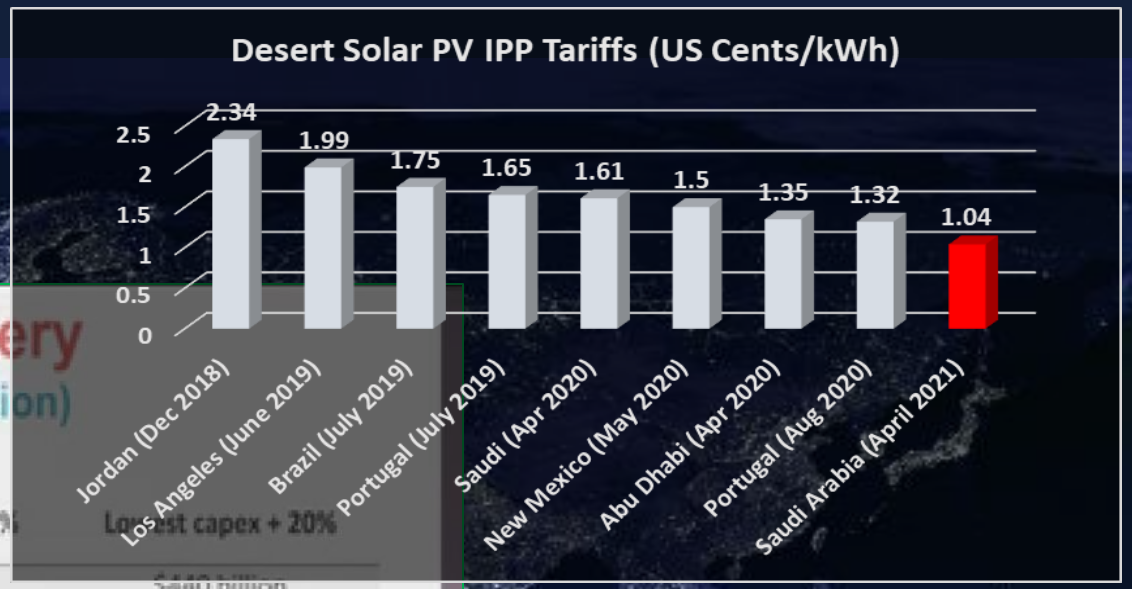
Department of Chemical Engineering
Faculty of Engineering
Imperial College London

[Currently Under Peer Review]

Using Brown-Schlesinger, we currently estimate the full ENERGY requirements to produce 4.75 kg of NaBH4 (amount of Solid H2 required to release 1 kg of H2 gas) to range somewhere between 200 kWh to 250 kWh. This can be done today, without waiting for any new technology breakthrough.

There are exciting pathways towards further cost reduction that can be unlocked through recycling "Spent NaBH4" electrochemically that can be a game changer that would further accelerate growth of Solid H2 Logistics

We Should Fully Leverage Lowest Cost Renewable Energy



2030 Whole System Projection (Rethink Energy)

India – 100% Solar, Wind and Battery

(based on one round of Dynamic System Simulation)

INDIA SWB100	Lowest capex	Lowest capex + 10%	Lowest capex + 20%
Capital cost	$365 billion	$403 billion	$440 billion
Solar PV capacity	810 gigawatts	950 gigawatts	1,070 gigawatts
Wind capacity	70 gigawatts	70 gigawatts	70 gigawatts
Generation capacity	4.8x	5.6x	6.2x
Battery capacity	2,263 gigawatt-hours	2,098 gigawatt-hours	2,073 gigawatt-hours
Battery average demand hours	21 hours	14 hours	14 hours
Annual super power	365 terawatt-hours	623 terawatt-hours	852 terawatt-hours
Fraction of days with super power	97%	99%	99%
Electricity cost (100% of super power utilized)	$0.01/kWh	$0.01/kWh	$0.01/kWh

Based on two years of hourly demand data for India (starting Jan 2018) & solar and wind generation. Regional simulations might return different results. © 2020 RethinkX

'Wright's Law' Points to 'Insanely Cheap' Solar Prices (Ramez Naam)

See: "The Great Transformation [Part 3] Disruption of Energy" @ YouTube (Tony Seba 2022)
See Min 15.:42 on India Analysis

Harnessing "Super-Power" from its deserts in Gujerat/Rajasthan and integrating with Hyperscaled NaBH4 Production will fast track India's path towards long term clean energy security …

Maximizing Ecosystem Level Benefits

Leveraging Symbiotic Relationships & Virtuous Cycles

1 Ecosystem Optimization - PRIORITIZE Infrastructure where it Really Counts

"Solid H_2 Logistics for the Rest"

Green Electron Network (Grid & Batteries, "GEN")

Conventional H_2 Logistics

Solid H_2 Logistics

Medium/Long Duration Energy Storage
Required at various segments of the Supply Chain

- Long Distance Supply Chain
- Complex Supply Chains
- Low Volume Users
- Highly Dispersed Users
- Intermittent Usage
- Unpredictable demand fluctuations

- Cross-border Inter-dependent infrastructure
- No/Limited Existing Usable Infrastructure
- Political Instability & Multipolar Geopolitics
- High Level of Land Rights/NIMBY/Legal Issues
- High/Rising Interest Rates
- SHORT time horizon to Decarbonize

IDEAL Conditions for INFRA

SEMI- IDEAL Conditions for INFRA

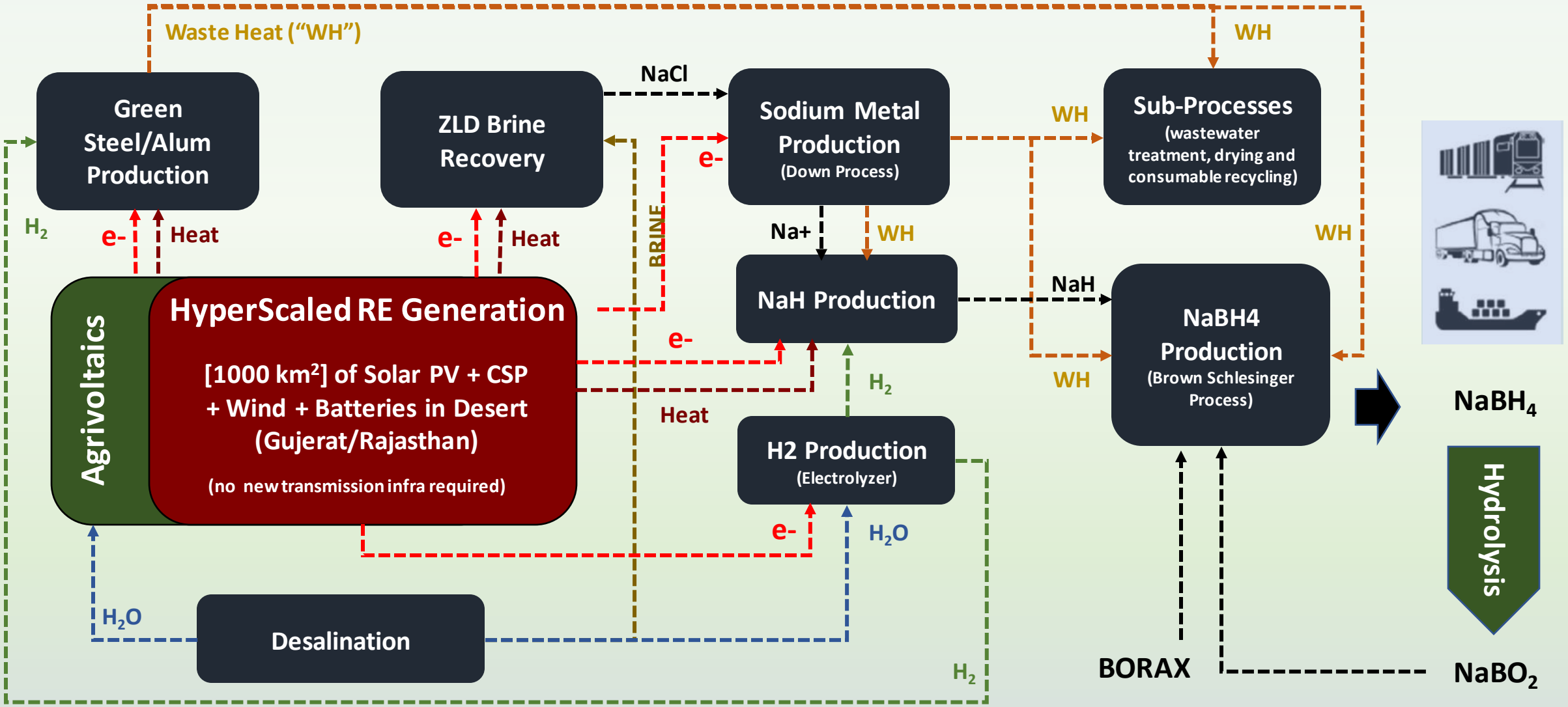
Increasingly POOR to ADVERSE CONDITIONS for INFRASTRUCTURE

10% 20% 30% 40% 50% 60% 70% 80% 90% 100%

Attractive for INFRA | Increasingly Unattractive | Highly Problematic | Economically Disastrous

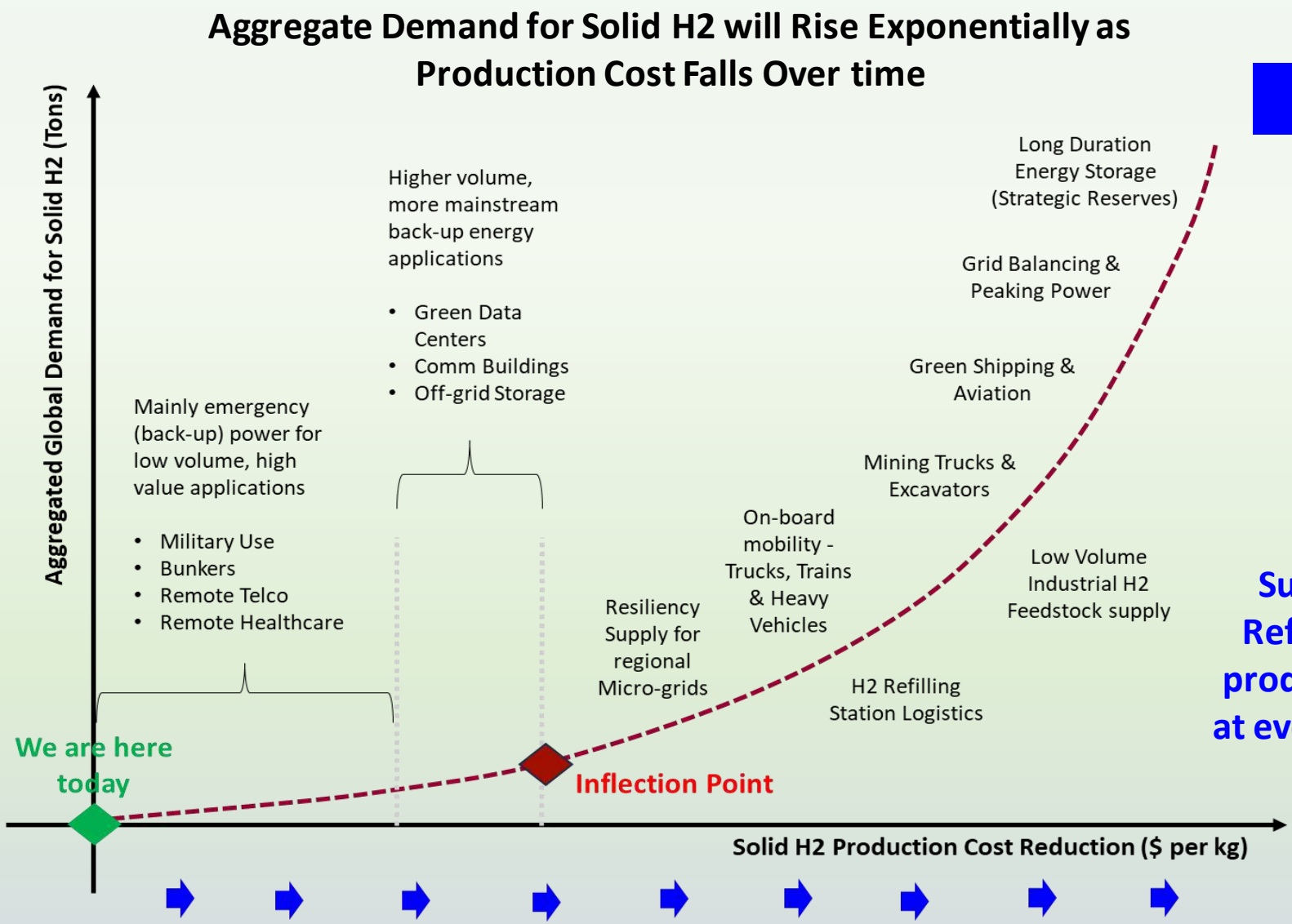
Incorporating Symbiotic Green/Sustainable Industry Clusters

Leveraging the Prime Site Complex to fast forward other Green/Sustainable Objectives



Optimizing Direct Heat (CSP) & Waste Heat to reduce Energy & Process Costs together with Desalination, Green Steel & Agrivoltaics

3 Unleashing A "Virtuous Cycle" that will Accelerate Renewables



Demand for even greater scale production of Solid H2 (more Sunlight Refineries)

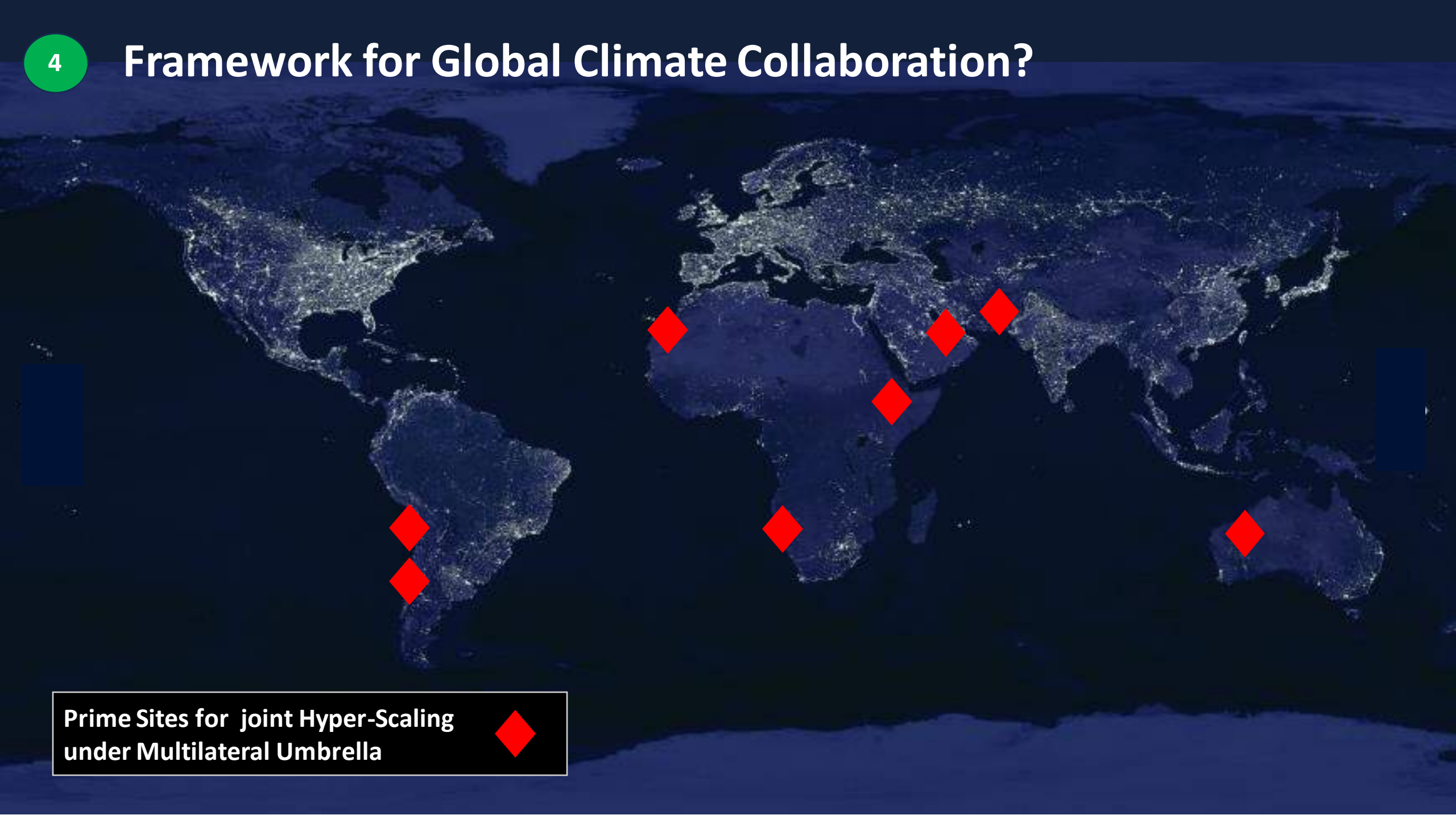
Much greater demand for "associated renewables" and lower component/ consumable prices

Lower cost of energy and greater logistical scale economies

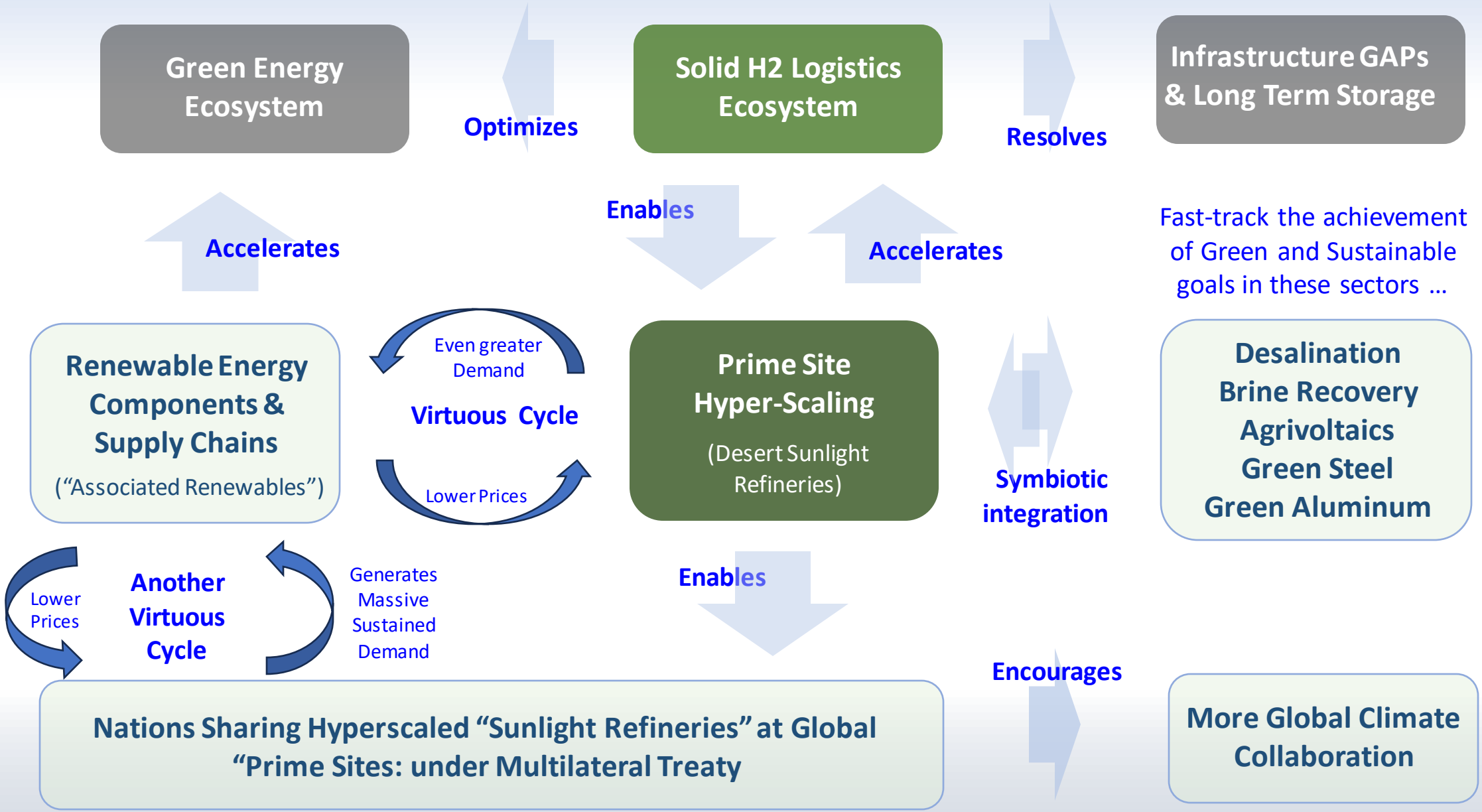
Sunlight Refineries produce SH2 at even lower cost

4

Framework for Global Climate Collaboration?



Final Thoughts


Green Energy Ecosystem
Optimizes
Solid H2 Logistics Ecosystem
Resolves
Infrastructure GAPs & Long Term Storage
Enables
Accelerates
Accelerates
Fast-track the achievement of Green and Sustainable goals in these sectors …
Renewable Energy Components & Supply Chains
("Associated Renewables")
Even greater Demand
Virtuous Cycle
Lower Prices
Prime Site Hyper-Scaling
(Desert Sunlight Refineries)
Symbiotic integration
Desalination
Brine Recovery
Agrivoltaics
Green Steel
Green Aluminum
Lower Prices
Another Virtuous Cycle
Generates Massive Sustained Demand
Enables
Encourages
Nations Sharing Hyperscaled "Sunlight Refineries" at Global "Prime Sites: under Multilateral Treaty
More Global Climate Collaboration

Unleashing the Ecosystem in INDIA

First Mover Advantage and Creating a "Virtuous" Self-Sustaining Cycle

Prime Site Hyperscaling Creates massive Sustained Multi-Year Demand for "Associated Components":

- Solar Panels/Wind Turbines
- Concentrated Solar Components
- Inverters & Electrolyzers
- Batteries (esp. Liquid Metal Batteries & Molten Salt)
- Fuel Cells & Other Associated Components

"HyperScaled" Production at Prime Sites (Gujerat/Rajasthan)

GREEN Steel/Aluminum: Co-locating production within the same complex and optimizing waste heat for integrated NaBH4 production

AGRIVOLTAICs under Solar Panels to increase food production with much lower evaporation. Lower temperature will also increase electricity production of Solar PV

LONG DURATION Clean Energy (Strategic) Reserve in the future can be stored in the form of Solid H2 (NaBH4) instead of Hydrocarbons – high density, safe, simple and low-cost storage with maximum flexibility/resilience. Producing Solid H2 in India and the ability to store huge amounts will greatly enhance Energy Security

Concluding Thoughts …

- There is compelling circumstantial evidence showing that the tipping point for a Solid H2 Logistics Ecosystem is near
- Current Assessment metrics do not fully appreciate the massive "Ecosystem Benefits" that Solid H2 Logistics can bring to the larger overall Ecosystem by filling the gaps/cracks and making it much more flexible, efficient and resilient. It's perhaps time that we revisit this.
- India has all the IDEAL Conditions to make HyperScaled Production Work and well placed to be "first mover"
- Galaxy FCT is looking forward to work with strategic partners and stakeholders to fast track the development of the Solid H2 Logistics Ecosystem in India and Beyond …

Solid H2 Logistics

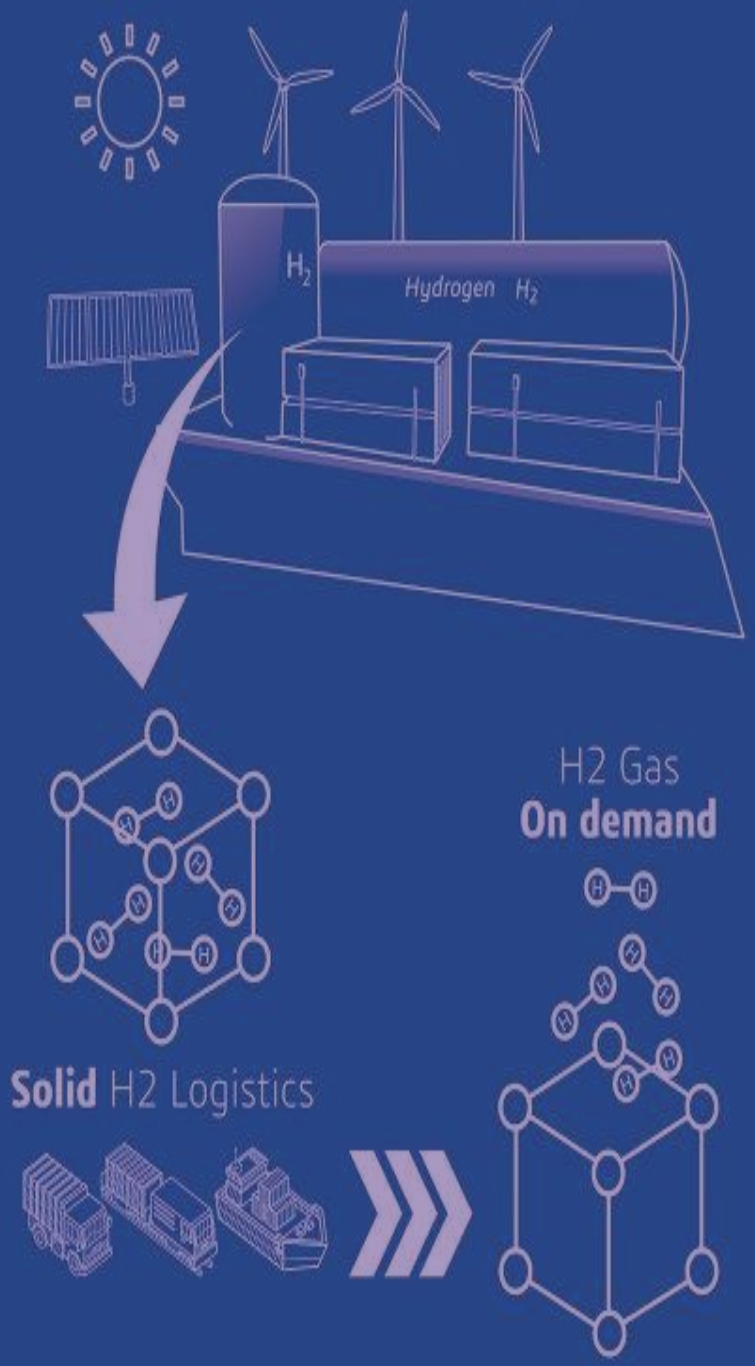
Making H2

"Cheap to Store, Easy to Move, Safe to Handle"

And

Infrastructure LIGHT

with an Efficient & Low-cost "Last Mile"



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Thank You

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