Capital vs. Human Focusing on Solutions for Societal Equity

Hydrogen-Powered Trains

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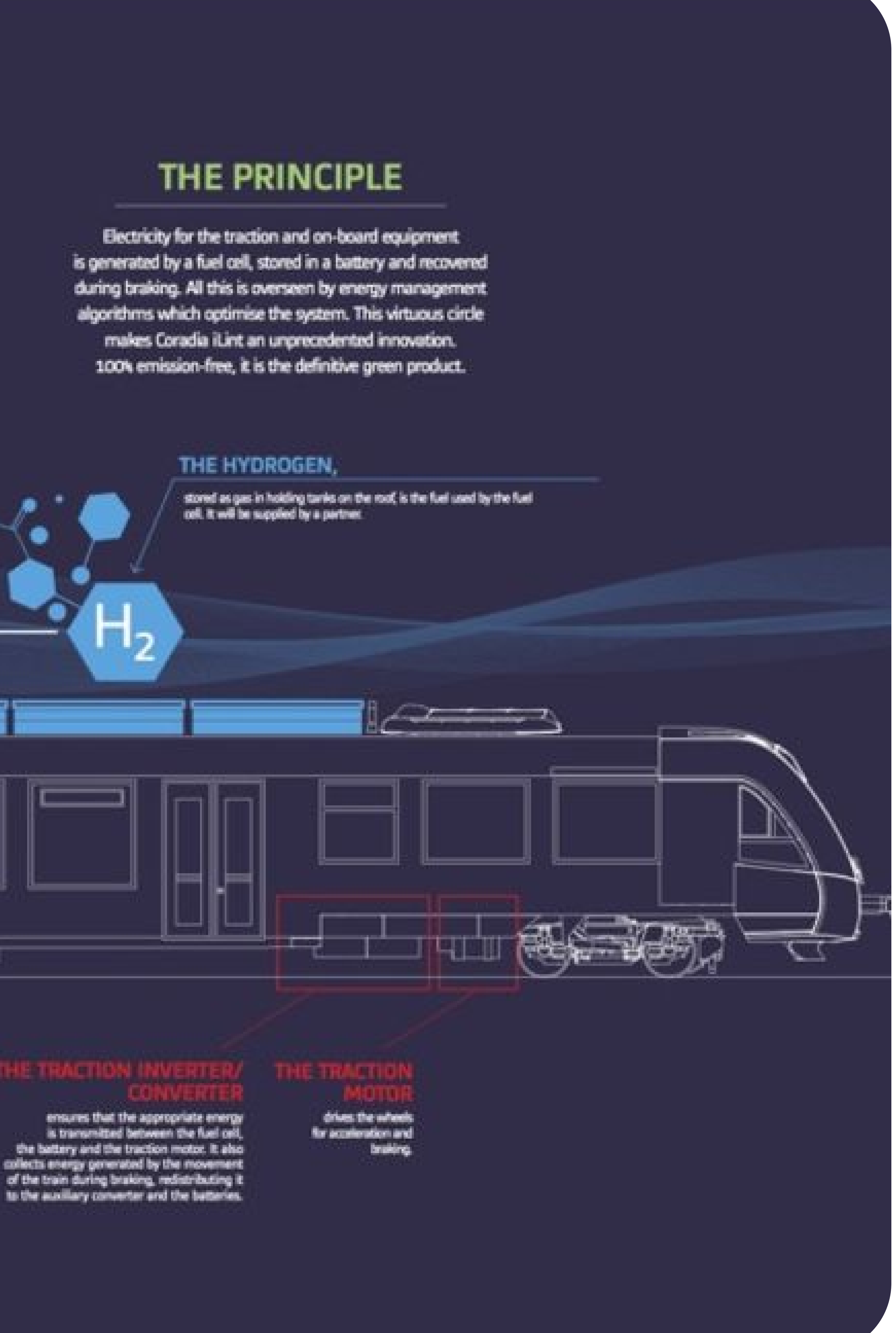


Contents of the Report

Introduction to Our Process

The goal of this semester was to understand the feasibility of hydrogen powered trains. To do so we

1) Needed to understand the current state of hydrogen and renewables throughout the world
2) Suggestion where and why it would be best to implement the trains
3) Research the financial and economic cost of our suggestion

Our steps were for each module was

1) Acknowledge our assumptions
2) Research through credible sources like news articles, existing companies, and science journals
3) Look for counter-arguments to understand all slides to the issue
4) Get mentors perspective
5) Remain critical to the information we say and statements we made

Defining the Problem

Laying out our assumptions

- Specific forms of hydrogen are not a viable form to utilize for a transition.
- Most industries are willing to invest in a fossil-free transition to a certain extent while rail transportation is already low-cost, so there is no financial incentive to switch to hydrogen specifically.
- Hydrogen’s biggest competitor is electrification (e.g., battery transportation).
- Switching to hydrogen will be too complex to implement via governmental policy alone. The private sector/entity is needed.
- Renewables are not yet up to scale for US energy needs and the American railroad infrastructure is not ready for these types of significant changes.
- The hydrogen trains in passenger cars will only attract middle to high-income users and further inequity unless addressed.

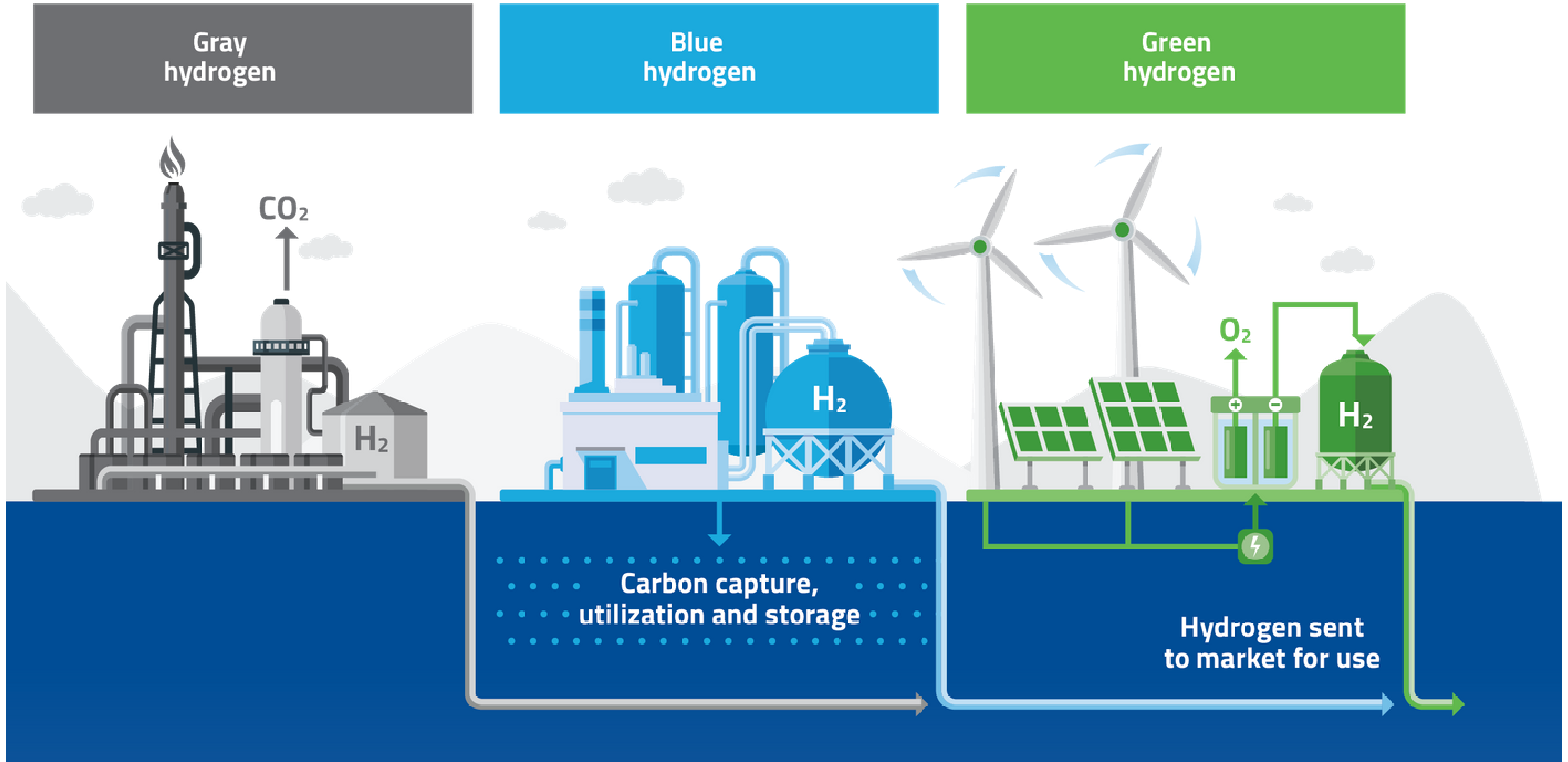
The Current State of Hydrogen

The Use and Cleanliness of:

- Blue Hydrogen
- Green Hydrogen
- Grey Hydrogen
- Fuel Cell Types
    - Alkaline Electrolyzer
    - Polymer Electrolyte Membrane
    - Solid Oxide Electrolyzer

Comparing Other Energy Sources

- Solar / Wind
- Natural Gas / Fossil Fuels



Gray (sometimes called 'brown') hydrogen is produced through fossil fuel processes. The process of producing it releases carbon straight into the atmosphere. Today most hydrogen is produced this way.

Blue hydrogen still depends on fossil fuels to produce hydrogen, but this occurs in plants equipped with carbon capture and storage. This makes it possible to reduce the carbon sent into the atmosphere using proven existing technologies.

Green hydrogen is an inexhaustible energy carrier that can be produced using renewable electricity to power an electrolyzer to produce hydrogen from water.

Understanding the Transportation Sector

The move to zero-emission transportation forces countries to confront their dated infrastructure and improve it for consumers and save operation costs.
This confrontation of old instruction brings out systematic issues on how the country handles change in the private and public sectors.

The USA

- Freight Trains are the majority user of the rail system
- Has legislation in place to push towards zero-emission transportation
- The culture leans towards individual traveling rather than using public methods

Europe

- Has the most concentration of running hydrogen trains
- On track to meet Paris Climate Agreement
- Aims to switch over all passenger trains to Hydrogen Fuel Cell by 2030

Asia

- Has plans in motion to switch to HFC
- Not much news on development
  - Focus is on passenger trains

Debunking Rebuttals

Storage of Hydrogen

Unsafe to store and have close to people

Not suitable for large scale implementation

The Cost

Transition to a net-zero hydrogen source going to be possible when green hydrogen is too expensive

Increasing capability vs. keeping it affordable

Stages to Supporting the Switch to Hydrogen

- Investment into R&D through grants
- Feed in Tariffs throughout industrial applications
- Governmental programs to build or abate infrastructural development
- Federal tax credit on railroad corporations and suppliers developing initiatives for hydrogen fuel-cell trains
- Training programs to ensure it is used with proper safety and environmental controls

Value Proposition

Proposed Solution

Laying out our assumptions

- In the medium term, the US could deploy hydrogen trains that run on a limited route (where there are hydrogen refueling stations). The EU could deploy more hydrogen trains with better technical quality due to their proactive policies and more remarkable ability to source renewable energy.
- In the long term, trains solely powered by hydrogen in the US can be feasible when renewable energy is available to produce green hydrogen grows and costs of hydrogen fuel cells and hydrogen drops (from demand due to other hydrogen applications).
- Hydrogen trains can be a good solution in regions where electrification is not logistically ideal and can allow for better connection of people who are living in isolated regions where electrified rails do not exist.

The Value of Hydrogen

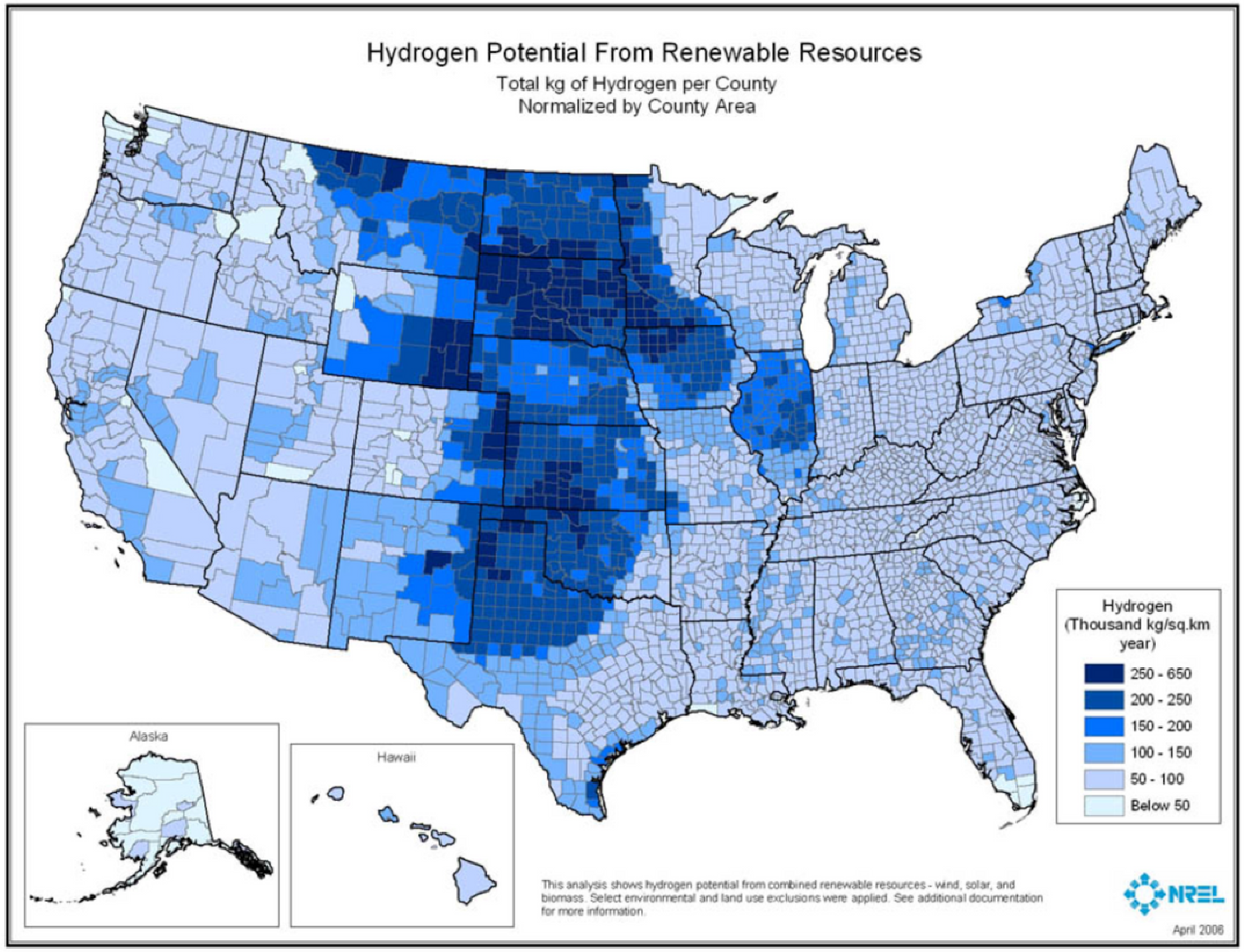
a switch to hydrogen is feasible in this environment as many banks and organizations offer sustainable finance solutions/transitions.

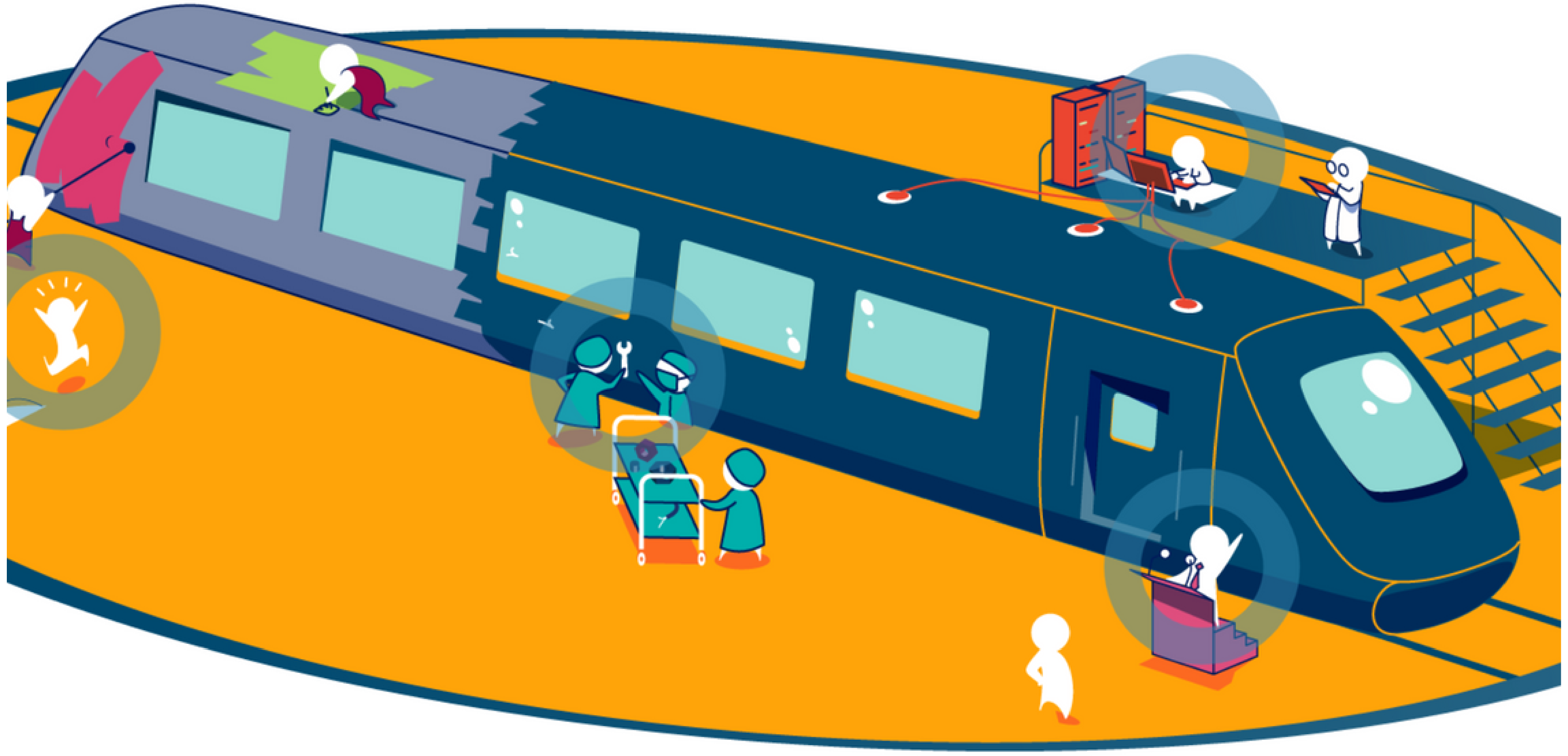
Competitve Advantage

Against Electrification & Battery & Diesel

Hydrogen Potential in USA

Such as renewables & water source & network potential





Logistics of Implementing Hydrogen-Powered Trains

Location

Hydrogen optimal efficiency with heavy loads and long distance, freight trains within the United States seem to hold the biggest potential for hydrogen-powered trains

Using Existing Gray Hydrogen Facilitates

Californian, Texas, and Louisiana can serve as retrofitted carbon capture, usage, and storage (CCUS) prototypes

Process on Implementation

- **Legislative & Investment**
  - Utilize governmentally funded grants for R&D for hydrogen production, delivery, and storage. Funding for such contributions would be rerouted from the approximate $4.9 billion/year in direct fossil fuel subsidies.
  - Engage with energy companies, government agencies, and institutions.
- Focusing on All Four Train Infrastructure
  - rolling stock and components
  - signaling
  - services
  - systems

Operational and strategic risks for intervention and collaboration

- Impacts of COVID-19/current climate status
- Contracts with the partnerships
- Logistics for sourcing the materials
- Risk management with security, accidents, technology, and performance
- Following ethical regulation with internal and regulations adults

2050

We predicted 2022-2050 Hydrogen Trains can be fully running in USA's Class I rail network

2021 - 2030 - Expeditious Next Steps

- Initiating R&D initiatives as well as grant programs to promote
- Focus on attractive solutions and scales

2031-2040 - Preliminary Scale Up

- Hydrogen costs down as demand increases and hydrogen production has promising large-scale projections.

2041-2040 - Diversification

- Expanding hydrogen past the early-adopter/prototyping segments.

Post 2040 - Aggressive rollout across the United States

- At this point, applications of hydrogen can be distributed on a larger scale. For trains, this would mean larger Class I rail lines implementing hydrogen power.

Second Conclusion

Hydrogen trains' trends are rapidly occurring throughout the different types of economies and train rails.

New wave climate-conscious consumer choices and net-zero governmental initiatives. Our overall solution is to push for more private and public investment, universities and institutional R&D, and campaigning the benefits of this type of infrastructure to the public.

As the industry's growth continues, more investment will bring about a positive feedback loop, propelling hydrogen-powered trains into the future.

Financial Argument

Laying out our assumptions on the U.S. Class I railroad fleet:

- 28,000 locomotives in 2020, which increases linearly.
- 92,282 miles of track in the U.S. class I railroad operators fleet.
- The same number of tender cars as locomotives.
- Locomotive structure costs $300,000 for HFC use.
- Locomotive structure costs $1 million for electrical use.
- Average train weight of 8,800 tons.
- Average output of 12,000 horsepower.
- Linear prices of HFCs and batteries.
- $15/kWh for pressurized gas hydrogen tanks
- "Tender" car structure costs $150,000.
- $2.5 million to electrify a mile of track.
- The conversion rate of either transitioning from diesel to hydrogen or diesel to battery starts in 2026 at 5% and incrementally increases by 5% every 5 years.

Cost of Infrastructure

Sourcing Hydrogen

Comparing costs of different methods of hydrogen production, transport, and storage

The Roll Stock and Components

Locomotives
Tender Cars
Boxcars, etc.

Scale to Implement

Starting in 2026 at 5% conversion rate and increasing 5%+ ever 5 years

Consumer Power

Customers demanding cleaner trains and using more eco-friendly systems

From conducting a cost analysis, the most ideal method of sourcing hydrogen would be to build conventional hydrogen refueling stations that rely on delivery of hydrogen and modular hydrogen refueling stations that can act as hydrogen storage (and optionally, production) sites.

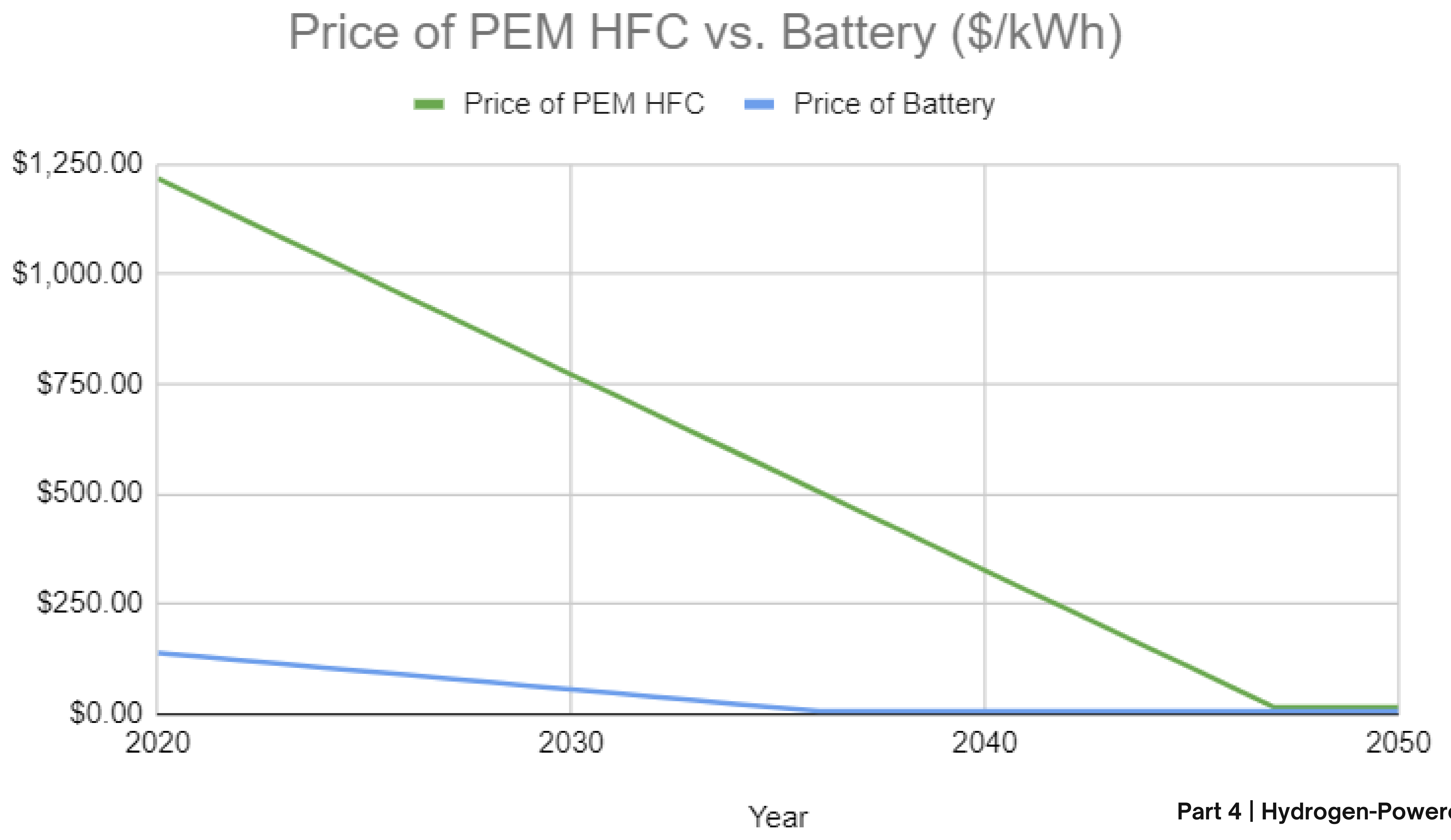
It costs $3.04M for the installation of a conventional station with a 100kg H2/day capacity and for 1 day's worth of H2 (50,000 kg). And it costs $2.82M for the installation of a modular station.

In the case that refueling stations with on-site hydrogen production are necessary, stations that utilize renewable-energy powered electrolysis are more economical than on-site SMR with CCUS, which may incur carbon taxes in the future.

For a carbon tax of $4 per ton of CO2 emitted, 50,000 kg of SMR-produced hydrogen and SMR with CCUS would incur carbon tax values of $2,152.96 and $977.28 respectively.

Meaning 50,000 kg will cost $4,824.28 instead of $3,847.00 and for regular on-site SMR and on-site SMR with CCUS while on-site electrolysis hydrogen will cost $3,966.00.

Getting into the Costs



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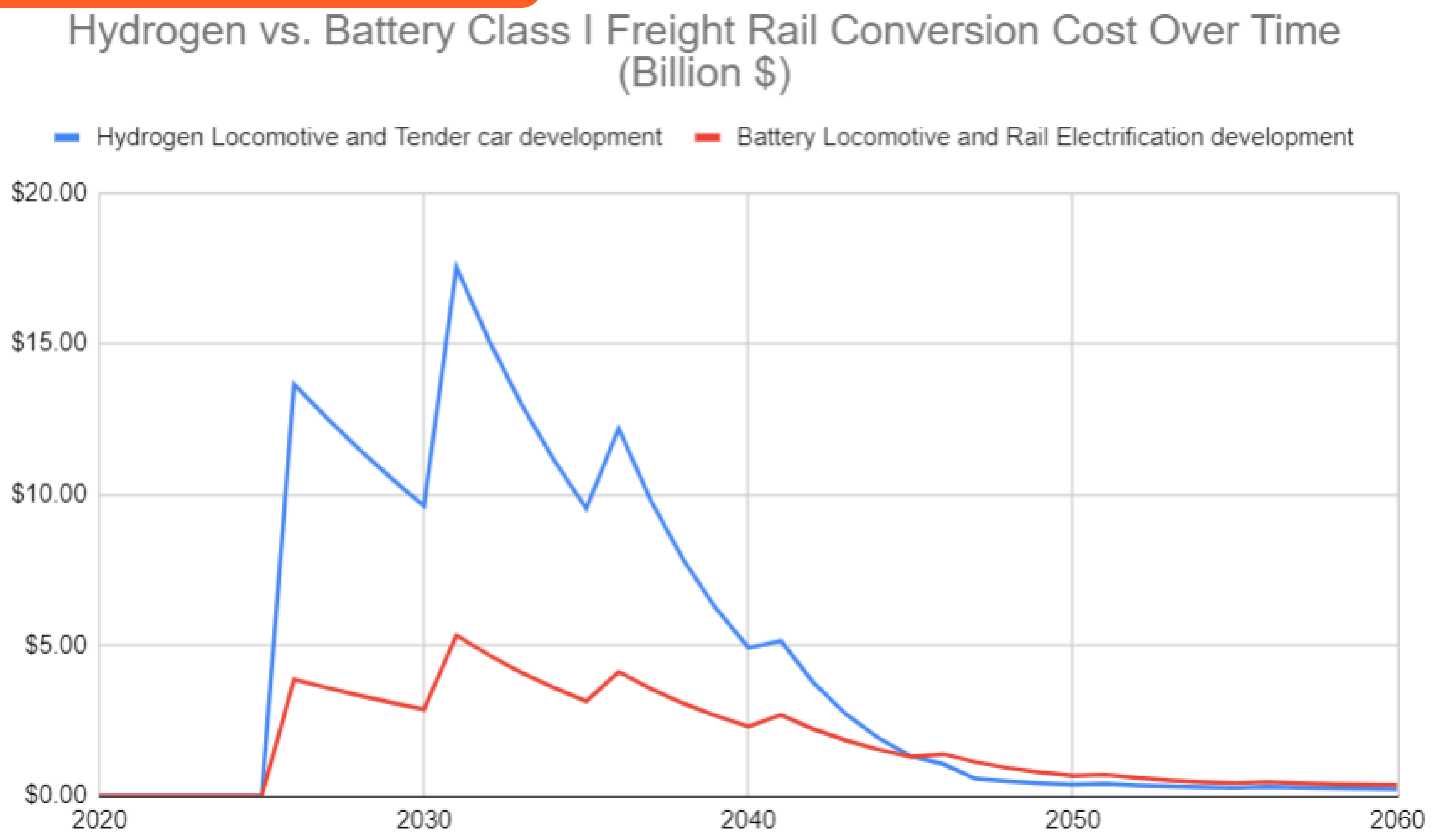

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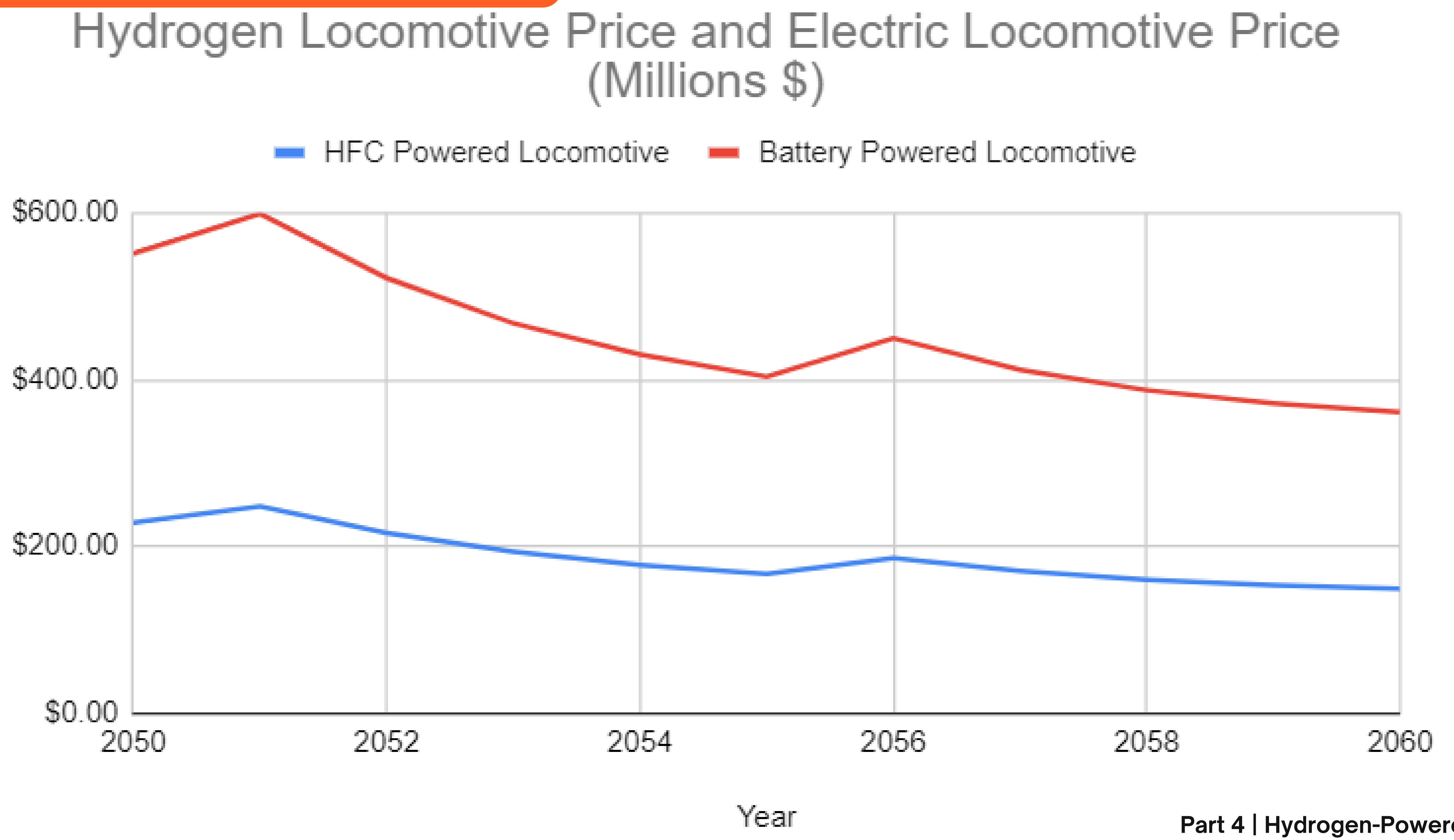

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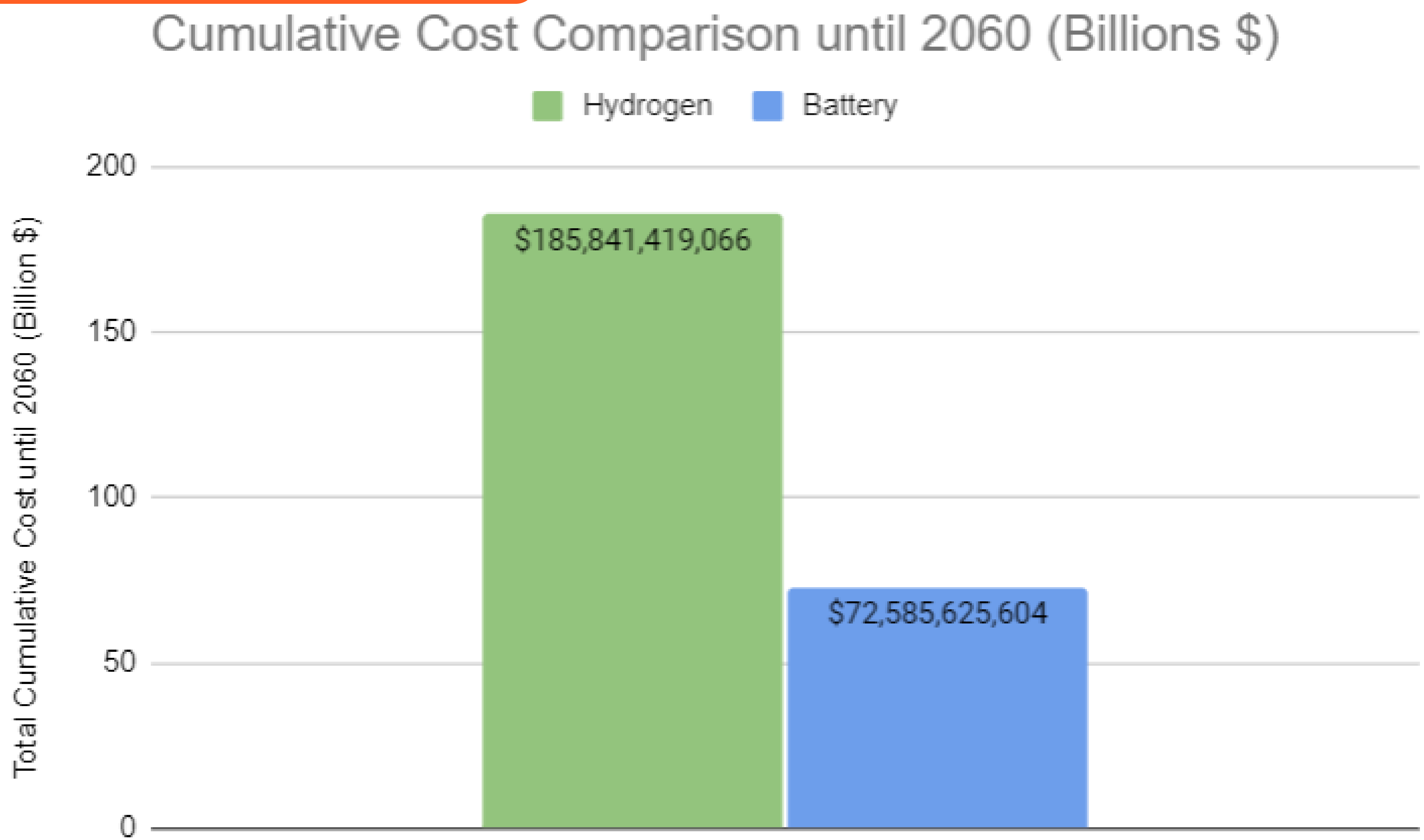

Final Notes

Proposal

Focus on R & D and legislations of hydrogen development for other sectors.

Electrification might be the way to go.

Things to continue to consider

Opportunity Cost to charge/refuel

Opportunity Cost of unutilized tracks during electrification

Lifetime of a train

Efficiency over time

Contributions of CCS as it aligns with Carbon Tax

Final Notes

Hydrogen Trains are a more expensive option when analyzed on a surface level, and would require a larger amount of governmental support and R&D to compete with the pricing of batteries in order to become competitive.

We are excited to have researched the feasibility and see the implementations occur in all stages.

Thank you for listening!

Contact

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