# VOLTIAK

Grid scale energy storage. Sixten Wall, 2021

LUNDS UNIVERSITET

Voltiak - Grid energy storage
Sixten Wall

Degree project for Bachelor of Fine Arts in Design.
Main field of study: Industrial Design.
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# Abstract

The main theme of this project is approaching the entire design process with logic thinking and feasible solutions at the core. Starting off with green house gas mitigation as the leading motivator, using relatively low technology - to solve a high importance issue. The result is a system based on widely available technology, re-imagining grid level energy storage system as a mechanical and highly viable solution.

# Acknowledgements

I would like to give a special thanks to everyone who has supported me in this project. Friends, family and classmates. This year has been upside down and the lack of face-to-face time with peers has definitely slowed the feedback system. Having my friend and former Industrial Design student Alexander Arcari available as the digital equivalent of classroom feedback has been very helpful, so I would like to give a special thanks to him. I would also like to give Andreas Hopf a special thank you, for having a very enlightening video-call in the initial stage of the project.


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# Sustainability and me

I love the planet, I want to see more of it and I want to take care of it. But like so many others I am torn between lifestyle choices. For an example what hobbies am I morally allowed to have (my big vice being motorcycling), what diet I should have and how strict I should be in my career choice? It is a constant debate, should one aim for the smallest possible impact or should one aim for the biggest possible impact? Having all of this said, it is way too easy to be confused by all of the green-washing propaganda we are fed through marketing and social media.

Most of the "sustainable" products, in the industry as well as in education, are guilty of further fuelling this cluster of misinformation. Sustainable, green or good for the planet are definitions that are thrown around plentiful and these words are being put as labels on everything from vehicles to disposable products.

Of course I am also guilty of preaching one way and acting another on many occasions. Therefore my main motivation for this bachelor project was to try to find out how to be as sustainable as possible in our profession.

# What is sustainable?

There are a vast array of messages being fed to us on what is actually destroying the environment. Some of them stating that we should abandon single use plastics, we should drive less and we should reduce our consumption. All of the above are viable recommendations to live by, but they are misleading the public to believe that these are the main contributors. If we look into the actual numbers, we can see why the above recommendations are irrelevant for actually getting the global warming situation under control.

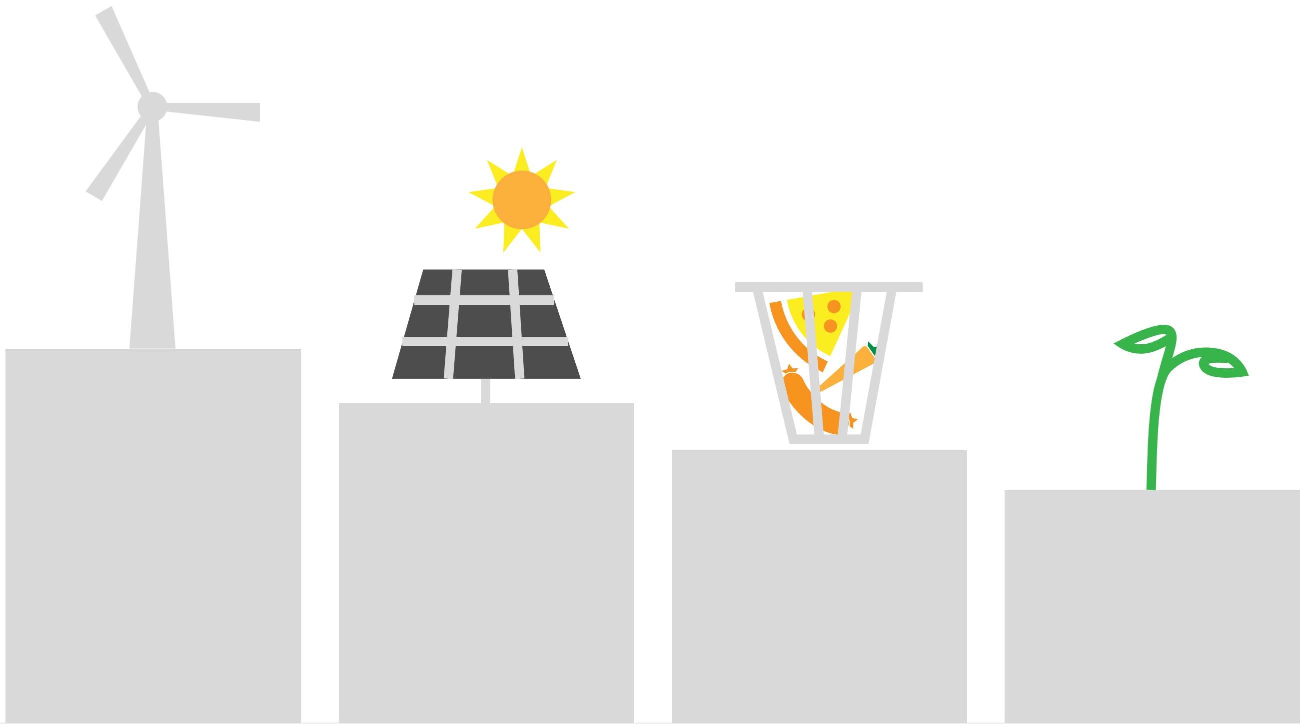
The sources I found all pointed in different directions, but most were not concise and tangible. To be able to compare we must decide on what we are measuring. Green house gas mitigation is then the best way to start!

## Sorting by CO2

This led me to the main starting point: Project Drawdown. Project drawdown is an independent organisation collecting and analysing data to publish areas of improvement in order of sequestered CO2[1]. At first place was Onshore Wind Turbines followed by Utility-Scale Solar Photovoltaic (Grid scale solar power) at second place. Third and fourth place was related to our diets, reducing food-waste and turning to more plant based diets, proving to be the most important steps we can take as individuals. Combining the first and second topic on the list, Wind and solar, we have a possible reduction of 267 gigatons of CO2 equivalent. To translate this to a more relatable number, that is 1,3 Quadrillion (1 300 000 000 000 000) plastic bags. Assuming 7,6 billion people on the planet, that equates to 171000 plastic bags per person, taking the average of 200g[2] CO2 per plastic bag.
That is quite the impact.

# Wind + Solar = 1,3 Quadrillion Plastic bags

That is 171 000 plastic bags per person on the planet



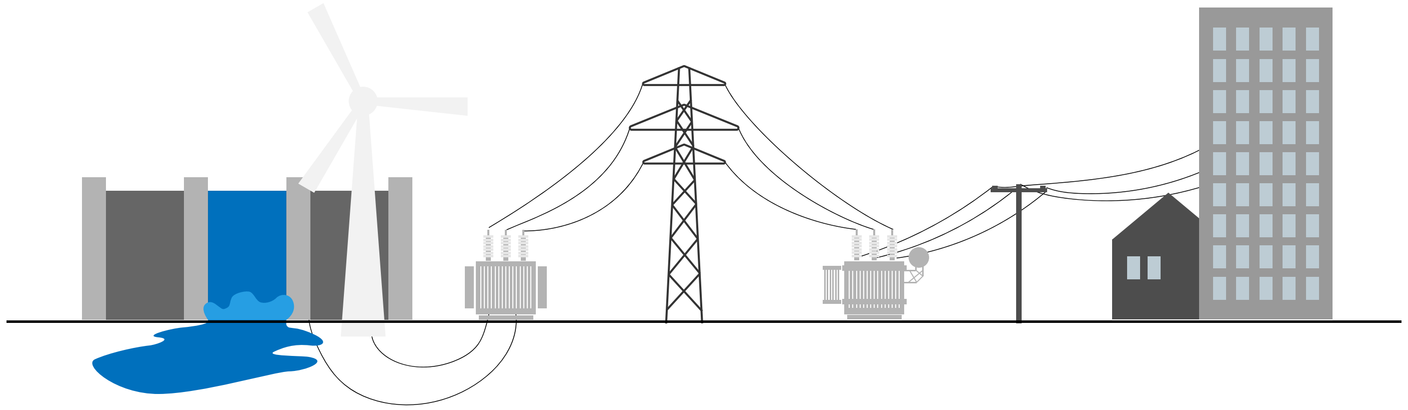
** Gigatons CO2 Equivalent Reduced / Sequestered (2020–2050)*

| SOLUTION | SECTOR(S) | SCENARIO 1 * | SCENARIO 2 * |
|---|---|---|---|
| Onshore Wind Turbines | Electricity | 47.21 | 147.72 |
| Utility-Scale Solar Photovoltaics | Electricity | 42.32 | 119.13 |
| Reduced Food Waste | Food, Agriculture, and Land Use / Land Sinks | 87.45 | 94.56 |
| Plant-Rich Diets | Food, Agriculture, and Land Use / Land Sinks | 65.01 | 91.72 |
| Health and Education | Health and Education | 85.42 | 85.42 |
| Tropical Forest Restoration | Land Sinks | 54.45 | 85.14 |
| Improved Clean Cookstoves | Buildings | 31.34 | 72.65 |
| Distributed Solar Photovoltaics | Electricity | 27.98 | 68.64 |
| Refrigerant Management | Industry / Buildings | 57.75 | 57.75 |
| Alternative Refrigerants | Industry / Buildings | 43.53 | 50.53 |
| Silvopasture | Land Sinks | 26.58 | 42.31 |
| Peatland Protection and Rewetting | Food, Agriculture, and Land Use / Land Sinks | 26.03 | 41.93 |
| Tree Plantations (on Degraded Land) | Land Sinks | 22.24 | 35.94 |
| Perennial Staple Crops | Land Sinks | 15.45 | 31.26 |
| Temperate Forest Restoration | Land Sinks | 19.42 | 27.85 |
| Managed Grazing | Land Sinks | 16.42 | 26.01 |
| Tree Intercropping | Land Sinks | 15.03 | 24.40 |
| Concentrated Solar Power | Electricity | 18.60 | 23.96 |
| Public Transit | Transportation | 7.51 | 23.36 |


## It started with wind.

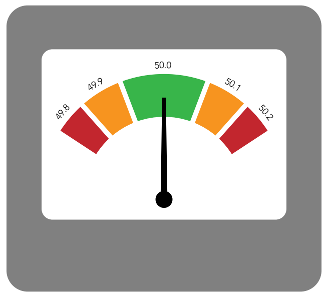
I initially started to look into Wind Power generation, having the idea to see how one could improve the current wind turbines. In the current format of wind generation there are many improvement areas, based on my own observation and brief research I found those to be:
Current wind turbines are tedious and demanding to manufacture and transport, impossible to recycle[3], visually obstructing, dangerous to wildlife[4] and loud. There are some exciting alternatives being developed, seen to the right. However after further research and consulting with mentors, I came to the conclusion that wind turbines is likely more of an engineering and aerodynamics project than it is a suitable Industrial Design Bachelor project. Back to the drawing board.

# 3 key points for understanding the electricity grid:



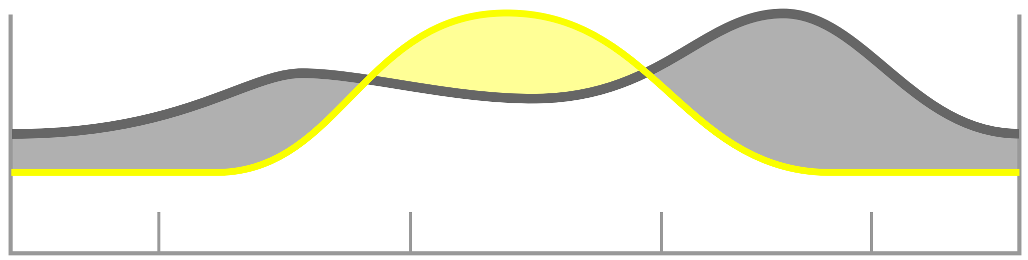
## 1. Production to use is INSTANT.

The entire chain of delivery for electricity is extremely fast. The chain of generation, transformation, transportation, re-transformation, distribution and use is less than 0.3 seconds[5], in other words almost instantaneous.




## 2. The grid is extremely well balanced.

The balance between energy generation and energy use is constantly in very precise symbiosis. The slightest imbalance of the grid will result in major problems. In most of Europe the grid is running at an alternating current of 50Hz[6]. Already at 49.8 or 50.2Hz the safety measures of the grid will kick in, resulting in a blackout.

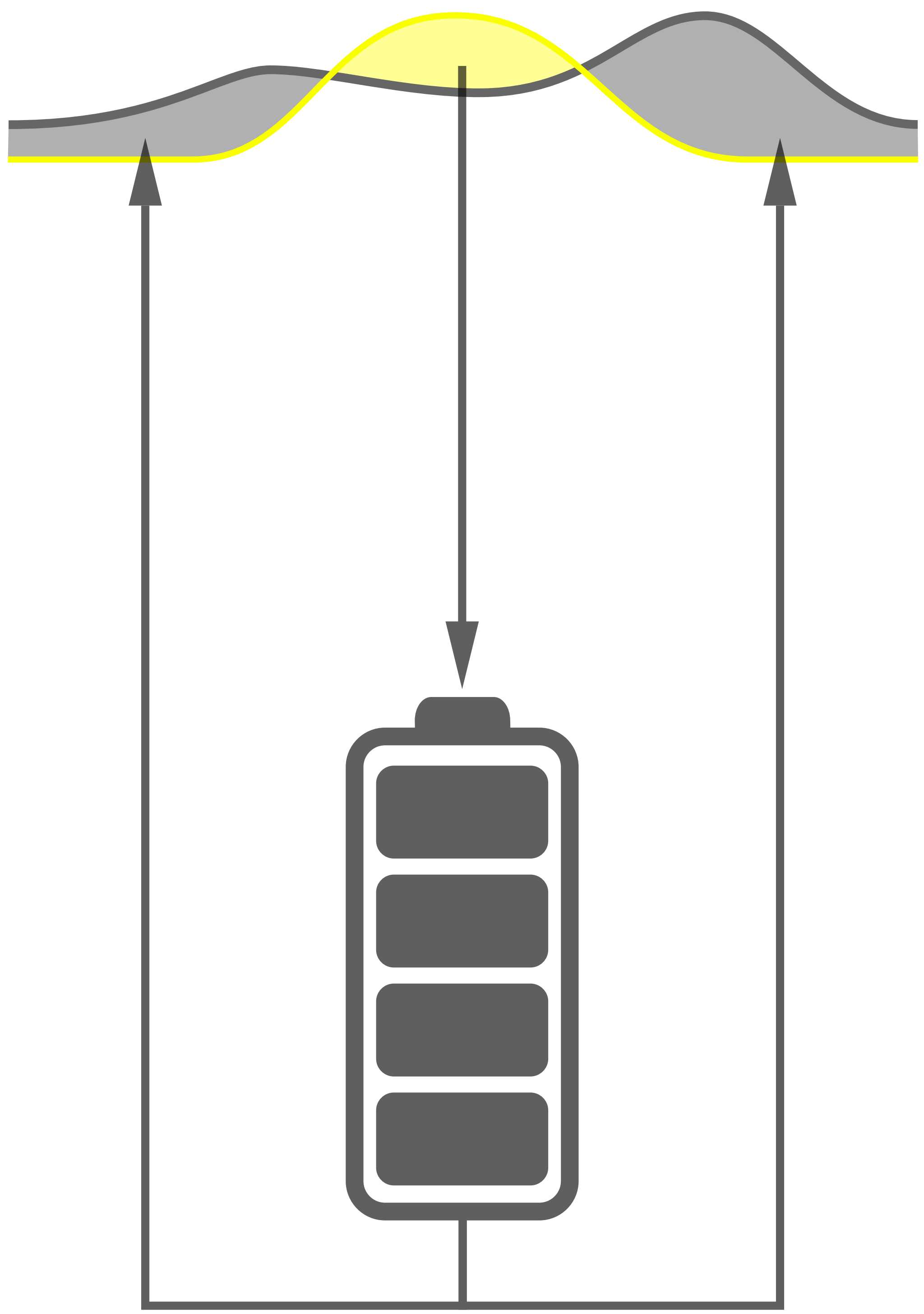


## 3. Renewables are intermittent

Renewable energy generation sources are dependent on the weather which is somewhat predictable, but infinitely variable[7]. This variability results in a mismatch between generation and use. The previous two points, will then tell us that we have to do something about this difference. Above you can see the dark line resembling the typical energy consumption in a day. We can see an increase in use as the day gets going, a lower point during mid-day followed by the daily peak in the afternoon. Compare this to the yellow line, which is symbolising solar power generation and you can start to see the issue, solar power naturally peaks at mid day. This results in the need for other generation sources when we don't have enough power to equal the consumption on the grid, which in many countries will mean that fossil fuels have to be burnt to satisfy the need. During mid-day when the solar cells are producing their peak output, we run into a different issue - we have too much electricity. This then has to be sold off for cheap to neighbouring counties or countries - or simply be wasted[8]. Our opportunity has been discovered: Grid scale energy storage.

# Opportunity:
# Grid scale energy storage

Previous facts led me to the obvious yet invisible issue with renewable energy sources. They are intermittent, but the grid has to be perfectly balanced. As described by Bill Gates: "Renewable energy generation is not the issue. Renewable energy generation is hugely over-invested - transmission and storage are the actual problems." [9] What we need is some sort of intermittence handling process, to take care of the excess energy we are not using, to be able to bring it back into the grid at times of need.



The new brief:

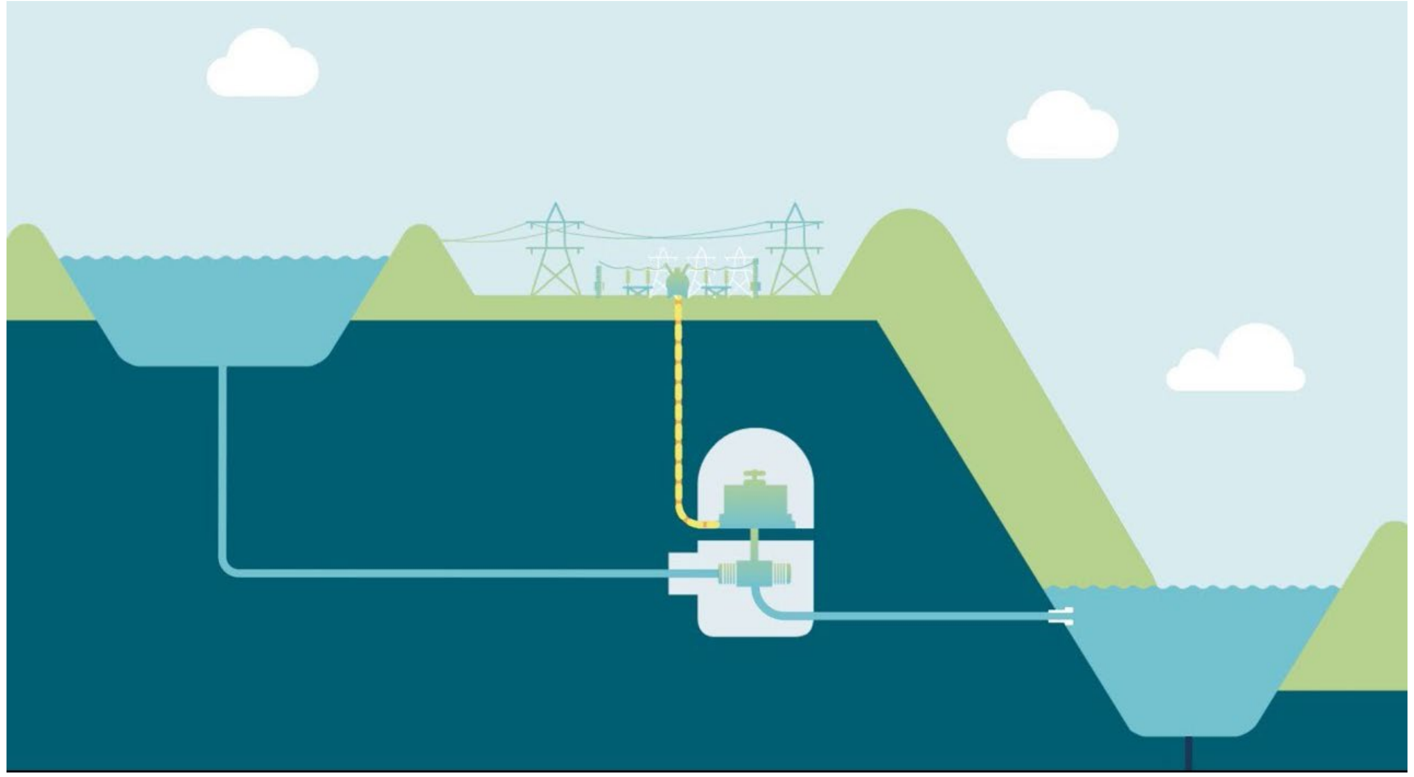
# Create a grid scale energy storage system, to support renewable energy

The intentions for this project were vast and many. With one of the driving aspects being feasibility, I wanted the outcome to be completely possible to make regarding engineering, physics and manufacturing. All aspects of my product have therefore either been inspired by something already existing or have been confirmed in retrospect with current technology to ensure viability. I am a firm believer that innovation is in most cases just a result of current ideas and technologies brought together, improved and applied in a different field. This will prove to be the case in most brilliant products, the core idea has most definitely already been invented in another field or in nature. Apple did not make the first mp3 player and Edison was not first to invent the light-bulb.

## The modern battery

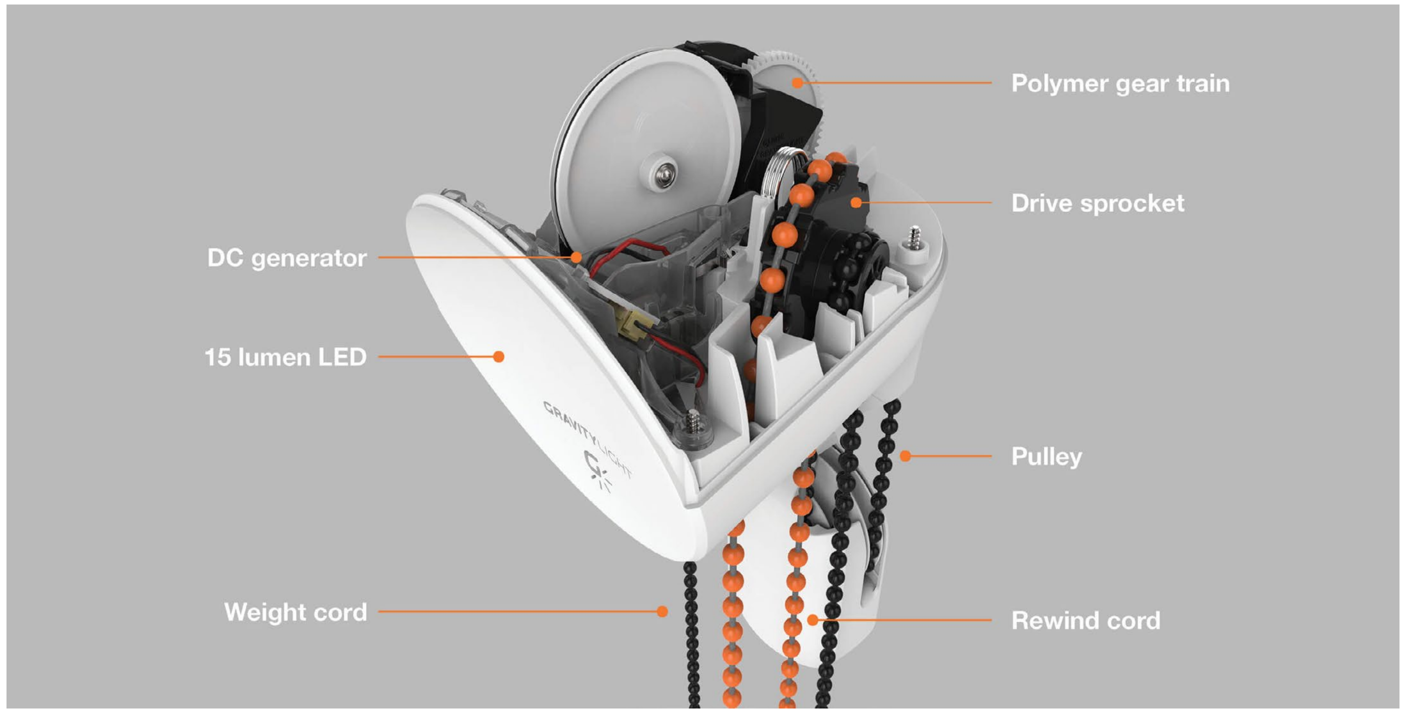
Alessandro Volta is credited for making the first battery of modern times, with the Voltaic pile pictured above. Volta's findings were published 1799 and gave way for a long range of electrical discoveries after his invention of the battery[10]. Artefacts have been found of suspected batteries believed to be 2000 years old, but too much mystery is still surrounding the artefact known as the Baghdad battery[11] to confirm its true purpose.
When thinking about energy storage, the Lithium-Ion battery is typically what comes to mind. The Tesla Gigabattery in Australia (pictured on the right) was a 125 million dollar investment build, but it saved 40 million dollars the first year in use.[12]

There are many more alternatives. Flow batteries, solid state batteries are among other concepts that are up and coming. These are however as of yet mostly for consumer electronics, or smaller implementations. Flywheel storage is another impressive variant of energy storage. This uses a weight rotating in vacuum on magnetic bearings that will be slowed down to give a short burst of very high energy.[13] All of which are very fascinating, but bring their own level of challenges when it comes to grid scale storage.



# Biggest batteries in the world

The most commonly used power storage in the world. 97% of stored energy is pumped hydro-storage (for the U.S. Market which has the most clear reports).[14] It works via a relatively simple principle. When there is excess electricity on the grid water is pumped from a lower to an elevated reservoir. Energy is now being invested into this system, it is being "charged" in terms of a battery. When more power on the grid is needed, this water will be let back down through a turbine - which will convert the kinetic energy (movement) of the water to electricity.[15] The system will provide power until the water of the elevated reservoir runs out. It is part of something called Gravity Batteries, due to gravity being what is holding the charge of the battery - in simplified terms.




## Dry gravity batteries

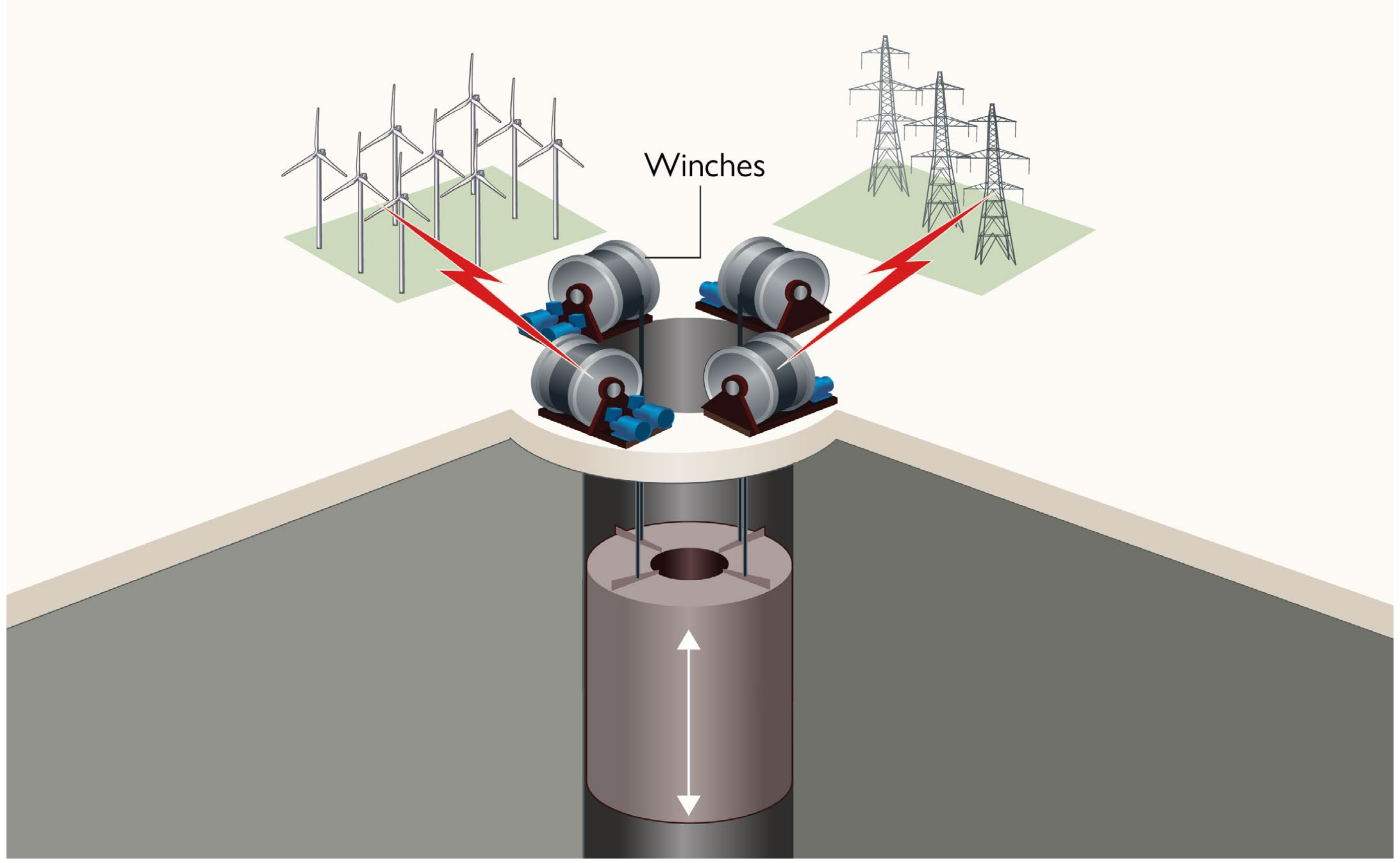
Facing the future of climate change, readily available access to water will not be a given. That leads to a subcategory called dry gravity batteries. All with their own benefits and drawbacks. The best way of explaining the principle is the GravityLight[16] (to the right). You have a bag filled with weight of any kind, it can be sand, stones or a water bottle. When you lift this bag up - you have charged the light - which will now slowly lower the weight back down towards the ground - powering a generator in the process to create light. This is effectively a gravity battery powered light. Intended to be used to light up off-grid households in the developing countries, it uses this principle in a very efficient way. It is simple - lift a weight, lower it back down and translate the movement to electricity. Just like the water dams. But there are many alternatives.

## ARES

Advanced Rail Energy Storage.[17] Rail based technology relying on existing train technology. This Californian company is aiming to store energy in a rail based system. Using heavy trains and a 6km long track to handle the 640 meter incline. The use of conventional train technology in this concept is why the rail has to be so long for this incline, since the steel wheels will only allow for traction up to a 6 degree incline. Another drawback with this system is when the weights are charged. A fully charged weight, also means that the belonging vehicle (train) is also getting parked. That results in a very expensive weight per vehicle ratio.

## EnergyVault

In my observation and research this solution has great potential in theory but suffers from a few fatal design flaws. The potential energy is based on centre of gravity, as seen by the above image - the difference in centre of gravity is resulting in only 30-40% used height. The tower is man made, and building tall and strong towers are an engineering feat that is both expensive and dangerous. The tower uses 110meter long steel cables[18], yet the concept is suggested to be close to wind turbines. The wind loads on these cables would induce a lot of movement that will interfere with the 10cm precision suggested, therefore causing discussions in the field if this is even a viable solution at all.

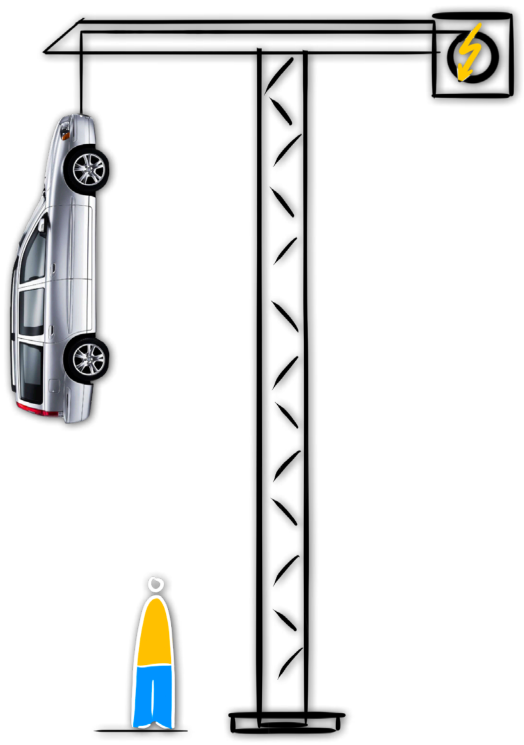



## Gravitricity

Gravitricity[19] is a UK based company aiming to use abandoned mine shafts to hoist a massive weight up and down these deep holes. The final concept is intended to hoist 50000 tonnes down these kilometer deep shafts. The numbers are there and the potential for this project seems great. The small and inconspicuous surface footprint is a very strong feature for this concept. The strength in the concept is also the weakness, since the engineering involved with lifting 50000 tonnes this distance would require a revolutionary winch system. Their 5000 tonne pilot plant should launch shortly, it is already overdue presentation date, but was slowed due to the Covid-19 situation.

## EnergyCache

Other alternatives include EnergyCache (above) which has been funded by the Gates foundation. In Bill Gates own words "It is basically a ski lift filled with gravel".[20] Although technically not a dry gravity battery, there are also buoyancy concepts using a pulley system to submerge floats under water to create motion. I find the EnergyCache to be suffering from the "weakest link" engineering challenge, since all the weight would be suspended from the same chain - therefore creating an immense strain on the individual links - limiting the size of this concept.



Your average telephone battery equates to a station wagon lifted 7 meters.

## It is not for your kitchen wall

Starting to calculate the potential energy of a gravity based system it was quickly clear that the system would not be appropriate to work as a household battery, as I had initially imagined. I was ready to call this a dead end, before figuring out where the gravity battery truly excels.

## Grid scale optimal

The gravity battery is much more viable as a grid scale system. Compared to most existing solutions, current Gravity battery ventures promise many advantages, such as:

**Half the price.**[21] Compared to a grid size Lithium-Ion battery.

**Safety.** A gravity battery does not rely on dangerous chemicals, avoiding risks such as fires and biological damage.

**No degradation.** Due to the mechanical nature of the system, the maximal energy storage capacity will not degrade after a certain amount of charge cycles.[22]

**No storage loss.** The system can remain idle indefinitely, without loosing charge. Potentially the system could then be used seasonally or in emergencies, being in standby for years without being recharged.

**Low maintenance.** Compared to servicing cells of a Lithium-Ion system, gravity batteries can remain safe with minimal operating maintenance.

The true area of excellence of this system is therefore at a grid size level, supporting the energy grid of entire cities or countys. This is where the project becomes challenging for someone not used to society level issues. Which was a cognitive struggle to keep a reference of scale, to make sure the weight is enough, engineering feasible and footprint makes sense.

$$\frac{m \times h \times g}{3600}$$

## How much power?

The principle behind the system is very easy to calculate. Potential energy is calculated by the mass multiplied by height elevated multiplied by the acceleration factor (which is generally agreed as 9.82). The resulting number is then by the unit of Joules. To convert Joules to Watt hours, the above result is divided by 3600 (3600=60x60=Seconds per hour, 1W = 1J/S.) Following that formula we get the result:
1MWh = 365tonnes per km.

## Huge business potential

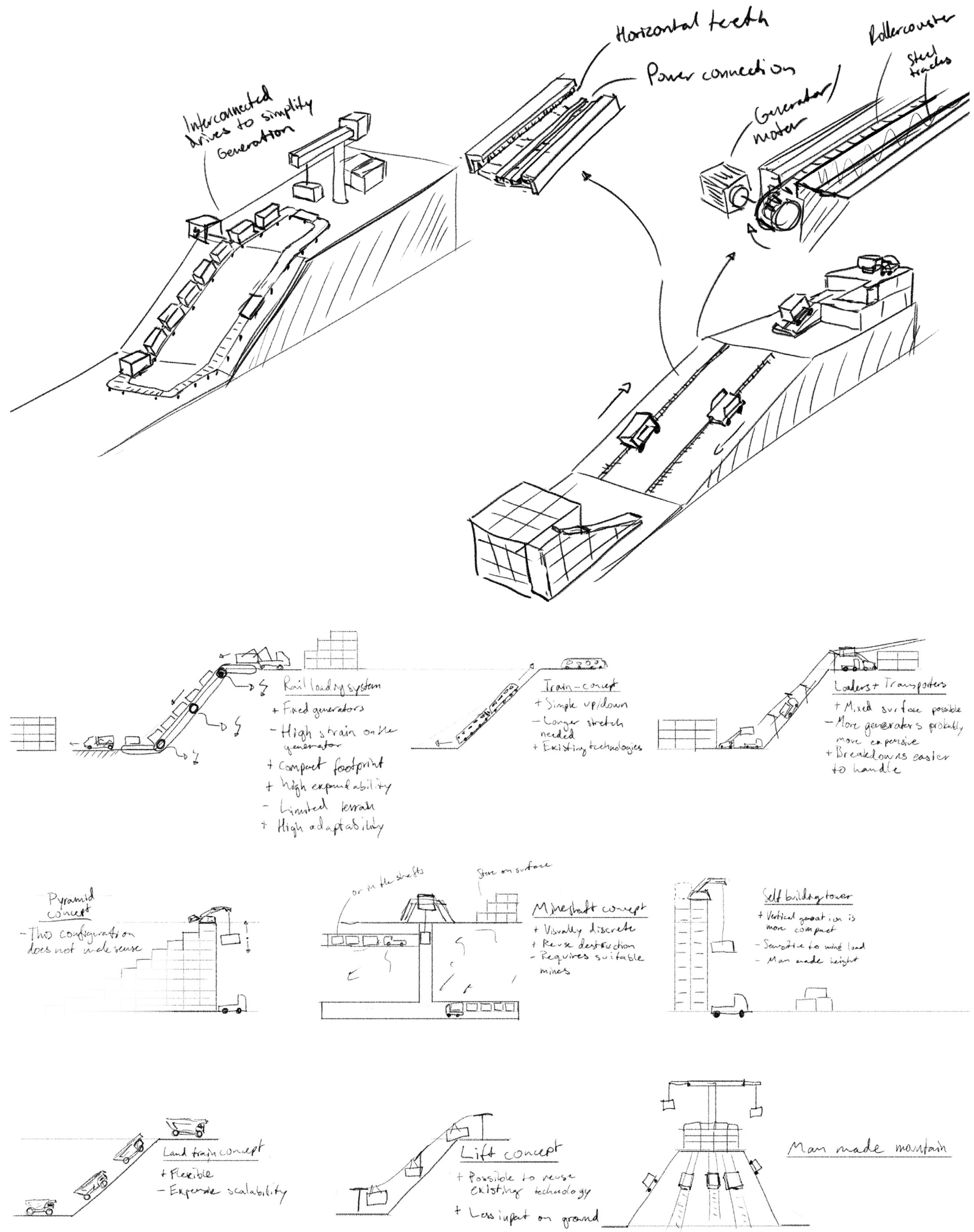
The energy storage market is projected to be 550 Billion Dollars by 2035 in North America alone. Quite a drastic increase from the 20 Billion Dollar market today.[23] Currently the market is standing wide open, since it is only very recently we have been getting the percentage of renewable energy produced high enough to notice that intermittence is an issue. Due to this market being in its infancy, there are not many alternatives implemented and available. The time for energy storage is now.

# Two Soccer fields to power Malmö

The experts say that if we can store 20% of peak power use, it would be enough to fully transition to renewable energy sources. When I did this calculation back in February, the peak hour that week was 4400MWh. To match 20% of that using the formula, we need two soccer-fields of shipping containers stacked 8 high filled with concrete, 660 meters apart in altitude. Perhaps we could spare the area of a few ball-fields in the name of renewable energy.

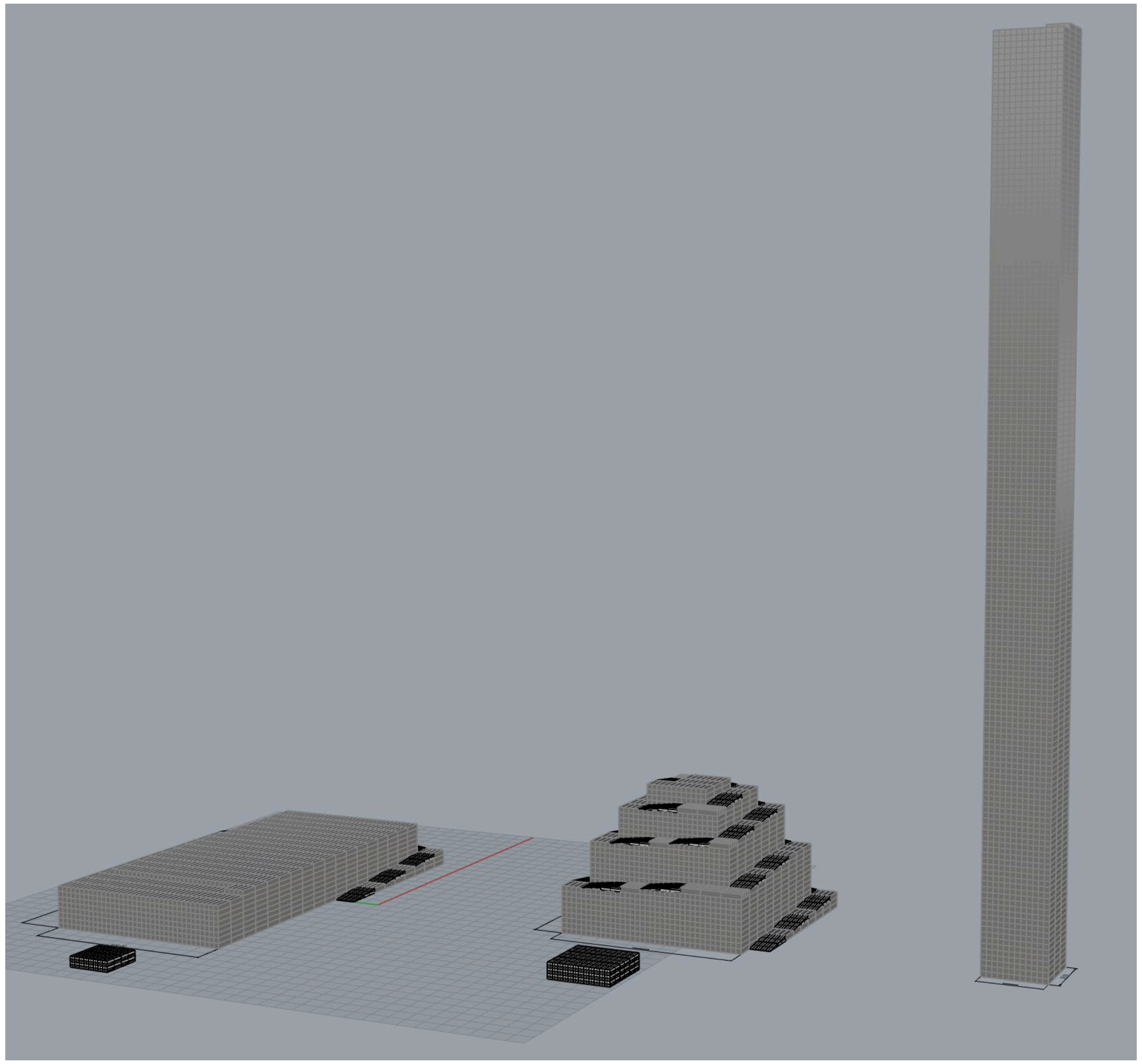
# Simple premise with infinite possibilities

The beauty of gravity batteries is the simplicity of the system. We need to haul a lot of weight up in altitude. This means that we could use any kind of movement. We could have electric trucks driving up an asphalt road, we could use ski lifts, conveyor belts, we could use trains, lifts, dam systems and so on. Due to the simplicity of the project most ideas are possible, however with varying success. To narrow it down, I decided to use the current shipping container business as a reference.



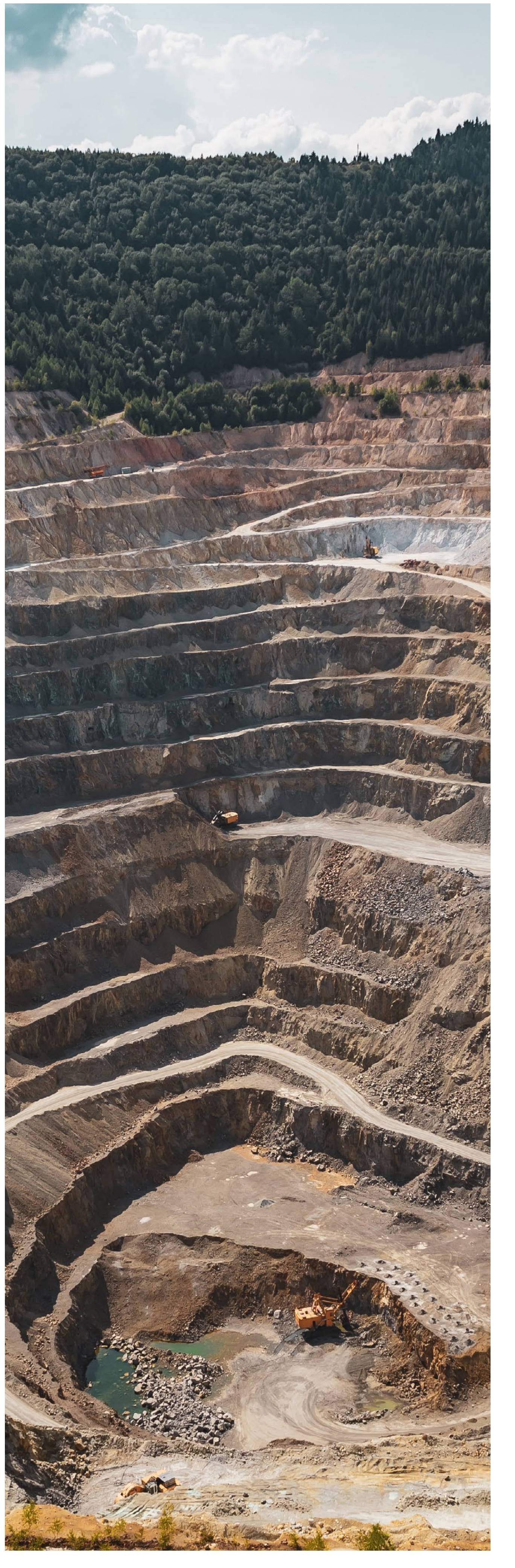
# 5244 weights

An experiment with the format of shipping containers (chosen because of the vast support in systemic transportation and storage) I did a simulation regarding format and footprints resulting in three different stacks. Using the footprint of a football-field, something that tends to exist and be justified in almost all places of the world, and stacking 10 high. I was able to fit 5244 shipping containers in this area. Comparing this to the footprint of EnergyVault, this would have had to be 128 layers high and 384 meters to account for the same capacity. Resulting in a plethora of engineering challenges of wind load, hoisting and extreme compression on the lower layers.



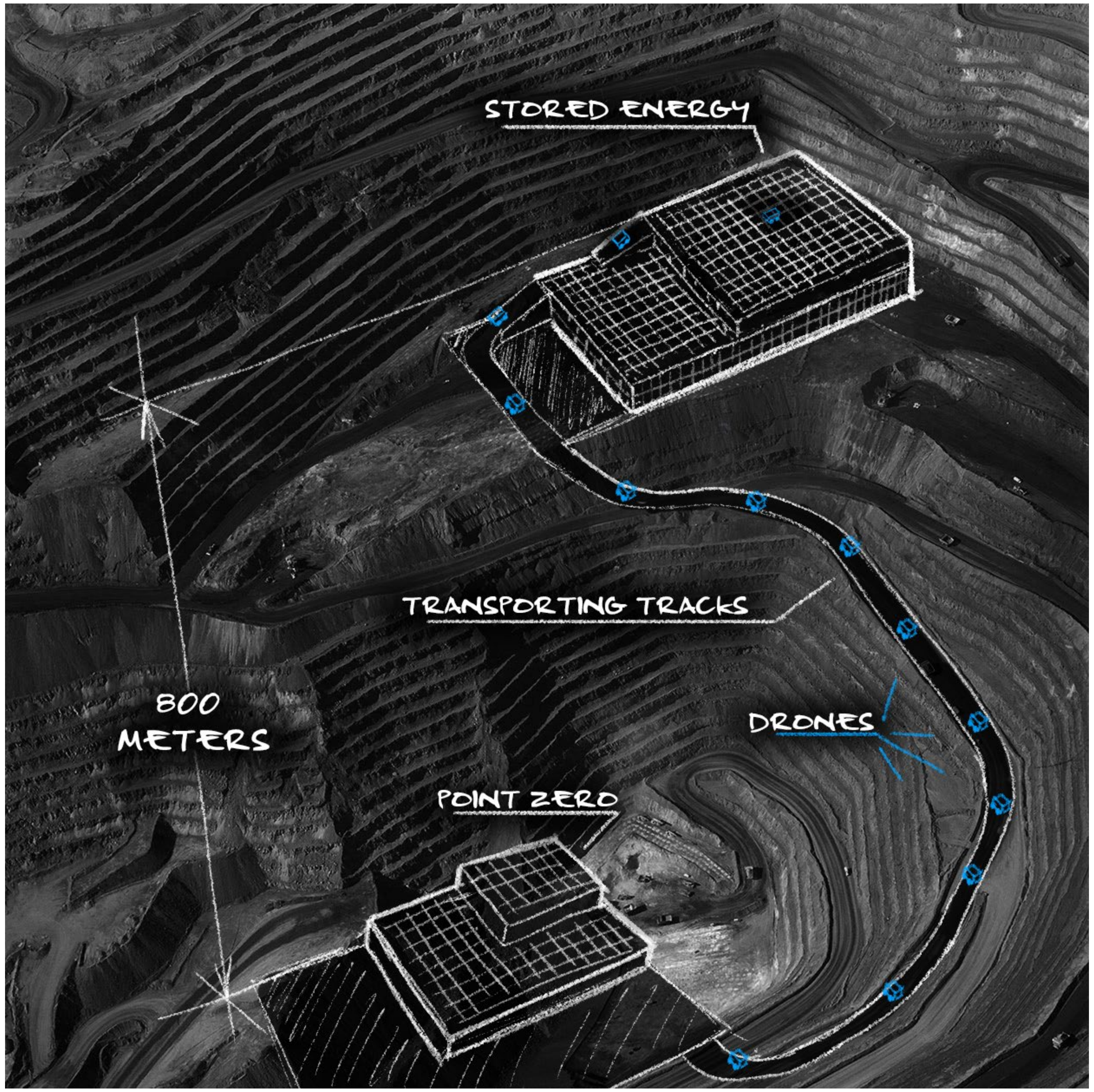
# Pinnacle of mankind vs the local quarry

The worlds highest building Burj Khalifa in Dubai is an engineering masterpiece. It measures 861meters and it is an absolute feat of mankind to be able to construct such a high tower. It is a result of compounding knowledge of construction and physics. The layered tower design is not an accident. The tower is constructed this way to disperse the vortexes that would otherwise result in excessive wind loads - in English - if the tower would be a different shape it would snap from the wind.[24] On the contrary the infinite numbers of open pit mines often reach height differences of more than a kilometer. These wounds in the surface of the earth exist from many different reasons. Decorative stone, gravel construction of roads and buildings as well as coal are many reasons why we have dug these massive holes over the course of thousands of years - with extracting weights of tens of millions of tonnes per year. So imagine if  we could re-purpose these mines (many recently closed as an effect of European coal coming out of fashion).[25] What if we could make these mines to act as batteries for our renewable sources - re-greening them and converting them to new green vistas reminding us that we can do better if we really try.



## ~~Pinnacle of mankind~~ vs the local quarry

Instead of trying to force a new engineering feat of space age proportion. Why not re-imagine the damage that we already done to create a new era of utility? If we could start a process of converting the current technology and businesses - the transition to an actually greener future would be so much easier - we have an opportunity to re-imagine the incentives. We could convert the destructive mines to batteries and the miners could be retrained as service operators and installers of these systems. We would then have even more economical reason for these solutions.




## Proof by reference

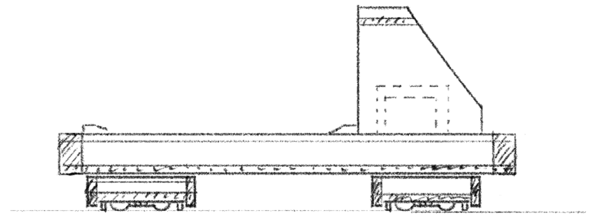
Taking inspiration from what is already available and comparing other movements and mechanics, I was able to get a much better perception of what is possible to implement. Functionality from the ARES project, shipping port drones and container stacking. However, the biggest challenge to conquer with this concept is the actual elevation. Conventional trains are perfect for efficiently moving heavy masses, the combination of steel wheels and rails make for very efficient energy transfer. With heavy loads, rubber tires will deform, therefore resulting in an energy loss due to heat generation. (Energy cannot be lost, only transformed). However, conventional trains have a major drawback in the context of gravity batteries: They cannot typically handle an incline larger than 4%.[26] So at a visit at my family in Stuttgart, we went to see the Zahnradbahn. This is a tram with a cogwheel driving the train up and down hills. After more research, cogwheel trains proved to be a long lasting technology - with examples build before the world wars still in use.[27] This technology will be perfect to adapt to the gravity battery!

# The designable three

Choosing the open pit mines as a place for the gravity battery led to the decision to narrow down to three main components of this system.

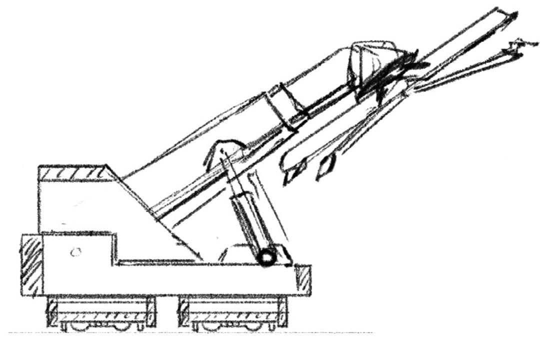
## The Weight

The weight is the capacity of the battery. Being stackable and of course containing heavy mediums. Using a universal shell would allow for the mass to be a result of many different materials. By-products from tunnelling, rubble from destroyed buildings or industrial waste could all be viable as “filling”, with a net positive economical contributor to the system. Having these separate from the drones will drastically reduce the cost of the system, since no expensive components have to be parked. Initially the idea was to re-purpose retired shipping containers, but in their current format they would not be able to handle the weight from concrete or landmass. An upgrade kit was considered for a while, but for the first generation system - a bespoke weight container would be developed.



## The Drone

The drone is doing the actual the conversion from potential energy to electricity. Using the same technology as mountain trams/trains, this is a construction we already know well but re-imagined for gravity battery use.



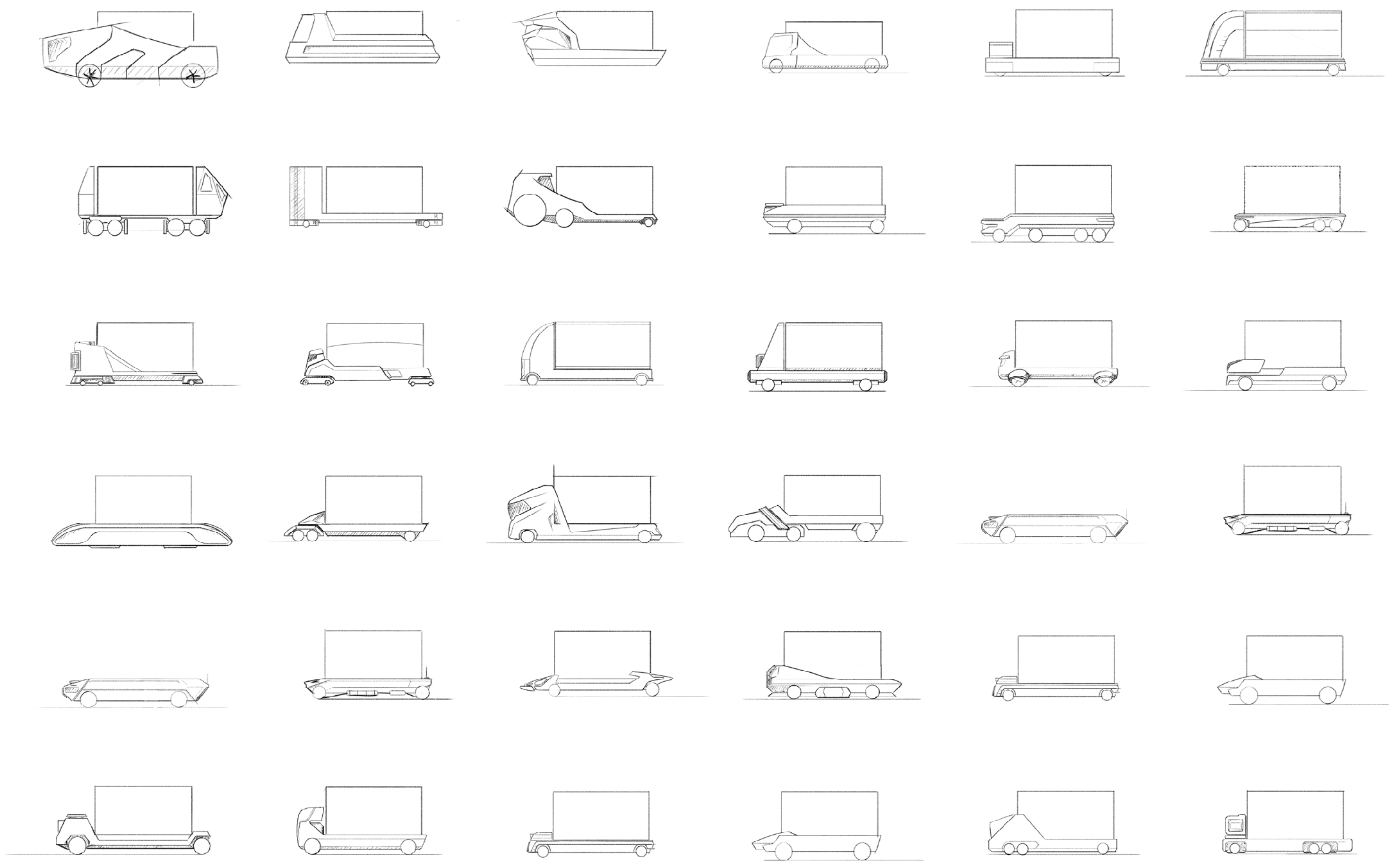
## The Lift

The lift is what would afford the loading and unloading of weights, or charging and depleting if you may. This function will dramatically reduce the footprint of the system - a huge advantage compared to ARES where every train cart must be parked in a trainyard at the highest point.

I want the concept to convey the idea of a possible future: I want it to inspire, to encourage the vision of a coming time of possibility and hope, not of doom and destruction. I want it to state:
“Here I am, and I am here to stay. Let’s enter the future together.”

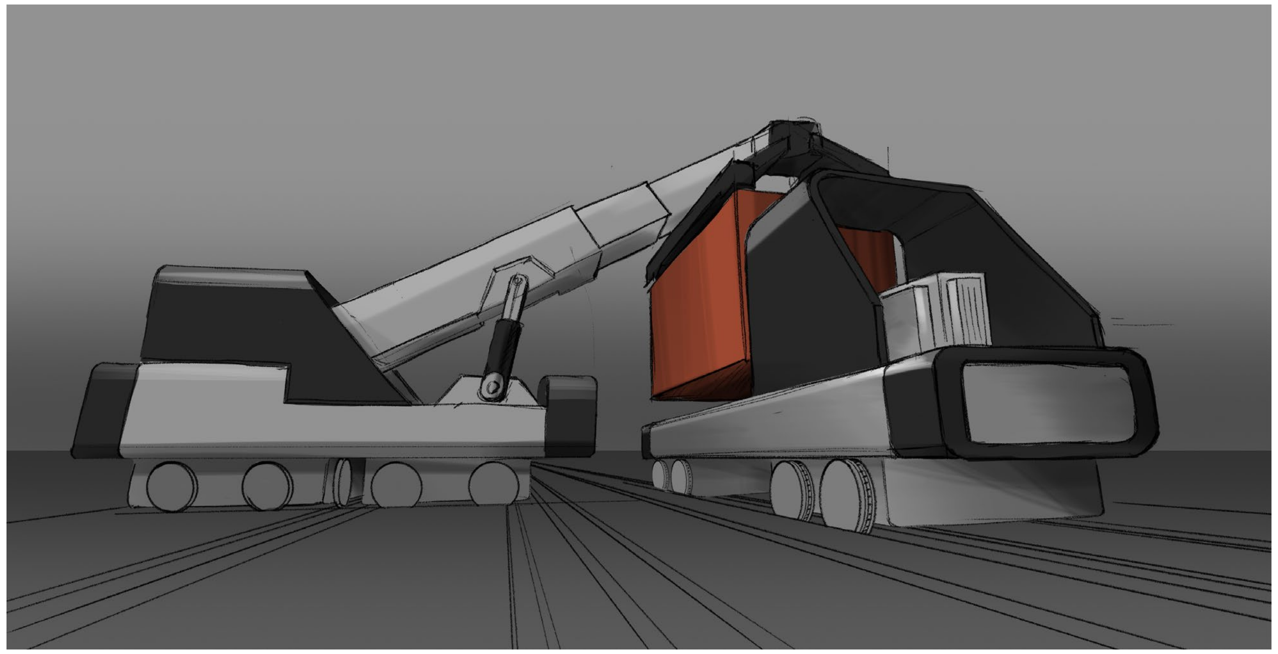
## The goal

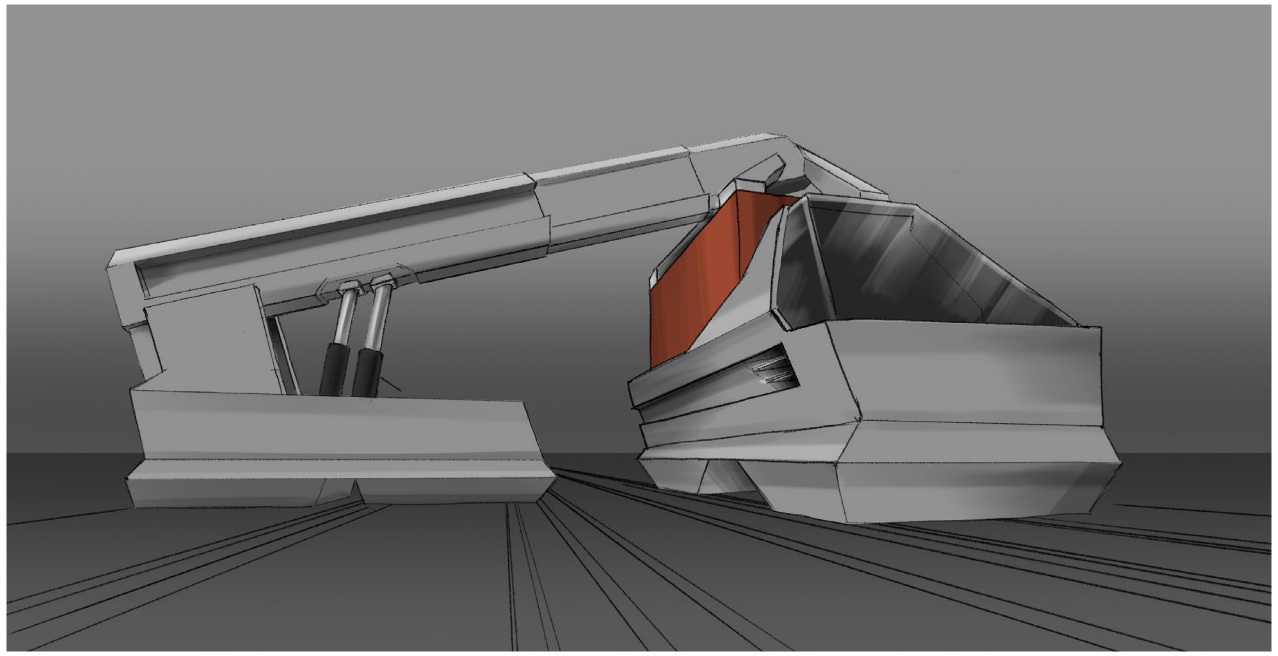
As it started approaching the final design, I set a goal for myself to what I wanted the design to convey. Added to the statement to the left, was the ambition to convey ruggedness and strength. I want it to tell you that it is electric and loaded with energy. I want it to be honest with its movement. I want it to look friendly, but not entirely safe - since it is still a potentially dangerous machine.

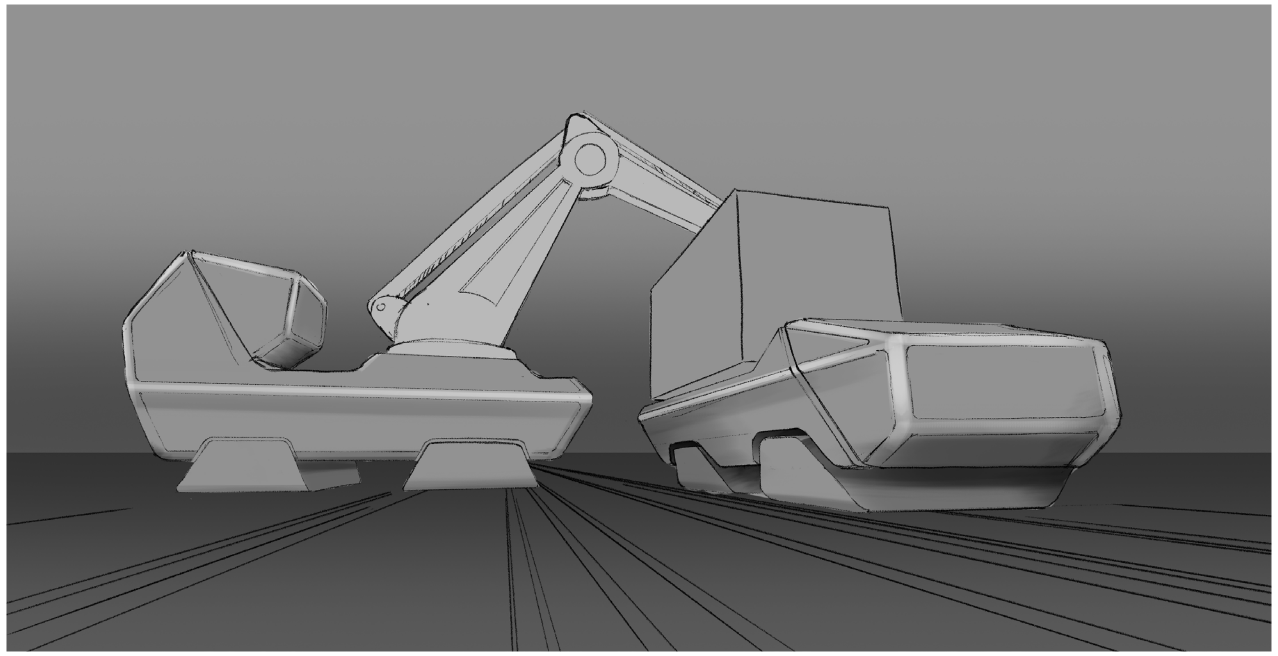


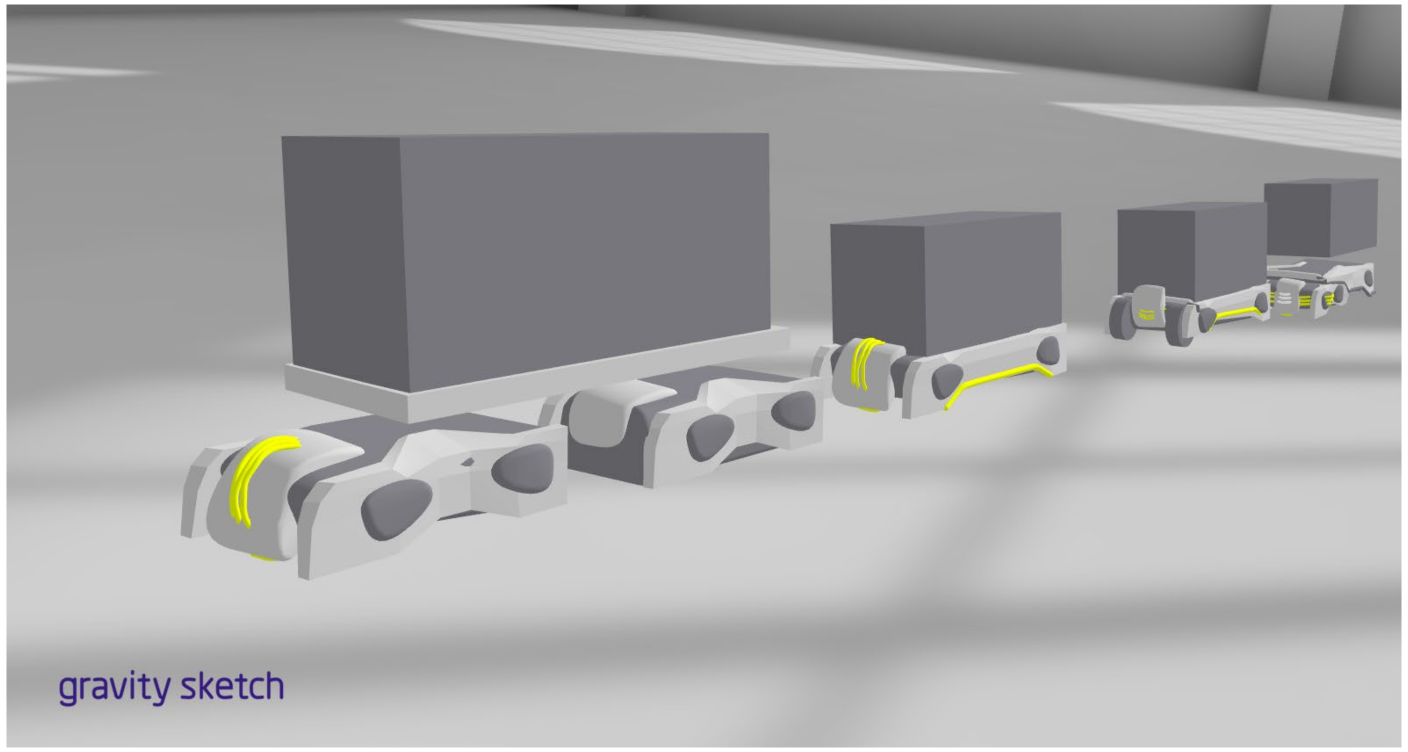
## Kick-off

The process for the kick-off presentation was not directed and decisive enough. Focus was put on form exploration on side views. But my mistake here was a lack of reference and mindful creating. The results to the right was what was presented at that occasion.







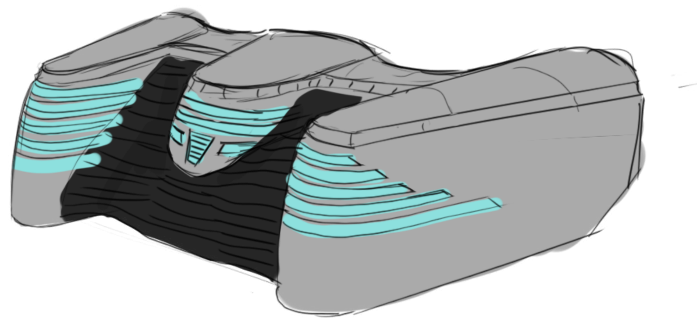



## Chaotic creating

Following the Kick-off presentation, I decided to go back to the basics. The leading motivation was to get back to something closer to the design goal of the project. Due to the infinite number of configurations there were no constraints for the amount of options possible for this product. To get my mind free and get back to a more three dimensional thinking, I went into some VR-sketching to play around with configurations of components and weights.

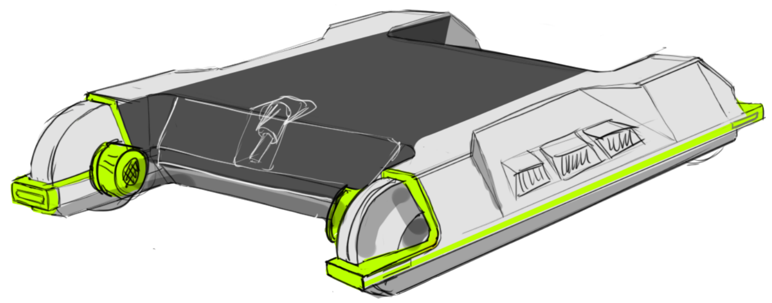
## Two contesters

With a revisited ideation process, two contesters were left. Keeping the design goals in mind. I found these to be much more relevant than what I first had come up with. The two main reference images to align with was the above. From BMWs E-scooter concept and a gaming headset - with a colour scheme that aligned with the goal I had in mind.



### Industrial vehicle

This was the chosen concept. Inspired by the philosophy driving the form of many cars, showing the strongest features where the power is being made. Since the motors would be placed near the edges, I wanted to create the form of a strong neck and shoulders. Using only these points as focus points proved to be giving a much too futuristic look. Introducing a grille brought it back to something resembling heavy agriculture machinery - which would give the vehicle a familiar form factor, while still pushing the boundaries of what the drone could look like.

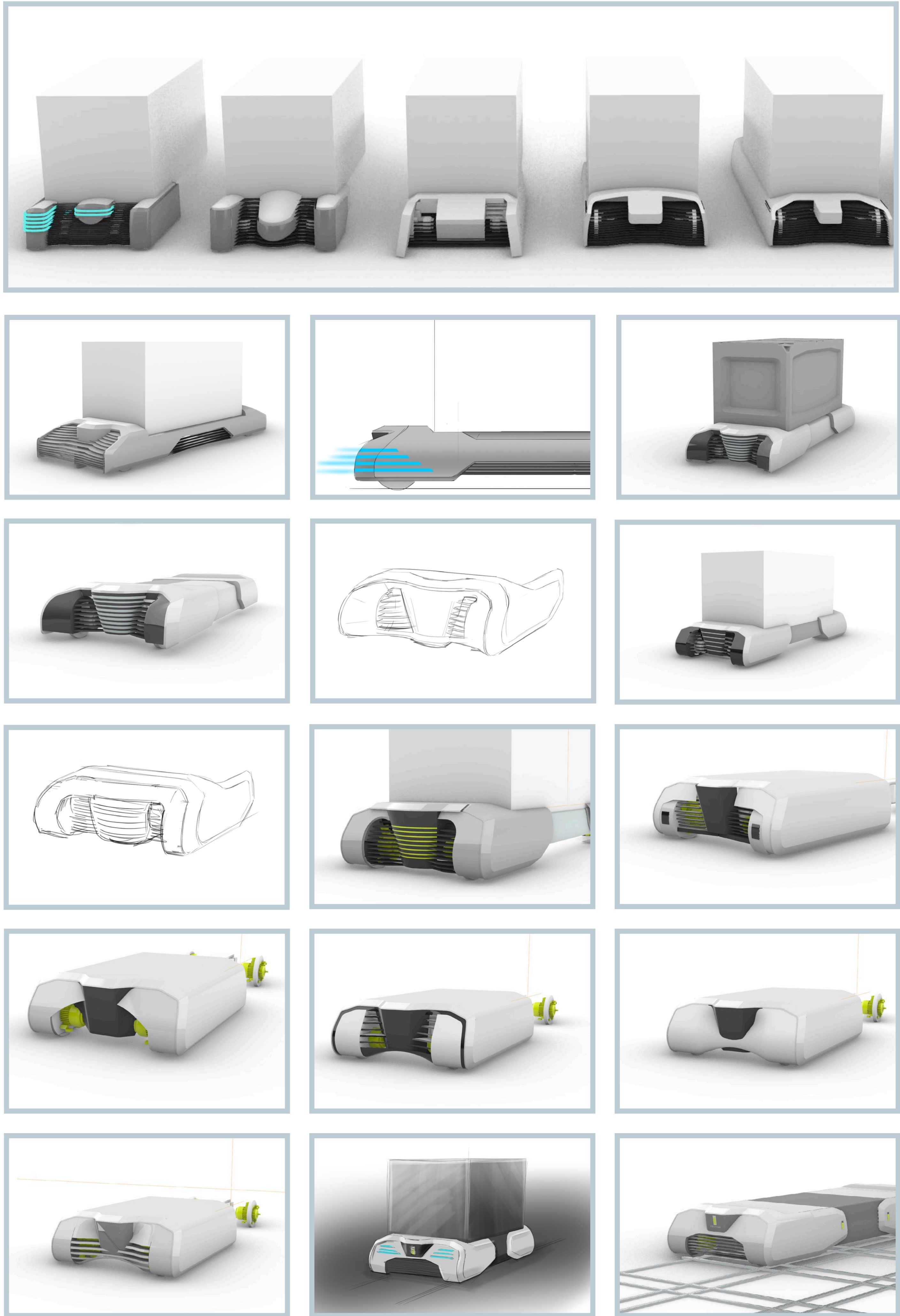


### Fourth revolution

This concept was inspired by the trains of the past, reintroducing them with a strong identity of futuristic optimism. One strong story to build this concept on would be the coming fourth industrial revolution[28] which is believed to be triggered by completely renewable energy generation. This concept would then aim to acknowledge the first industrial revolution and introduce design ques from the trains of the past.

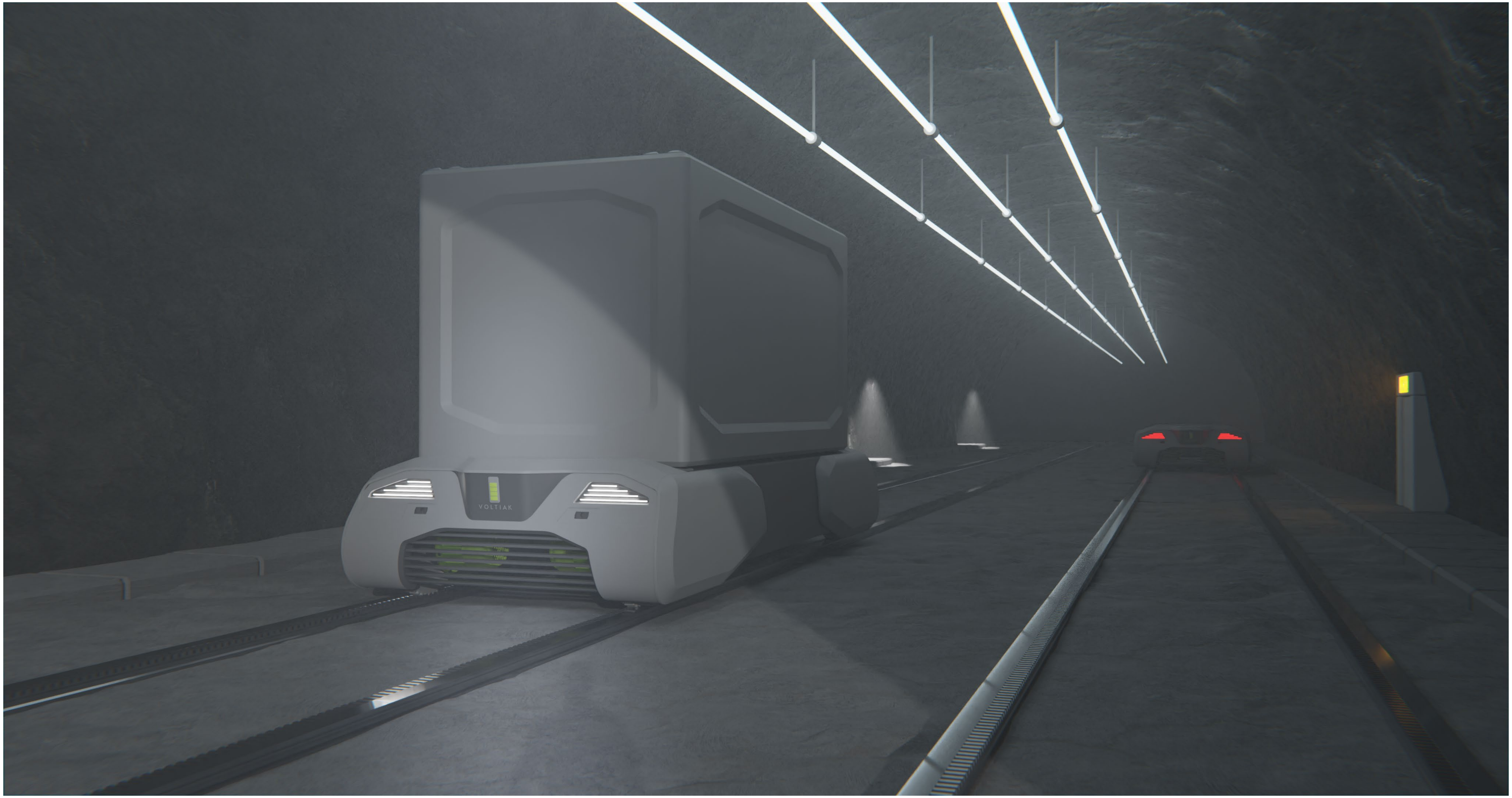
# Process for speed

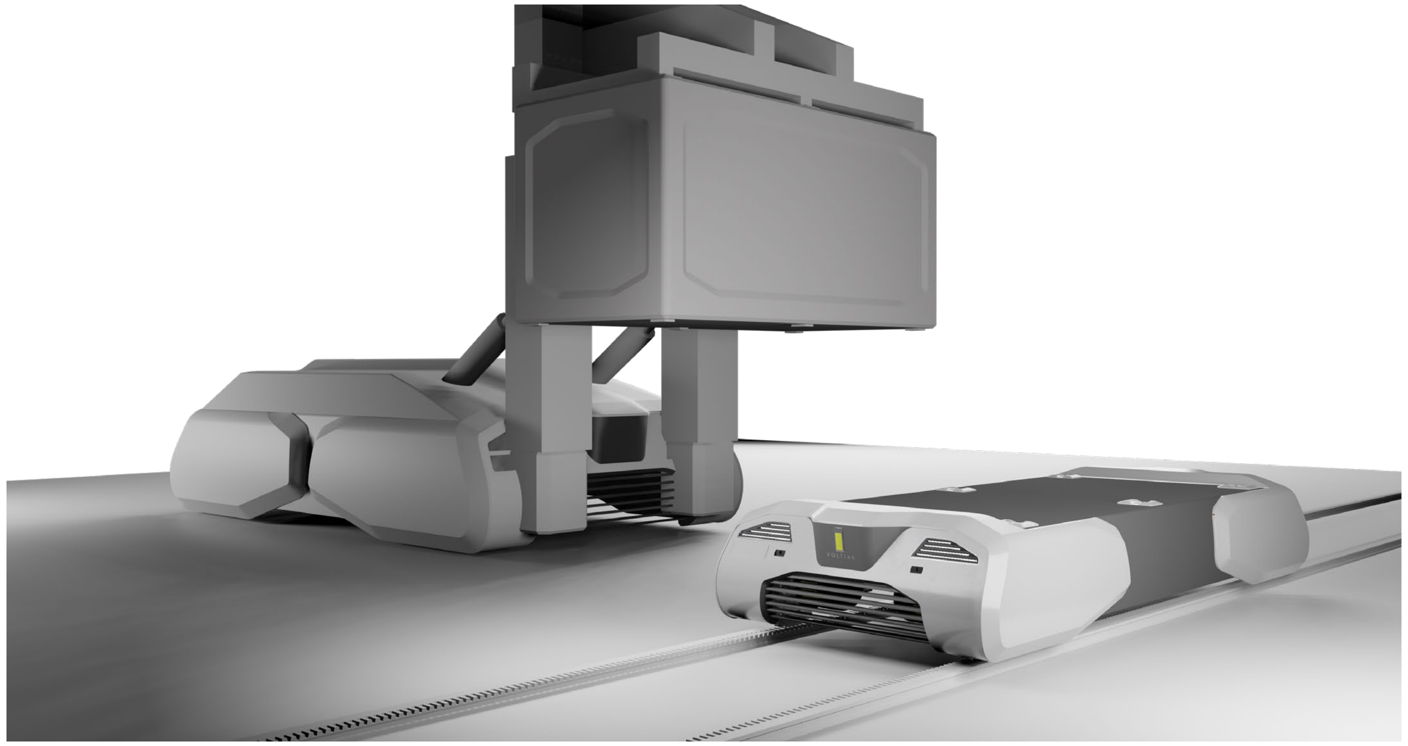
For me and at this point in my design journey, I am using a multi-media system for developing the form in the later parts of the system. Due to my relative proficiency (I am faster than most, but still not a professional) with 3D modelling tools, my method of choice for developing form and shape is to start off with a sketch, translate to 3D form with rough but efficient surfacing and then reiterate with sub-5 minute sketches. I have found that this is the fastest way for me to develop form and shape. Using the effortlessness and freedom of loose sketches I am able to quickly explore iterations of the developed shape, with the 3D modelling as continuous reality-checks that it works in real life and from all angles.

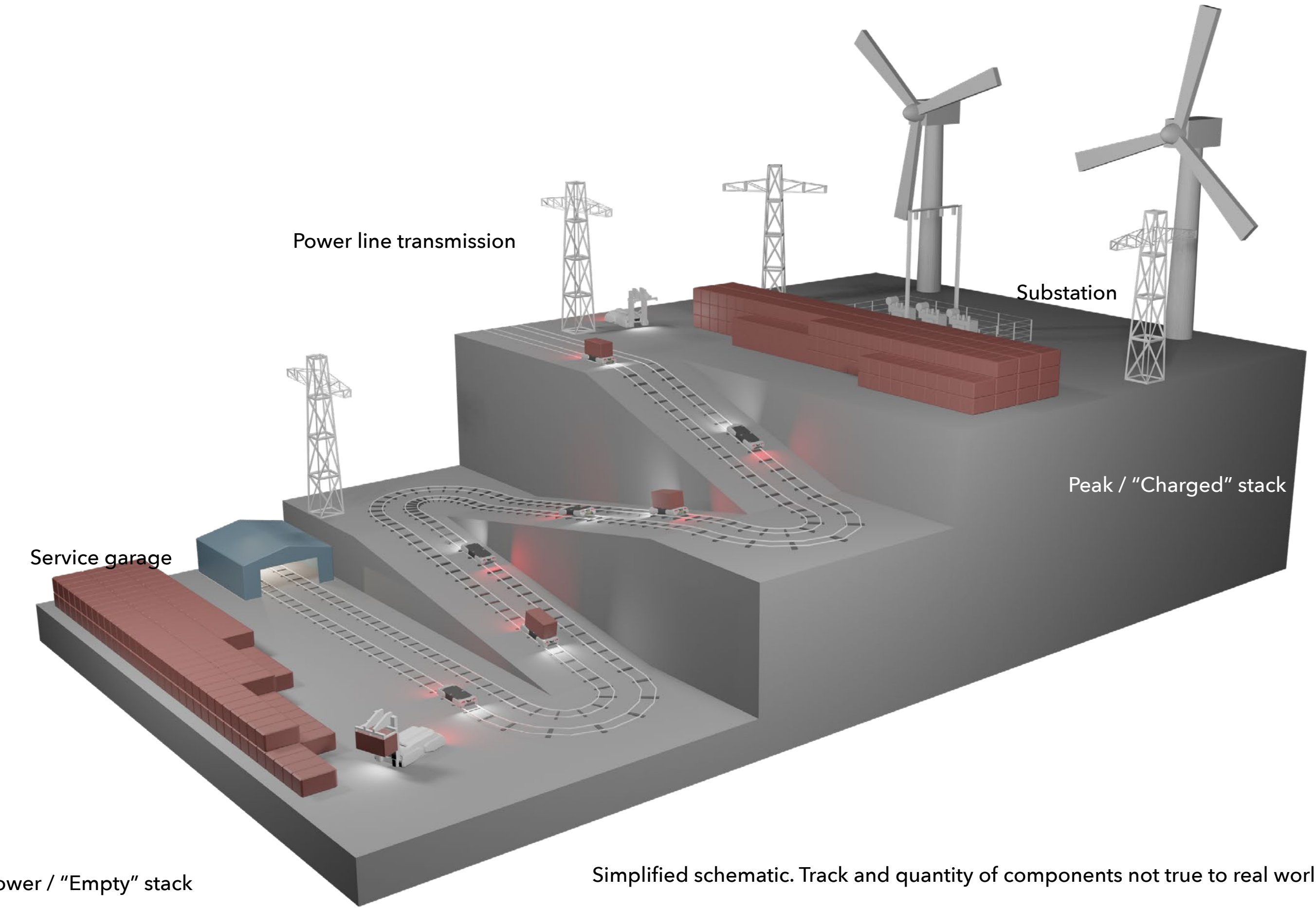


## Real time renders

Just a few moments before the final presentation, my Keyshot licence expired. At the same time, Maxwell kept on losing my licence and deleting my work. I took this as an opportunity to finally learn a software I have long been curious about: Blender. Open-source, free to use and including a real time render engine called Eevee. I saw a huge potential for future client and personal project work, if a 4K render is 60 seconds (closest to real time my current setup) instead of an hour. All of the coming renders are made with the Eevee real time render engine.


VOLTIAK





Simplified schematic. Track and quantity of components not true to real world.

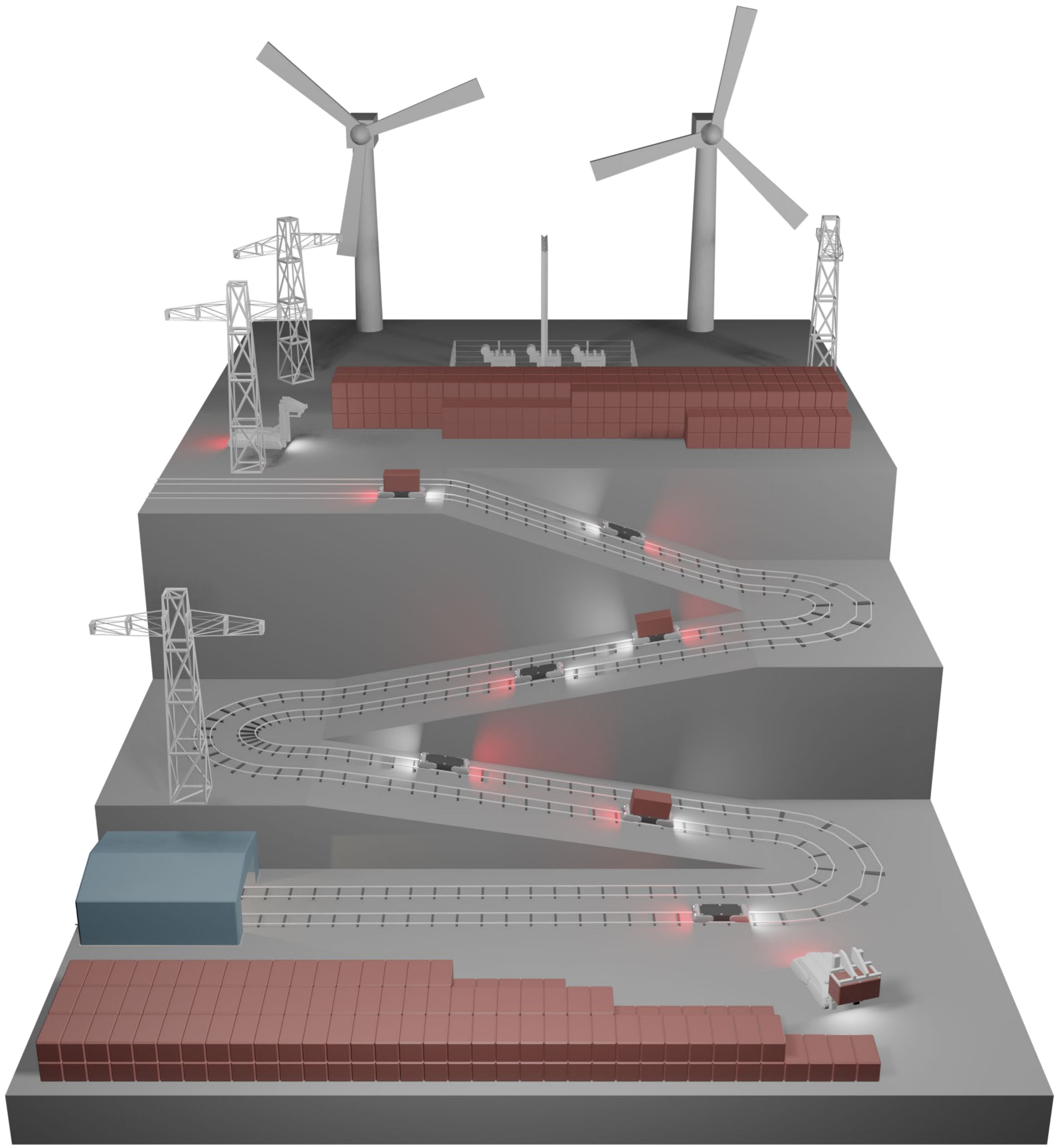
# Voltiak Concept

Above are the four core components of the system: the lift, the weight, the rails and the drone. The lift is handling the organisation and loading of the weights. The weights are filled with excess landmass, concrete from old building or other heavy debris. Looking into the density of concrete as a reference these would be around 120-150 tonnes of weight. The drones are the workers of the system and are doing the actual conversion of electricity to potential energy, relying on the rails for support, power supply and traction.

The basic premise for the system is simple: We have a location with difference in altitude with two collections of weight: one stack at the top and the other at the bottom. At each collection there are lifts loading and unloading the weights onto the drones. The drones take excess electricity and invest this by lifting weights to the top. Once electricity is needed back on the grid, the drones take weights downhill implementing regenerative braking, slowing them down the hill and converting the potential energy into electricity. The system premises will house a servicing garage to effectively handle any mechanical problems that might occur. There would also be a local substation to transform the electricity of the rails to transportable energy for high voltage powerlines.

Compared to existing systems we find a number of unique benefits to this system. The system is highly configurable, being able to decide max capacity by number of weights and max output by number of drones. The system is highly weather resistant and does not cease to operate in windy situations. Material availability is much higher compared to chemical based batteries and due to its mechanical nature. The cradle to cradle life-cycle of this system allows for much more recycling and re-purposing compared to Lithium-Ion batteries.[29] Most of the load bearing will be made by the ground. This eliminates the need for astronomical strength of engineering on weight bearing constructions.

This flexibility will allow the Voltiak system to be implemented in open pit mines, desert areas or in a future with less water - at the very locations the pumped hydrostorage is located today. Thanks to the modular way this system there is a possibility to develop each component independently, ensuring loads of potential for a long living system inviting new talented partners to join. The system could also be adapted for price range, with more advanced systems for clients with large budgets and more barebones systems where money is better invested in other parts of the grid. All of the above results in a highly feasible system, that could be implemented tomorrow.



# The 1GWh goal

Comparing this system to the industry set golden target of 1 GigaWatt hour battery capacity and running the math. We find that in a 1000 meter deep quarry we would be set with 2500 Weights slightly bigger than a 20 foot hicube container to fullfil that goal. At a 30 degree average incline (Pilatus Railway has a steepest incline of 45 degrees) we find that 2000 meters of rail per direction would suffice. If the full GWh capacity should be discharged within eight hours again using the Pilatus railway speed as reference - we would need 125 drones to accomplish this. That would mean one drone every twelve seconds during the discharge. Allowing a loading time of two minutes per lift, that gives us 20 per station - totaling 40.

That is a lot of numbers but the summary is simple, it is infinitely modular. Number of drones defines charge/discharge capacity. Altitude difference or number of weights defines total charge capacity. Length of rail defines the incline to climb required by the drones and therefore the engineering challenges. Comparing this to the Tesla Hornsdale Power reserve at 194MWh, we could use less than 500 weights or just a 200 meter incline (and less than 400 meter rails) instead.

2x 2000m | 125 | 2500 | 40


## Form

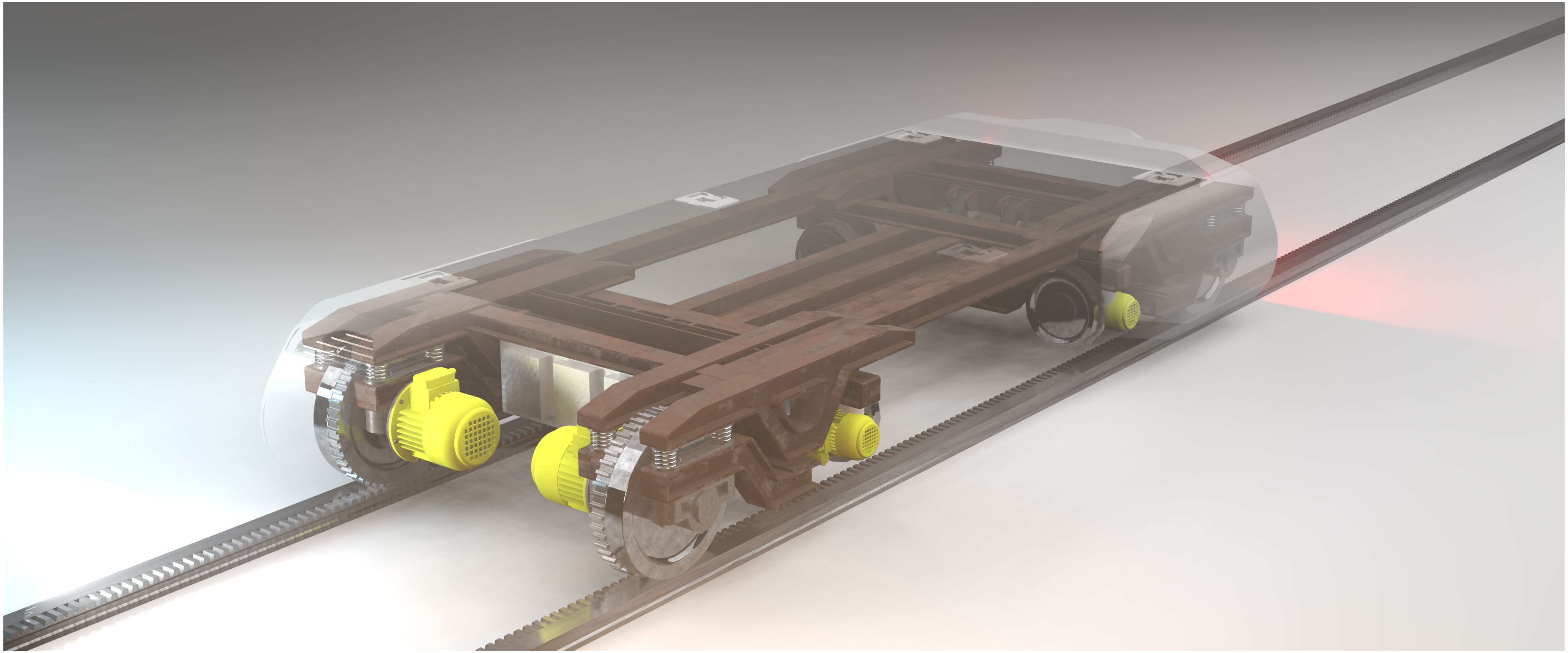
The form language of the drone is intended to clearly state the purpose and nature of the system. Clearly stating that it is electrified and hard wearing. The expression is a balance between making a product that states that it is a part of an optimistic and caring future - while still conveying power and force. It will be 150 tonnes in motion after all. The weight has been left simple, with large surfaces that could be an excellent spot for marketing and partner company graphics. The large light grey side panels of the drone also make for excellent branding spots for the client of the system, imagined above being Vattenfall.

## Safety

The face of the Voltiak drone is symmetrical front and back, to reflect its primary movement direction, which will be front and back. The light bars will change colour to indicate direction, both for safety as well as for observer clarity. The drone is using a twin camera setup in each direction (seen in the darker spots of the renders), to maintain personal safety for both service operators along with stray civilians. It will also act as impact prevention for unexpected obstructions or other drones.

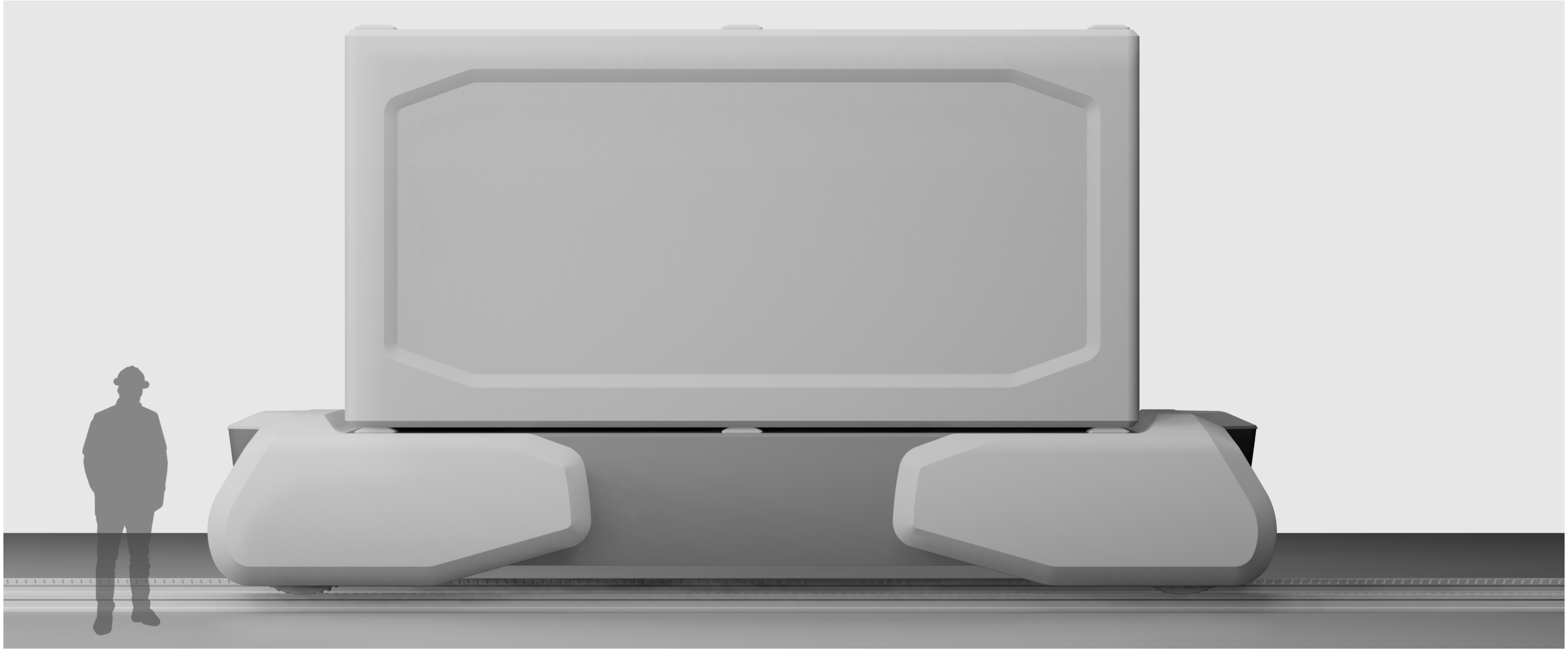
# Voltiak brand identity

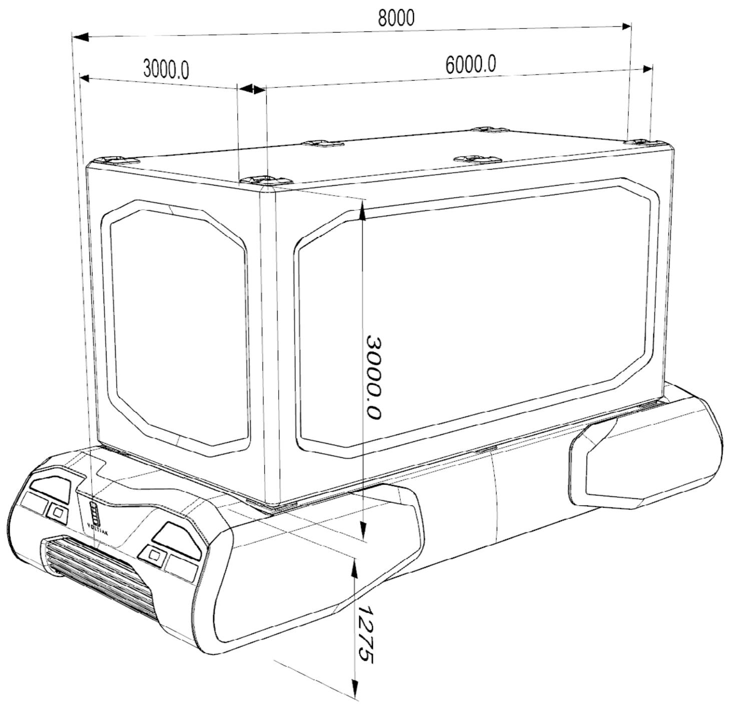
The working name for this project ended up being Voltiak, the name is a play on the Voltaic pile. The first modern battery. The logotype is a scaled rectangle containing four stacked rectangles, bearing the same proportions of the weights of the system. This layered effect is also a nod to Volta's first battery, due to its stacked configuration. This identity seemed very appropriate, due to the possibility of this becoming the first viable battery of its kind.



## The internals

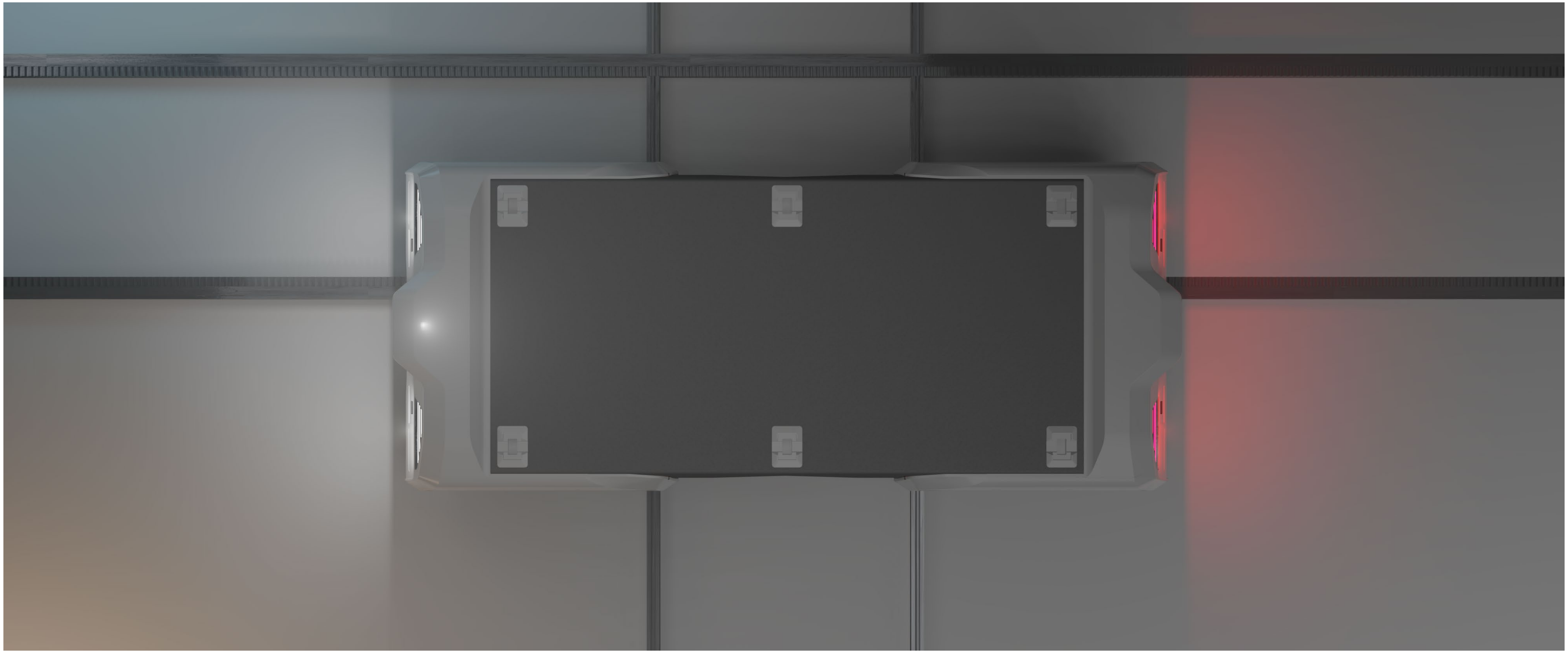
The internals are all modelled based on current technology. The chassis is a standard train carriage configuration with the power being rail based just like the New York City and London subway systems[30]. This to avoid using overhead lines interfering with functionality during loading and unloading. The drone is using a combination cogwheel with train wheel design. Using the train wheel for load bearing along with an inner cogwheel, which eliminates the risk of loss of traction, improving both efficiency and safety. If a traditional train wheel would loose traction going up or downhill the slip could quickly escalate to increasing speed and potential derailings, making the cogwheel addition optimal for steeper inclines. The surrounding bodywork is mainly cosmetic and easily removable to enable easy access for servicing. This will also allow for a traditional train carriage style construction, resulting in a cost effective and more accessible chassis. Taking inspiration from the track service vehicles, I implemented a secondary set of wheels. Which would allow the carriage to strafe sideways, allowing for a track change relying on the drones and not a network of switching tracks. This could drastically improve the loading and unloading systems.





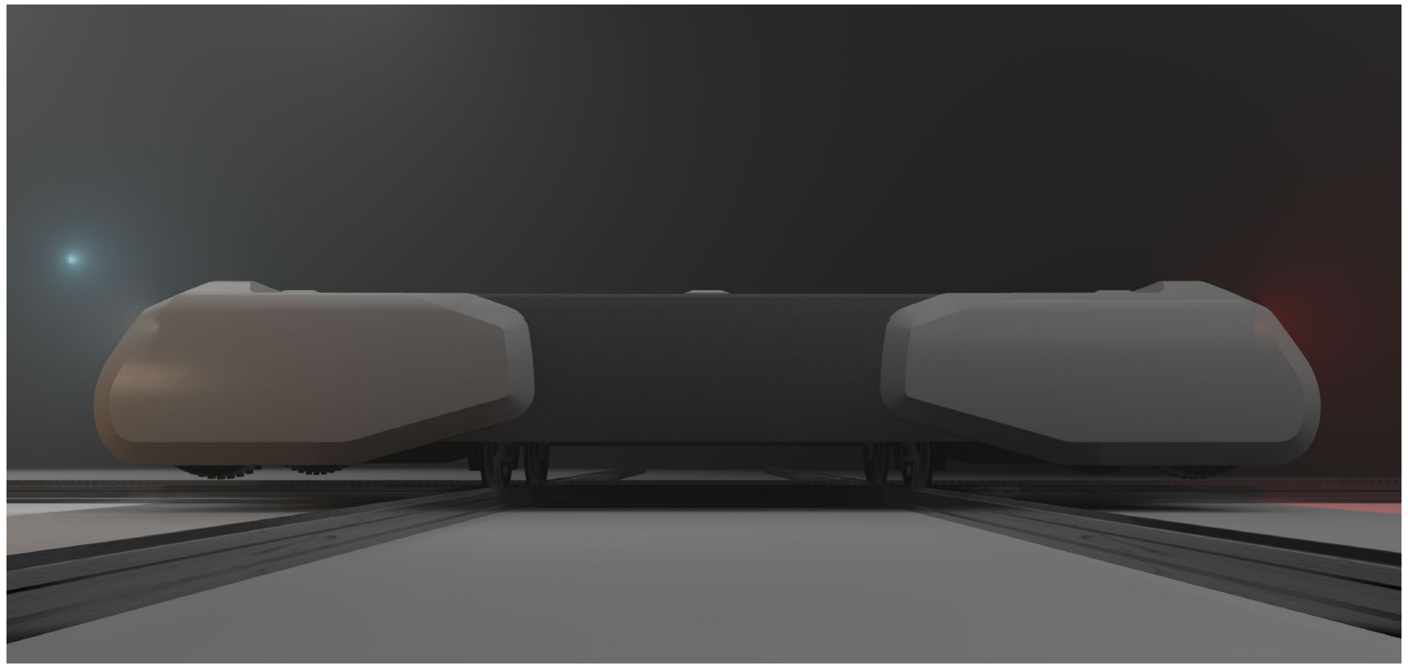

## Dimensions

The dimensions of the system was set based on what would be reasonable loads to lift. Looking into the density of different variants of concrete we find that a 3x3x6 meter weight (A 20 foot hicube shipping container is roughly 2,5x2,9x6m) would give us a mass of somewhere between 130 and 160 tonnes, which would require creative solutions for how that mobile lift would work. There are mobile cranes possible of lifting 1200 tonnes but the biggest serial manufactured forklifts top out at 72 tonnes. This would be the next step for innovation in this project.



## Re-imagining directionality

A big challenge with maintaining a compact footprint of rail-based systems is the turning radius. My ambition was to introduce a system which would allow for sideways strafing of the drones. This would allow for much more flexibility, at loading and unloading sites. As well as being able to easily separate drones in need of service at more parts of the track. The use case for this function would be unloaded drones, realigning with a new track. With the risk of becoming a gimmick - this will have to be further researched before I call it a feature.



## Maintenance

To ensure longevity, the drone was designed with the goal of being a highly serviceable product. All components would be easily accessible with an ergonomic working position, using a trench style workshop (visualised above) at the location of the battery. All panels are made of lightweight composite to be easily removable without heavy lifting. The motors have clearance to be easily disconnected from the chassis, ensuring a smooth recovery if something goes wrong.  The under-mounted transformer is top mounted, allowing it to be lowered straight down for service. Other bodywork components and load bearing systems have been simplified for reliability and feasibility.

## Re-purposing for people

This re-purposing of destroyed areas would mean that a whole new access and purpose could be given to these open pit mines. Allowing for new recreational areas to be made, in conjunction with giving them a purpose for green energy storage. A win-win for every part of the system.

# Economical aspects

The economical viability is always of huge importance when it comes to the possibility of implementation of a product and concept.

The first economical benefit is naturally to take care of the excess energy. Since excess energy is sold off for cheap or simply being wasted, it is a resource that is being given away. Likewise when energy is at a great need prices skyrocket due to overloading of the system.[31] As already proven by the great savings from the Tesla grid battery system, energy storage have the potential for huge economical benefits.

Current gravity battery technologies have a prognosis for half the cost of Lithium-Ion batteries, which would arguably be even lower due to the simplicity of the Voltiak system. This in conjunction with the much longer lifespans of rail based movement, that has an average service life of 50 years today[32] will ensure a much more affordable solution than chemical cell storage.

The weights are static components so once the container has been developed waste products and landmass could be used as a net positive part of the economics of the system.

Due to the ever decreasing popularity of coal in western countries, many coal mines have been closed in recent years and the mines that are remaining are facing an uncertain destiny. This is a perfect opportunity to repurpose these mines to gravity batteries, converting the economic depencence in these communities from fossil fuels to a renewable future.

The final economical aspect I considered was the cultural value of this system. Due to the possibility of regreening the wounds of the earth and introducing them as recreational areas in conjunction with good publicity for the renewable energy in the county.

# Predicted issues or challenges

This system is of course not perfect. Huge strain would be put on the tracks themselves, resulting in challenges in engineering for longevity for skewing/slipping tracks in relation to the ground surface.

The cogwheel and cogged tracks would suffer from abrasion - resulting in a longevity challenge with more servicing of drivetrain as well as tracks.

The weights in this format could turn out to be upwards of 130 tons, assuming we could fill some weights with material the same density as concrete. We then face some challenges with lifting these with a forklift format vehicle, with the current market leaders stating around 70 tonne payload capacity.[33] The format and relationship of the weight and lift would therefore have to be further developed.

The stacking of the weights is also an engineering challenge, making sure that they could handle the compression of multiple weights in height.

Connected to both tracks staying in place as well as the compression of the weights, we face a geoengineering challenge - with making sure that the platform for lifted/"charged" and level zero/"empty" would be stable, flat and avoiding landslides.

The power supply is based on the same system as train or tram power supply. Something that would have to be calculated is the amount of substations per drone and meter of track that would be needed - as well as how to balance this supply/draw efficiently.

Water drainage, sabotage protection and personal safety also remains to be fully explored and resolved.

# Other future improvements of system

Looking into other areas of implementation would be beneficial. Like the massive electrification of many countries in Africa, where solar power strategically beneficial - but intermittence is a huge factor of electrifying a brand new grid. Gravity batteries could give way for a massive potential in electrification.

The power supply should be further defined to make for a more believable system. The connection between the drone and the power supply has not been clearly shown in the concept yet.

I would like to get expert feedback from electro-, geo- and mechanical engineers to further improve the viability of the concept.

Further refinement of the concept itself will also be made and presented for the exhibition and my portfolio.

# Ending note

Connecting back to my starting point. And making a difference. This bachelor project was for me just as much about design philosophy as a sustainable designer as it was about the project itself. I would like to declare my personal findings to wrap my project up. I have not invented everything that is visible, but I do not believe that is necessarily the point of the designer.

Thomas Edison did not invent the light-bulb, but he is credited for making the first viable version of it. Historians give him this as an effect of his showmanship. He was available for media, understood a good show and good public image was crucial to the success of his products. I believe that is our role as designers as a part of a sustainable future. We are here to visualise and excite people of possibilities, because good things happen when we inspire others.

That is where I find myself in this project. It is about combining existing technology to a solution that is highly feasible, that is considering the energy system as a whole - with a chance of improving it for the better. If the VOLTIAK system can allow for the introduction of renewable energy, it is hopefully avoiding the traps of green-washing and is contributing according to the science.

With that said, this Voltiak is not on its own going to save the planet, it is not single handedly going to solve the energy crisis and there will be large implications in material and cost connected to the construction of this system. As designers for the future, we have the responsibility to read and learn, be critical and use the tools we have been given - to stay motivated as well as motivate each other - to make a difference.

Thank you for your time.

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