Developing green hydrogen low-cost research and development platform in Bhutan

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Keywords

Bhutan, green hydrogen, storage, low pressure, low cost, R&D, climate change adaptation

1 Introduction

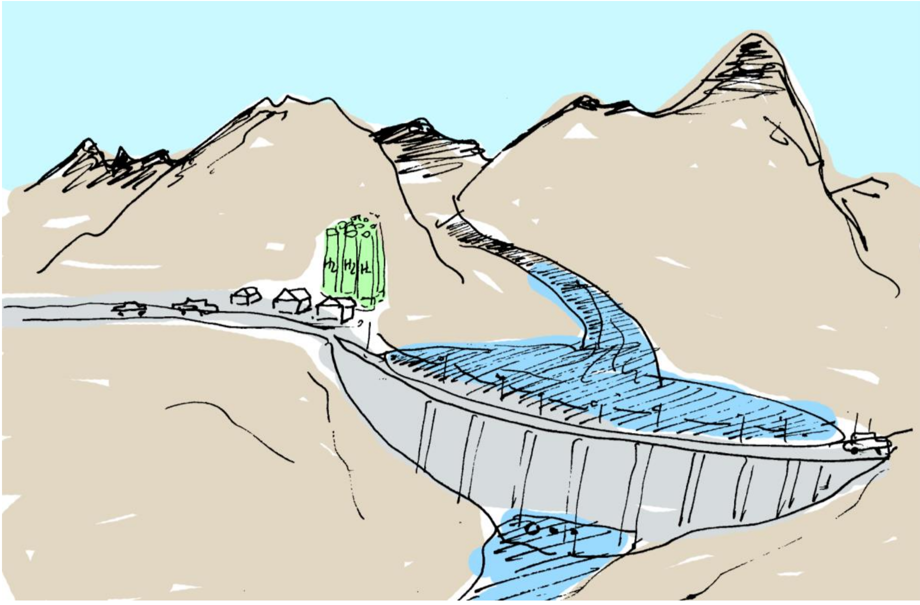
“The power sector is the largest source of the government revenue and the premier contributor to the country’s gross domestic product. […] Power generation in Bhutan relies almost exclusively on hydropower. The total installed capacity of existing hydropower plants is 1,488 megawatts (MW). Since all the existing plants are run-of-the-river types, the total generation drastically drops to about 300 MW during the winter dry season (December–March) due to low water levels. This falls short of meeting peak system demand during winter dry seasons. To deal with the seasonal power shortage, Bhutan has curtailed industrial loads during the winter months. Power has been imported from India, especially in the winter, but this will become increasingly difficult to arrange because India has its own power shortage during these months.” [1]

The hypothesis is that investing in large amounts of chemical batteries is expensive, unpractical, and hard to scale, while developing flexible hydrogen tanks [2] from local materials and becoming a major exporter of green hydrogen-derived electricity would provide Bhutan:

- The ability to store energy to operate its own industry in the dry season.
- Electrify hard-to-reach rural communities.
- Improve Bhutan capacity to control electricity export price over time.

DOI: 10.5281/zenodo.8171636

Figure 1. Illustration of hydrogen storage near a Bhutanese hydro plant. Cesar Jung-Harada



How will Bhutan develop its grassroots green hydrogen research capacity without creating material dependencies from external trade partners? Learning from recent experiments in Indonesia, this paper proposes a low-cost, local, inclusive roadmap with specific design and engineering principles for the constitutional monarchy.

2 Design / methodology / approach

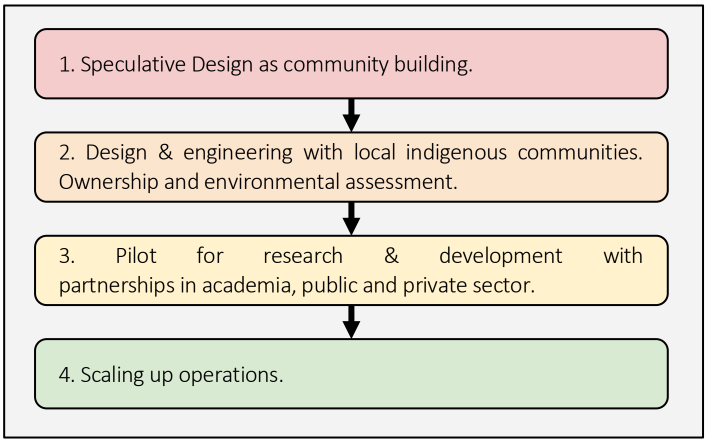
Promoting the development of new sources of energy, or energy storage can be costly and time consuming for a small nation to develop. The Bhutanese hydro power history started in 1961 with the transboundary river Jaldhaka with the support of Indian technology and investments, completed in 1966. Over the years, hydropower has brought most needed revenue to the Bhutanese government, multiplying its ability to provide health, education and alleviating poverty. [3]

According to the World Bank, “Bhutan has a significant untapped hydropower potential [...] estimates the overall hydropower potential at 30,000 MW. [...] (In 2020) Sustainable hydropower development is a critical part of Bhutan's socio-economic development strategy. Hydropower revenues, from export sales of about 70% of hydropower generation to India, comprise about 27 percent of government revenues and 13 percent of GDP. Its share of GDP can rise to 30 percent when hydropower is under construction from jobs, supply chains, civil works, and services created. The revenues from hydropower through taxes, dividends and royalties will reach Nu 26 billion, or 36 percent of the total government revenues by the end of the 12th Five-Year-Plan (FYP, July 2018-June 2023). Gross value added to the economy will be Nu 65 billion, or 35 percent of GDP.” [4]

The capacity and amount of electricity traded between the two partners has grown tremendously, but in recent years, Bhutan has grown concerned about hydro-debts with India, pricing dispute, ownership of the companies that own the power infrastructures, unequal employment opportunity for Bhutanese nationals in Bhutan, environmental impact, and long term water scarcity further degraded with Global Warming.[3]

Given the opportunity Bhutan may choose to rapidly develop its own energy storage capacity, intellectual property, creating local jobs, using local materials, minimizing environmental impact, the soaring debt [5], and dependency with its trade partners. This document proposes a strategy for the development of Bhutan hydro-generated green hydrogen storage in stages.

Figure 2. Stages of development for innovative technologies to benefit the local population.
Cesar Jung-Harada



The concept can be simplified in the following stages:

1. **Speculative Design as community building**: Facilitate the local community to imagine their energy future. The Speculative Design [6] and participatory (Design Thinking) approach is inclusive and can increase the "buy-in" from the local population.
2. **Design & engineering with local indigenous communities. Ownership and environmental assessment:** work with the local community to develop open technologies, as much as possible with local materials and know-how so it can be scaled without excessive dependences and externalities. At this stage the FabLab [7] infrastructure and hacker ethos are critical.
3. **Pilot for research & development with partnerships in academia, public and private sector**: once the local community has established its ownership and expertise, find local and global investors while ensuring Bhutanese collectively own the majority of the shares of the businesses. At this stage the methods developed by the Appropriate Technology [8] and the Low Tech [9] movement can be very valuable.
4. **Scaling up operations**: serving the environmental, water, energy and economic ambitions of the Bhutanese people. At this stage, the Jugaad entrepreneurial mindset [10] can help to scale.

3 Data / sample

Based on previous work "Balon Balon Ijo" (Bahasa Indonesia for "Green Balloons") that won the Bali FabFest "Special Mention Award" of production of floating solar hydrogen in the maritime environment (Bali, Indonesia) [11], this research is about an experimental system of hydrogen gamified education and R&D (research and development), storage and transport from which we can learn from for the mountainous environment of Thimphu, Bhutan.

4 Case Study 1: Bali, Indonesia

4.1 Speculative Design as community building (August 2022)

Table 1: Speculative Design as Community Building

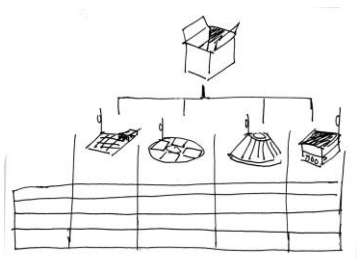
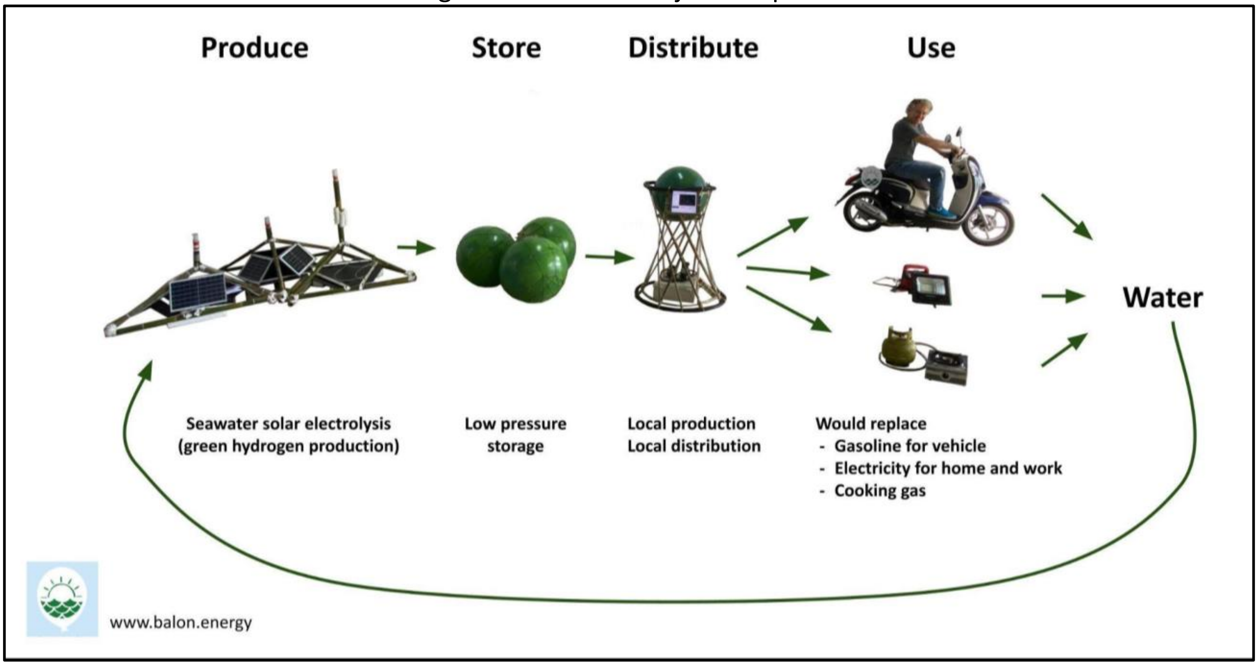
	
Invite local and global participants. Create sets of simple and affordable materials.	Leads to the parallel production of experimental setups that collaborate and compete towards higher production efficiency and cost reduction.
	
Prof Alvaro Cassineli working on water electrolysis.	Markus Leutwyler working on IOT sensors and communication.
	
Ratna Mardiani Mulya, Aldo Ikhwanul Khalid testing in the sea	Ratna Mardiani Mulya, Aldo Ikhwanul Khalid role-playing the distribution of hydrogen tanks
	
Role-playing by placing the supposedly hydrogen-filled balloon in the restaurant kitchen	The whole team debating story telling and marketing a fictitious energy startup.

Figure 3: Balon Balon Ijo concept

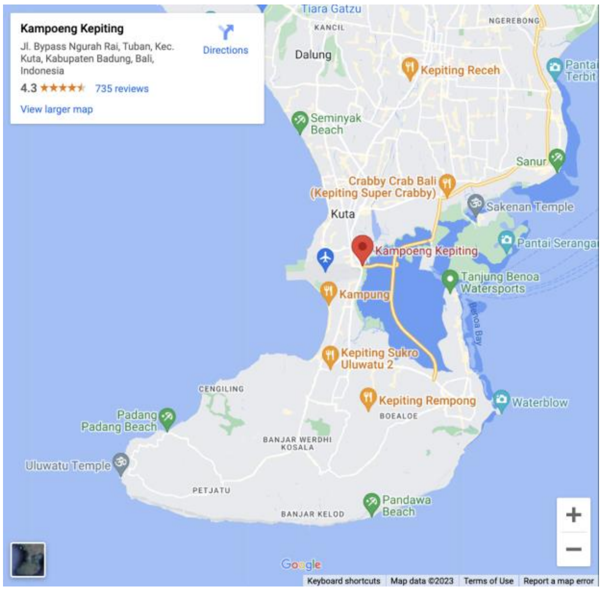
Figure 4: Balon Balon Ijo concept



In this case, we go “all-the way” in the role playing and with a set of prototype or “film props”, film and a website, we present a vision of a possible future company. Using a similar language a tech startup would use, we introduce the concept of a decentralized floating solar hydrogen technology that local people can own and operate. All the images above are from the website: https://balon.energy/ retried July 2023.

4.2 Design & engineering with local indigenous communities. Ownership and environmental assessment (Aug 2022 - Aug 2023)

Table 2. Getting to know the local community's challenges and opportunities

<table>
<tr>
<td>
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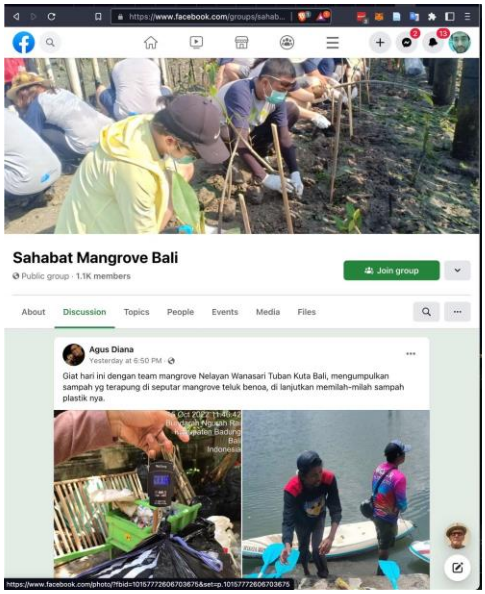
<td>
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<tr>
<td>Since we know our floating solar panels are rather fragile, we were looking for a marine site that would be protected from strong waves and ocean currents. The Kampoeng Kepiting seems like a perfect site.</td>
<td>Through discussions with local environmentalists, we heard about an indigenous community that regularly operates marine waste clean up and mangrove planting volunteer groups.</td>
</tr>
<tr>
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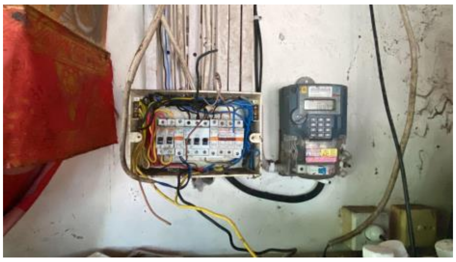
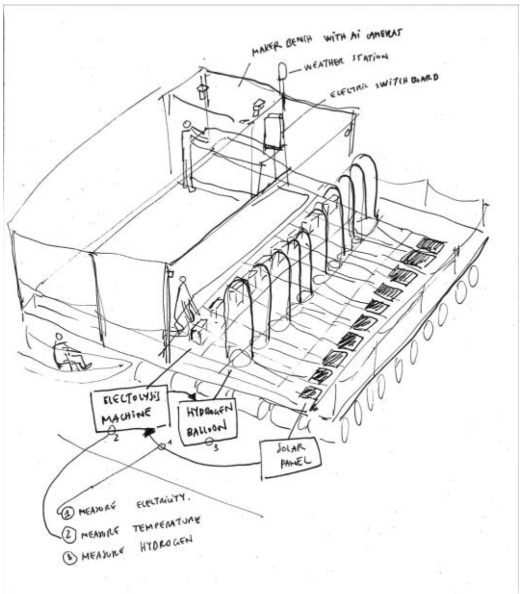
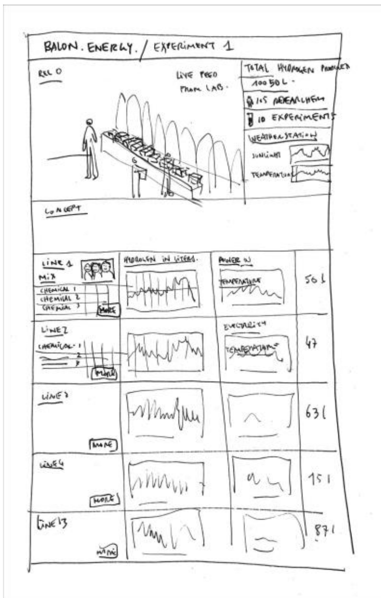
<tr>
<td>We volunteered a couple of times and they told us how the construction of the highway and the sediments had damaged their mangrove and fisheries.</td>
<td>As they can no longer find enough crabs locally, they have to import crabs from other communities and refrigerate them at a very high cost.</td>
</tr>
</table>

The next phase is to engage with local indigenous people, introduce ourselves, ask them what they feel about our concept and learn about their culture, fears and ambitions, how their environment has been changing over the years.

Table 3. Co-Designing with the local community, the energy research and development facility

	
Prof Dwidiani, Cassinelli and Adrian Li meet with Kampoeng Kepiting elders and leaders. We share stories, drinks and foods.	They tell us about their history, the cultures, their challenges and their goals.
	
We inspect their existing power installation	We agree on a potential site.
	
We develop together a physical design for a floating platform that would host 10 parallel solar to hydrogen experiments as well as underwater oxygen injection.	We develop together a digital website to monitor in real-time the 10 experiments and how they perform, doing open science publicly.

For this particular experiment, it is important to mention that our plan is to provide

- 90% of the time, the installation has 500W of solar panels that it will provide for the indigenous-owned restaurant - not doing water electrolysis for hydrogen production, but simply reducing the cost of operations of the restaurant.

- 10% of the time, the installation 10 solar panels will be used by the local University researchers and the FabLab members to develop nontoxic catalysts and optimize locally-produced electrolysis machines.

Instead of a sequential series of experiments done in a controlled lab environment with a small number of highly skilled researchers, the design of this experiment is parallel, in the field, and the R&D effort is done with an heterogenous group with a collaborative innovation approach. Instead of being focused only on the science and engineering, we are considering more factors such as scenarios of usages in complex social and cultural context, as well as the availability of local materials, cost of build and maintenance. The overall set up uses IOT and AI to gamify research and communication. [13]

4.3 Pilot for research & development with partnerships in academia, public and private sector (Aug 2023 - Aug 2024)

The next steps will be to:

1. Discuss the vision, the goals and the value we can create with the experiment
2. Discuss the mitigation strategy in case of accidents, accountability structure, guarantees.
3. Conduct an environmental and marine biology baseline survey. Ideally that work is done by an external independent third party such as another university or qualified environmental NGO.
4. Develop an initial business model, life cycle analysis and agree on the ownership and management of the floating structure.
5. Develop research protocols with the local university and FabLab network.
6. Agree on the licensing for the intellectual property with the long-term benefits to the community and the ability to share the results of experience
7. Reach out to potential sponsors.
8. Reach out to potential industrial and financial partners.
9. Get permission from the local community and the officials to build together.

After all the preparation work is clear and we have the “green light” from everyone:

1. Studying and identifying local fabricators
2. Identifying environmentally friendly local materials
3. Co-develop a design
4. Build the platform with the local community

As of July 2023, our goal is to operate the facility with volunteers and governed by consensus. Over the course of one year:

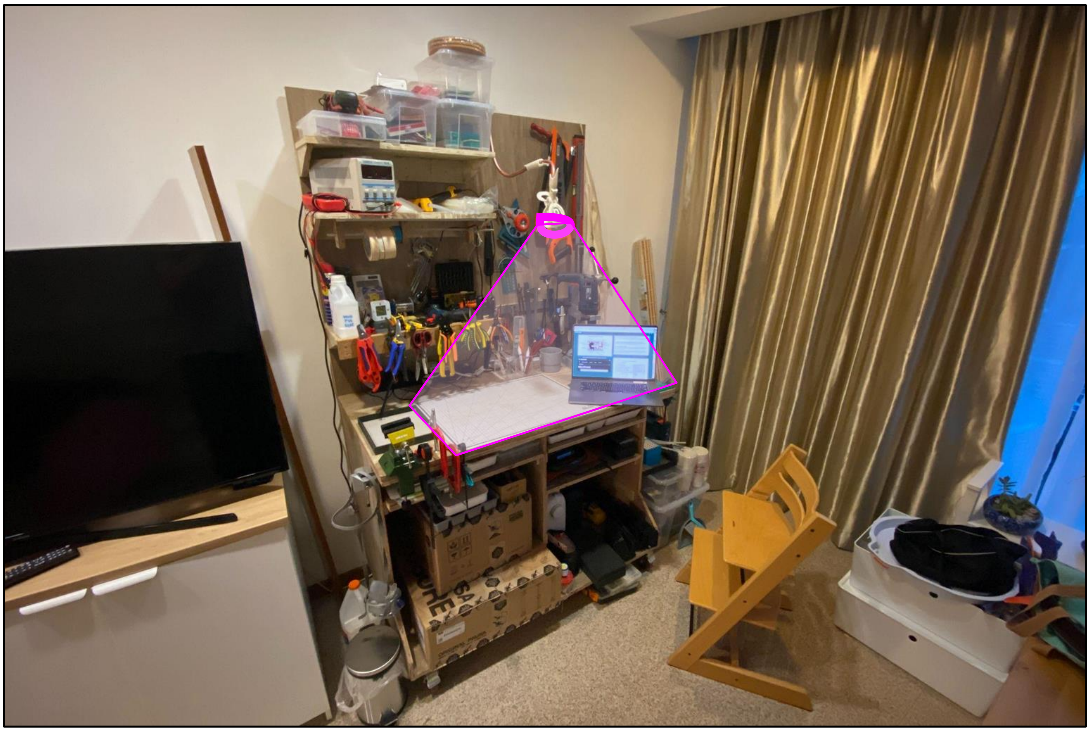
1. Starting with commercially available solar panels and small hydrogen electrolysis machines, the researchers will progressively progress to develop, prototype and test their own designs.
2. Each week, 10 teams adjust their experiments on the floating platform trying to produce as much hydrogen as possible with custom non-toxic catalysts.. Every 3 months, the lowest-performing experiments are replaced by new concepts, and possibly new teams.
3. The website allows us to monitor in real-time the weather conditions as well as document and share what each team is doing in terms of chemistry, material science, hydrogen production. This allows for a transparent collaborative and competitive research and development process which is common in events such as “Hackathons”.

At this rate, over the course of one year, the platform would be able to support:

Table 4. Calculating the number of experiments for one platform over one year.

10 research lines * 52 weeks = 520 experiments / 1 year

Figure 5. “MakerBench”. “Single table FabLab” to maintain the platform and support experiments



On board of the platform there should be a workbench, with the tools necessary to maintain the platform and also prototype experiments, document and communicate with an overhead webcam on a flexible arm. This way, the platform is always connected and the collaborators at sea, can work with with their remote counterparts, making a local project, global.

4.4 Scaling up operations (Aug 2024 - Open ended)

It is too early to early to know what will happen on the platform and how well the experiments will perform, but the project has gathered a lot of interest in Bali and beyond. In this part of Indonesia, there is a strong desire to replace fossil fuels, rare minerals and metal batteries with greener alternatives. The population of Bali is also cosmopolitan and our study site is very close to the airport, easily accessible to the public, and regularly visited by local and international volunteers and visitors alike, also thanks to the popular seafood restaurant.

It is satisfying also to note that even if the hydrogen production is low, the installation will still be useful for

- Immediately reducing fossil fuel electricity usage and cost for the restaurant refrigeration and lighting.
- Education as we will all certainly learn a lot.
- Tourism as many visitors will see the platform and hear about the research effort.

5 Results

In our experiments methodology we found that:

1. Using Speculative Design is a potent way to engage the local population through imaginative workshops, the making of prototypes, stories, role playing, films and website that tell stories of "what could be".
2. Mixing local, indigenous, youth, elders and global visitors is a great recipe to generate a wide variety of ideas while reaching a lot of depths in many different areas.

On the technical side:

3. Low pressure hydrogen is relatively easy and safe to prototype for the key components or substitute being accessible almost anywhere
4. There is a very strong interest from the public at large to learn and participate in the development of green energy. Also a very strong interest from academic, industrial, investor and government [14] to evaluate how such energy would serve their constituencies.
5. Hands-on parallel experimenting, documenting and sharing is an effective approach to develop early-stage designs, prototypes, and test use-cases, that are necessary to increase industry adoption.
6. Having an inclusive and open-science approach is leading us to design technology solutions that are low cost, lost risk, and possibly scalable fast

6 Research limitations / implications

1. **Sample size**. The education and R&D system developed is suitable to run 10 parallel experiments, for a maximum of 40 researchers simultaneously. We believe that there is a "sweet spot" in terms of numbers of parallel experiments that maximizes the individual and collective rate of learning and produces conclusive and industrially-useful results.
2. **Replication of the experiment**. Indonesia and Bhutan are a very different and unique energy markets. While Indonesia is a vast archipelago, Bhutan is a very mountainous, relatively low-resource country that is a large clean energy exporter yet not expected to be a leader in hydrogen production globally [15]. Despite of being a large energy producer, Bhutan suffers seasonal energy shortages [10]. Bhutan is unique for many other reasons in terms of culture, relationship to nature and how GDP is not the main success indicator - but rather GNH (Gross National Happiness) [16]. All these unique traits make it hard to replicate the Indonesia design in the Bhutanese context.

7 Practical implications: Thimphu, Bhutan.

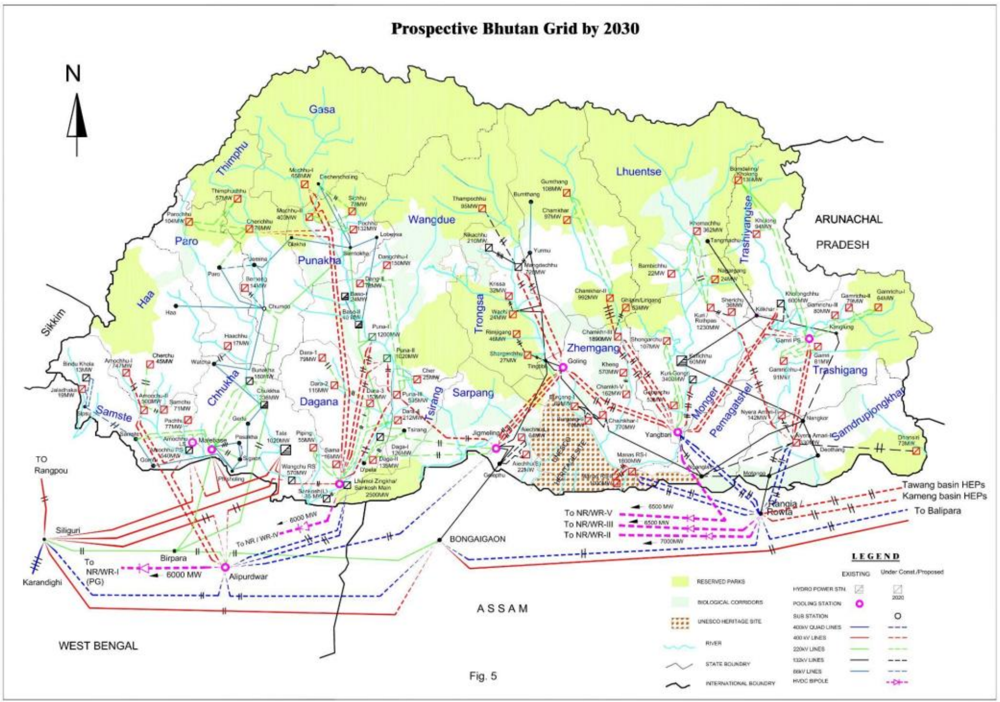
While the previous research and prototyping has been done outside of Bhutan (in Indonesia, Malaysia, Singapore, Hong Kong), some of the findings may be transferable to Bhutan where domestic usage of electricity per capita is also low. We are using consumption figures for the study "Feasibility of renewable energy storage using hydrogen in remote communities in Bhutan" by D.C. Young, G. A. Mill, R. Wall. [17]

As we attempt to transfer what we have learned in Indonesia to Bhutan, these questions arise:

Table 5. Basic questions we are asking ourselves in the Bhtuanese context.

	Question	Considerations
1	**Where** should we locate this research facility?	● Near an excess energy source ● Geographically safe (avoiding landslide, flooding area, high biodiversity area) ● Away from residential area in case of explosion and fire ● Easily accessible by the experimentators ● Near a community that is welcoming the project
2	**Who** should be part of this experiments?	● Find a responsible supervisor for theses open experiments and ensure the safety, creativity and accountability of the participants ● Network and create incentives for participants ● Facilitate the elaboration of research protocols ● Admit the selected participants based on criteria collectively defined.
3	**What** can they use hydrogen for?	While it is good to have green hydrogen, it is also very important that it is immediately useful on the ground. In the previous experiment in Bali, the outlined domestic uses were: ● Cooking, by burning the hydrogen ● Electricity for lighting and appliances, by running the hydrogen through a fuel cell ● Mobility, powering a lightweight vehicle such as an electric scooter, by compressing hydrogen in a small high pressure tank. In the greater scheme of things, hydrogen is also regularly use in industrial processes and for chemical applications.
4	**When** is the right time to do this work?	Bhutan has very contrasted seasons, with a wide temperature range. In the planning It is important to do appropriate work depending on the season.
5	**How** should the experiment and the future businesses be structured to benefit all?	Bhutan key indicator of success is happiness (rather than GDP). Such positioning may create a very positive climate for green energy storage. There is also a strong arts and craft culture, with many people that are good at making things. We are thinking in particular about the textile industry that could be very valuable in engineering flexible, low cost gas envelopes to store hydrogen at low pressure.

Figure 6: Central Electricity Authority, System Planning & Project Appraisal Division, Sewa Bhawan, R K Puram, New Delhi, India. "National Transmission Grid Master Plan (NTGMP) for Bhutan. Vol-I. In fulfilment of consultancy rendered by CEA to RGoB" Page 32. April 2012. Retrieved July 2023. https://cea.nic.in/wp-content/uploads/page/2020/12/ntgmp_volI.pdf



The region near the Baso 2 Hydroelectric power plant is not far from the capital city of Thimphu.

Thimphu is the host of a large SuperFabLab that is well equipped. The local knowledge in textile manufacturing will also be valuable to design and prototype gas envelopes using local materials.

Table 6: How hydro-powered generated hydrogen experiments could be started at a very small scale in Bhutan.

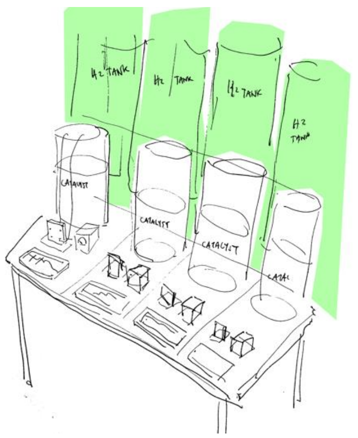
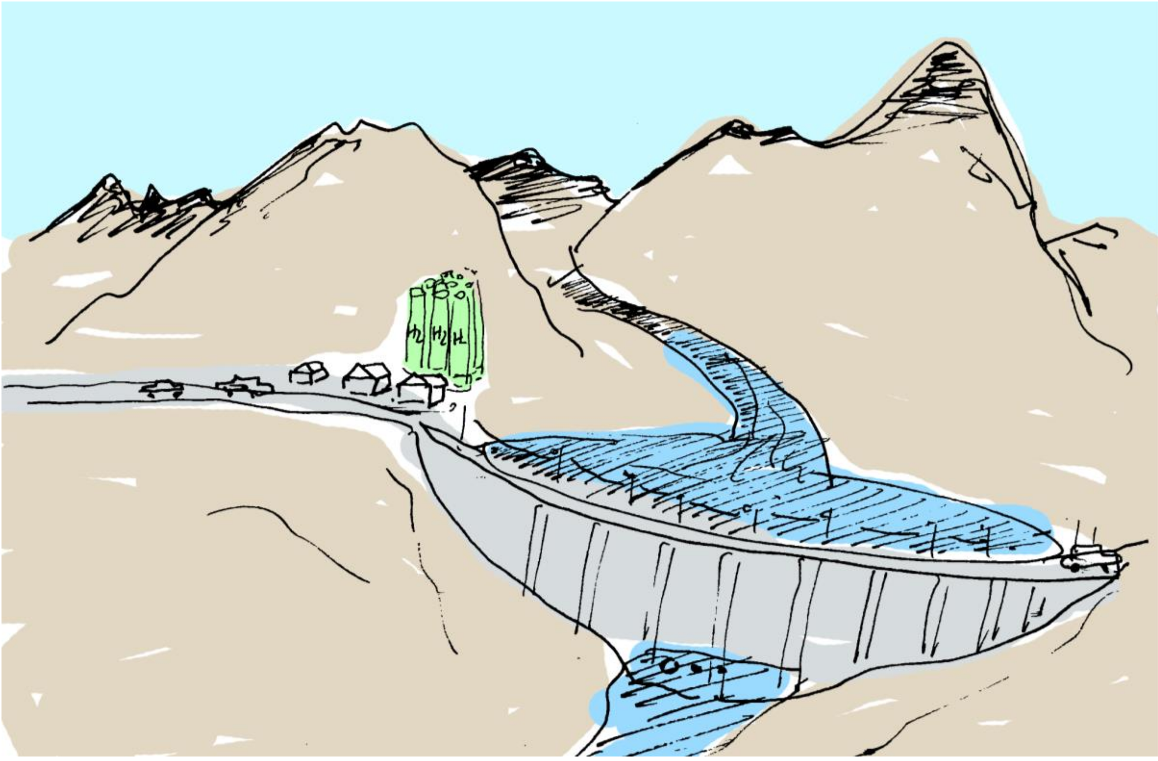
	
Thimphu SuperFabLab is well equipped https://www.fablabs.io/labs/BhutanSFL	The early experiments could be done using only a tabletop and small power supplies

Figure 7: artist impression of a flexible hydrogen storage near a hydroelectric dam in the mountains of Bhutan.



Eventually, the pilot can be done at a larger scale, nearby a hydroelectric facility. A larger facility could accommodate may more research lines, multiplying experiments, producing big data and possibly leveraging AI to explore even more electrochemical combinations.

8 Discussion

As global warming is affecting the livelihood of an increasing number of people, we are forced to look for ways to mitigate and adapt to these new constraints, even if it is not economical initially. For every innovation, the process of research and development is inherently wasteful, but necessary. In July 2023, hydrogen is not a financially competitive option yet, most of it is produced from fossil fuel [18], and it has not gained economy of scale yet. But by its abundance, availability everywhere, and the fact that using it produces no environmentally negative byproduct, makes it a particularly desirable storage of energy worth pursuing for the long run.

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In the field of environmental conservation, research studies have demonstrated that it is the indigenous people that are some of the most effective environmental conservationists. Intuitively it makes sense since most indigenous people live what urban dwellers see as “nature” and are entirely dependent on their surrounding natural resources. In a sense, every single human group has been adapting to its local conditions, innovation after innovation, so we – urban dwellers – have much more to learn from indigenous knowledge, know-how and sensibilities. [19]

This research started by looking at the specific challenge of storing green energy in the cleanest way possible, hydrogen. As we are doing this work we are discovering social and behavioral patterns of innovation with indigenous, and in low resources contexts. Even if we these experiments are all still on-going, it has been clear that all the participants have appreciated having some sort of financial ownership, governance of the project, and the prospect of having a piece the intellectual property, the means of production and the commercialization of the product.

On the technical front, large flexible gas and liquid bladders have seen rapid improvements. They have become easier to manufacture in all sizes and shapes, applications, versatile in how they can be deployed, stationarily or mobile, including in extreme weather conditions.

Table 7: large flexible fuel bladders in a variety of contexts and applications

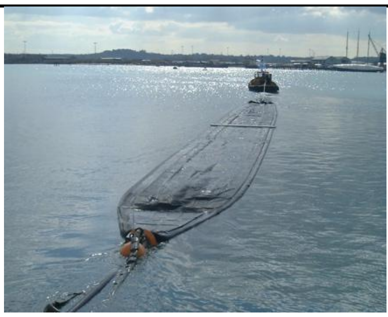
	
Airmen from the 380th Expeditionary Readiness Squadron unroll a fuel bladder at the DOD's largest fuel bladder farm, at Al Dhafra AB, UAE. Photo by Jennifer Hlad. Retrieved July 2023. https://www.airandspaceforces.com/fueling-freedom/	Fuel bladders field, by Techno Group. Retrieved in July 2023. https://www.technogroupusa.com/fuel-bladders-tanks/ Such products are readily available. https://www.water-storage-tank.com/flexiblefueltank.html
	
Fuel bladder ranging from 380 L to 760,000 L capacity moved on ice. Retrieved in July 2023. https://academic-accelerator.com/encyclopedia/fuel-bladder	The Dunlop Dracone barge "Trelleborg Flexible Liquid Containment Solutions" with a capacity just under 1000m3 behind a towing boat. Retrieved July 2023. https://dunlopgrgblog.files.wordpress.com/2014/11/dscf0020.jpg

Table 8: aesthetic parallel

	
Arctic King Fuel Bladder, 125,000 L each, with low cold-crack temperature below -46C. Retrieved July 2023 https://www.sei-ind.com/products/arctic-king	Bhutanese Prayer flags. Credits: Pawo Choyning Dorji. Retrieved July 2023. https://bhutanage.com/2020/09/11/prayer-flags/

It does not take a great effort of the imagination to visualize how Bhutanese aesthetic may appropriate large hydrogen storage bags.

9 Conclusion and original value of the paper

Throughout the project, we have experienced that Innovation in the energy sector can be **inclusive**, with experts and beginners, young and senior, urban and indigenous, local and international. Alternatively, to the well know process of Design Thinking, **Speculative Design** may be a more appropriate approach to get people to “open up” and create future visions in the context of international development work with minority groups. **Role-playing “with props” and storytelling** can help to collectively set the agenda of what technology could and should do. This participatory and open approach appear to be a credible way to rapidly co-develop Climate innovation in the face of the multi-crisis.

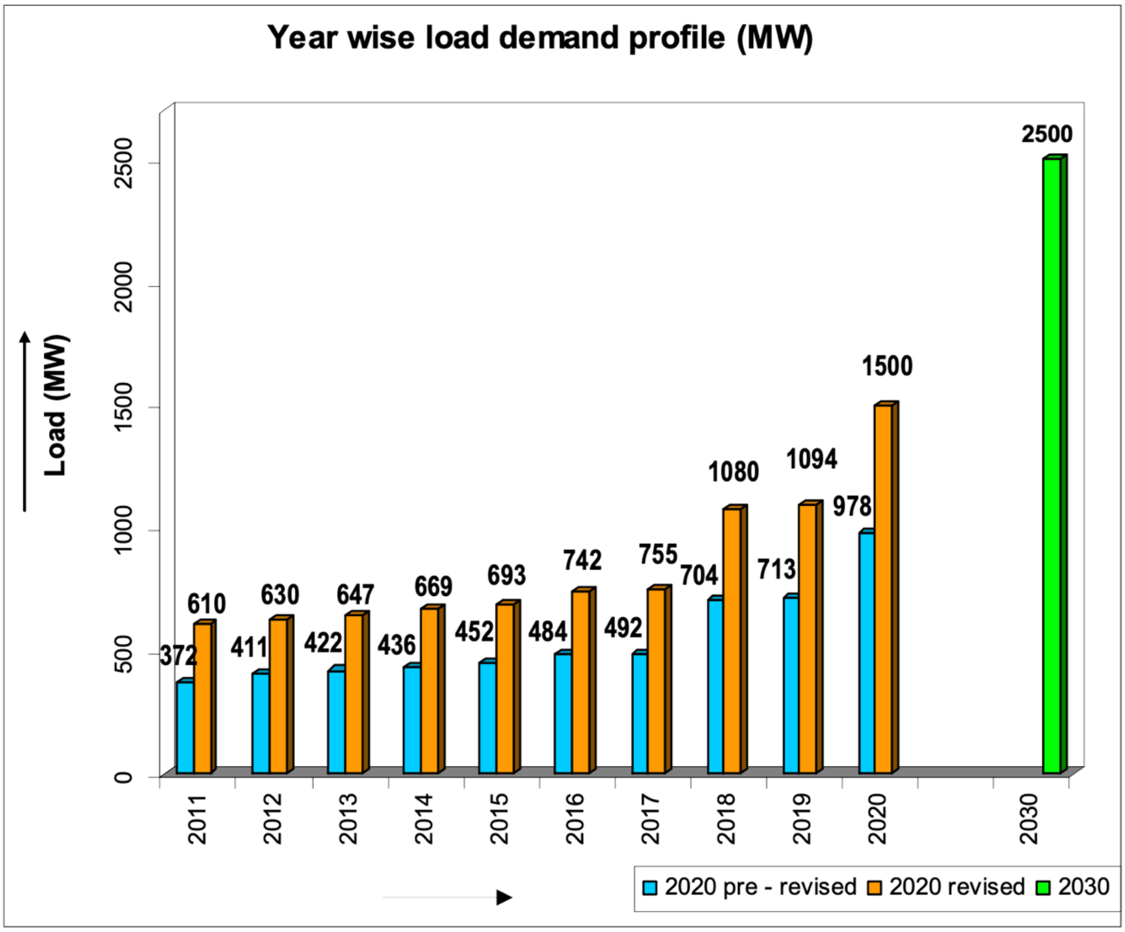
Unlike celebrated art forms such as cinema, theater or danse that are clearly about creating imaginary worlds, Speculative Design is still a niche that is often misunderstood, considered grey area, possibly more fine art rather than design. For that reason, the utilization of Speculative Design in the context of development work must be clearly explained as the methodological framework from the start. Speculative must be complemented by other disciplines to produce a lasting impact.

In the Indonesian case study, we are entering a more advanced phase in which more private and public interests are starting to compete. We are transitioning from the “Speculative Design as community building” phase to the “Design & engineering with local indigenous communities. Ownership and environmental assessment” phase in which real world risks and opportunities are pressing, requiring a change in strategy and positioning.

Bhutan energy demand is poised to rapidly grow in the coming years, while its debt to GDP dangerously increases [5]. Bhutan needs to improve its ability to manage its energy and trade.

Figure 7: Central Electricity Authority, System Planning & Project Appraisal Division, Sewa Bhawan, R K Puram, New Delhi, India. "National Transmission Grid Master Plan (NTGMP) for Bhutan. Vol-I. In

fulfillment of consultancy rendered by CEA to RGoB" Page 21. April 2012. Retrieved July 2023. https://cea.nic.in/wp-content/uploads/page/2020/12/ntgmp_voll.pdf



Bhutan with its abundant and fast-growing hydroelectric supply, dependency with India and supportive civil society when it comes to innovation with its network of FabLabs has all the components for attempting to tackle this globally strategic technological race in a new and unique way. We think the method we have employed in Indonesia has some merits; and while it is hard to anticipate the quality of the outcomes in the Bhutanese context, might be worth attempting in the early stages to engage a variety of stakeholders and produce strategic designs directions.

Acknowledgements:

This research has been sponsored by Amber Initiative (USA), Supply Frame (USA), Seeed Studio (China), MakerBay Foundation (China)

References

[1] Asia Development Bank, "Bhutan: Sector Assessment (Summary): Energy", [Online]. Retrieved July 13, 2023. Available: https://www.adb.org/sites/default/files/linked-documents/cps-bhu-2014-2018-ssa-01.pdf

[2] Amit Ranjan, "India-Bhutan Hydropower Projects: Cooperation and Concerns" October 2018, ISAS Working Paper, NUS Institute of South Asian Studies. Retried July 13, 2023. https://www.isas.nus.edu.sg/wp-content/uploads/2018/10/Working-Paper-No.-309-India-Bhutan-Hydropower-Projects-2.pdf

[3] Andrea, "Envelope tutorial, Silent-Runner," 2022. Retrieved July 13, 2023. http://silent-runner.net/index.php?title=Envelope_tutorial

[4] The World Bank "Sustainable Hydropower Development Project. Identification/Concept Stage (PID). Report No: PIDC225036". 25-Sep-2020. Retrieved July 13, 2023. https://documents1.worldbank.org/curated/en/711541601227609171/pdf/Project-Information-Document-PID-Sustainable-Hydropower-Development-Project-P174327.pdf

[5] NIDUP GYELTSHEN and PHUNTSHO WANGDI, Nikkei.com. "Bhutan growth soars amid hydropower building boom. Rising debt to India could make country the Greece of South Asia, critics say" UGUST 17, 2017 14:00 JST. Retrived July 13, 2023. https://asia.nikkei.com/Economy/Bhutan-growth-soars-amid-hydropower-building-boom

[6] Pradipto Chakrabarty "THE BASICS YOU NEED TO KNOW & UNDERSTAND ABOUT SPECULATIVE DESIGN", UX Planet. Jan 25, 2023. Retrieved July 2023. https://uxplanet.org/the-basics-you-need-to-know-and-understand-about-speculative-design-8a8bf5be4162

[7] FabLab Bhutan. https://www.fablab.bt/

[8] Appropedia. Chris Watkins, RichardF, Lonny Grafman (2006–2023). "Appropriate technology". Appropedia. Retrieved July 20, 2023. https://www.appropedia.org/Appropriate_technology#:~:text=Appropriate%20technology%20(AT)%20is%20technology,be%20sustainable%2C%20small%20and%20appropriate.

[9] Low Tech Lab, Corentin de Chatelperron. Retrieved July 2023. https://lowtechlab.org/fr/actualites-blog/equipe-low-tech-lab-corentin-de-chatelperron-co-fondateur

[10] Navi Radjou, Jaideep Prabhu & Simone Ahuja. "Jugaad Innovation: Think Frugal, Be Flexible, Generate Breakthrough Growth". Retrieved in July 2023. https://naviradjou.com/book/jugaad-innovation-think-frugal-be-flexible-generate-breakthrough-growth/

[11] C. Jung-Harada, “Balon Balon Ijo.” Retrieved July 13, 2023. https://balon.energy/

[12] Seeed Studio, “SenseCAP Sensor Hub 4G Data Logger - with built-in rechargeable battery version.” 2023. [Online]. Available: https://www.seeedstudio.com/SenseCAP-Sensor-Hub-4G-Data-Logger-with-builtin-battery-p-4852.html?queryID=42aeffe0eafaa243286391a432768bf0&objectID=4852&indexName=bazaar_retailer_products

[13] D. Young, G. Mill, and R. Wall, “Feasibility of renewable energy storage using hydrogen in remote communities in Bhutan,” *Int. J. Hydrog. Energy*, vol. 32, no. 8, pp. 997–1009, Jun. 2007, doi: 10.1016/j.ijhydene.2006.07.002

[14] The hydrogen and fuel cell center ZBT GmbH, “Bhutan’s Prime Minister Lotay Tshering is eager to learn about the hydrogen technology and economy.,” Mar. 2023. https://www.h2fc.center/nc/en/news/news-anzeige-eng/detail/News/hydrogen-economy-prime-minister-of-bhutan-informs-himself-at-zbt/

[15] A. Klevstrand, “Which ten countries will be the biggest producers of green hydrogen in 2030?,” Feb. 17, 2023. https://www.hydrogeninsight.com/production/exclusive-which-ten-countries-will-be-the-biggest-producers-of-green-hydrogen-in-2030-/2-1-1405571

[16] A. Zhou, W. Zhou, and P. Manandhar, “A STUDY ON THE PROSPECT OF HYDROPOWER TO HYDROGEN IN NEPAL.” Asia Development Bank, Aug. 2020. [Online]. Available: https://www.adb.org/sites/default/files/publication/631781/study-hydropower-hydrogen-nepal.pdf

[17] S. Tzung, “Carbon Negativity In Bhutan: An Inverse Free Rider Problem,” Sep. 12, 2022. https://hir.harvard.edu/carbon-negativity-in-bhutan-an-inverse-free-rider-problem/

[18] "The Future of Hydrogen. Seizing today’s opportunities. Technology report" IEA (International Energy Agency), June 2019. https://www.iea.org/reports/the-future-of-hydrogen

[19] UNEP "Unsung heroes of conservation: Indigenous people fight for forests". 05 APR 2023 . Retrived July 2023. https://www.unep.org/news-and-stories/story/unsung-heroes-conservation-indigenous-people-fight-forests