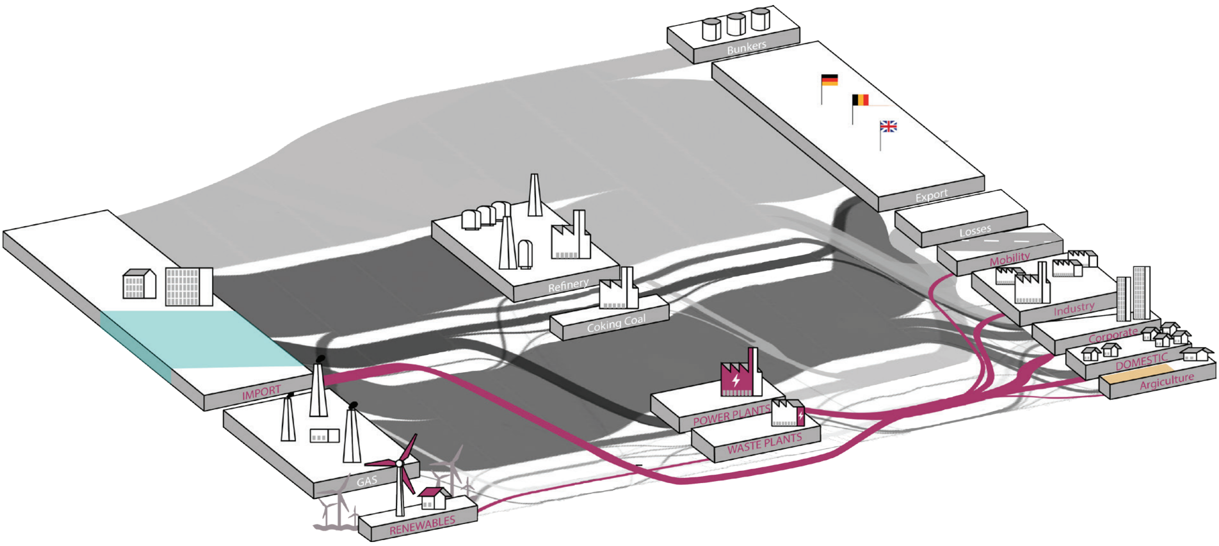
ENERGIZERS

RESEARCH BOOK

CP

COMPLEX PROJECTS
DEPARTMENT OF ARCHITECTURE

2019



INTRODUCTION

Consuming energy has always laid at the base of humanity. Humankind has been burning things for energy since the dawn of civilisation, by the harnessing of energy in the hydrocarbons bonds of wood. In the last two centuries humanity has made a shift from wind-and water- powered energy sources, to what we now regard as “fossil fuels” and now arguably back. Most human activities in our modern society depend on a regular and interrupted supply of energy. Therefore, energy is fundamental to our quality of life. Which subsequently has led to a strong relationship between energy and economic power, which intensively shaped the distribution of wealth today and therefore the world that we live in. Since the beginning of the millennium, however, humanity has entered a “post-industrial” society, where our constant connectivity to an abundance of knowledge together with computing power have replaced raw energy and materials in generating wealth. This subsequently gives the opportunity to in nowadays age make the transition to different energy sources that would free humanity again from its dependence hydrocarbons: finite resources. It can be regarded as a new paradigm shift, which ultimately has an impact on human society again and will arguably take shape in our urban context.

This book discusses energy consumption and production of the district Amsterdam Zuid-oost, and elaborates on how the current transitional energy phase will reshape our urban context. The issue is raised that humanity’s new necessity of renewable energy storage contradicts the motives behind the energy transition because current vessels used as energy storage remain depended on finite natural resources. Therefore, this thesis poses to search for new matters to store renewable energy.

Figure 1, title. Source (2018).

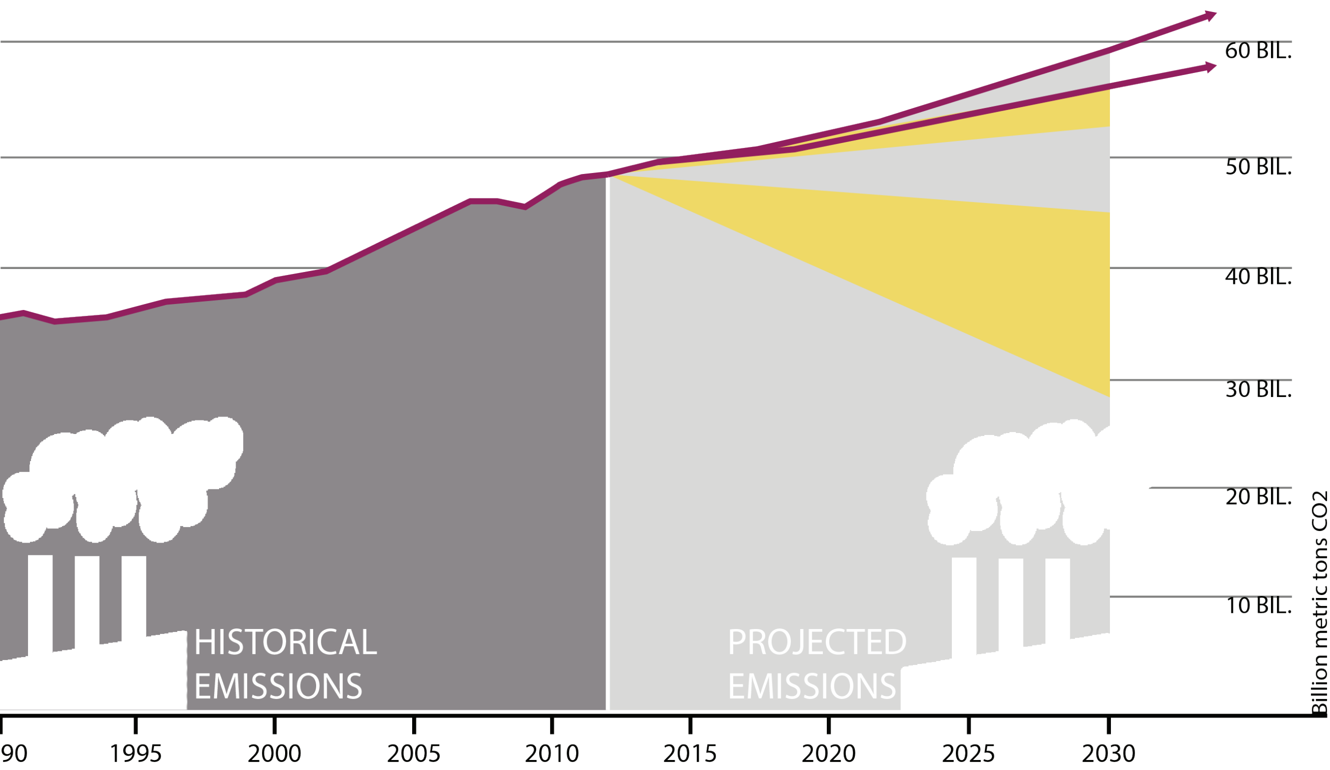
TITLE

CLIMATE CHANGE

Climate change as a global phenomenon is for a greater part getting accepted by the majority of mankind as the catalyser to change our ways of energy consumption. This part of the research on district Amsterdam Zuid-Oost elaborates on the impact of energy consumption on the area from a current, historical and future perspective. Because our energy consumption is based on the climate we live in, together with the regional resources available and the position of the economy, first the trend of the average yearly temperature in the Netherlands is analysed. As can be seen in the diagram, in the past century there has been a steady increase 0.3 degrees of average yearly temperature from the beginning of the twentieth century until the 1980's. During the eighties, the trend changed. The temperature increased more rapidly, and annual averages started to differentiate more intensively.

Extrapolating the trendline, we argue that the temperature in the Netherlands will further increase from 10.9 on average in 2017 to 11,9 degrees on average in 2040. This increase of 1,0 degree is lower than the predicted average global increase of 1.5 degrees by the United Nations (source). Generally, the increase in temperature is primarily caused by the rapid increase of Co2 emissions in the past century. From the beginning of this millennium, The Netherlands has aimed for a decrease of co2 emissions. In 2016 the total amount of co2 emissions produced by the country has decreased by 10.5 per cent from 220 megatons per year in 2000 to 197 megatons. The total emission is predicted to further decline to 154 megatons per year in 2030. After 2030 it is expected to decline less rapidly.

Figure 1, title. Source (2018).


60 BIL.
50 BIL.
40 BIL.
30 BIL.
20 BIL.
10 BIL.
Billion metric tons CO2
HISTORICAL
EMISSIONS
PROJECTED
EMISSIONS
90
1995
2000
2005
2010
2015
2020
2025
2030


Zuidoost

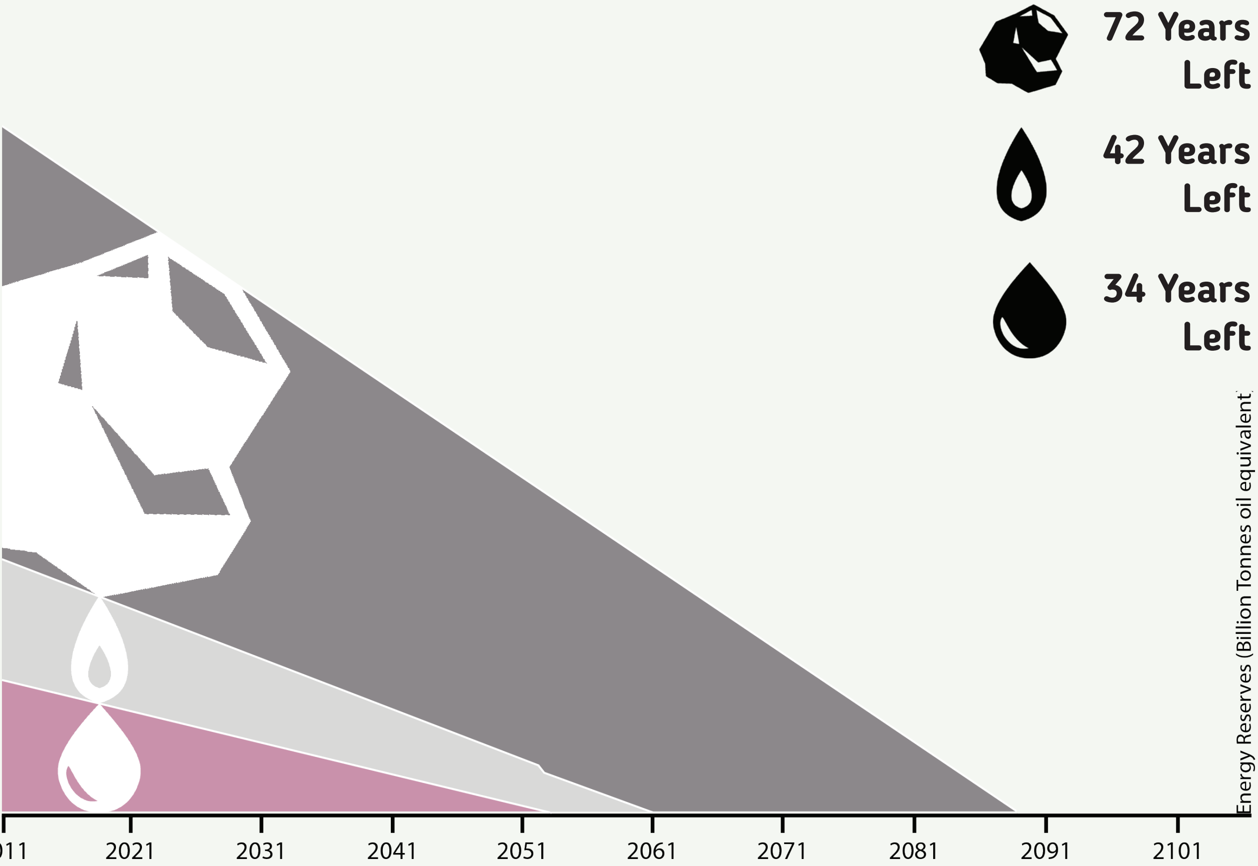
> 1.000.000 M^3
500.000 - 1.000.000 M^3
200.000 - 500.000 M^3
100.000 - 200.000 M^3
500.000 - 100.000 M^3
20.000 - 50.000 M^3
10.000 - 20.000 M^3
>50.000 M^3

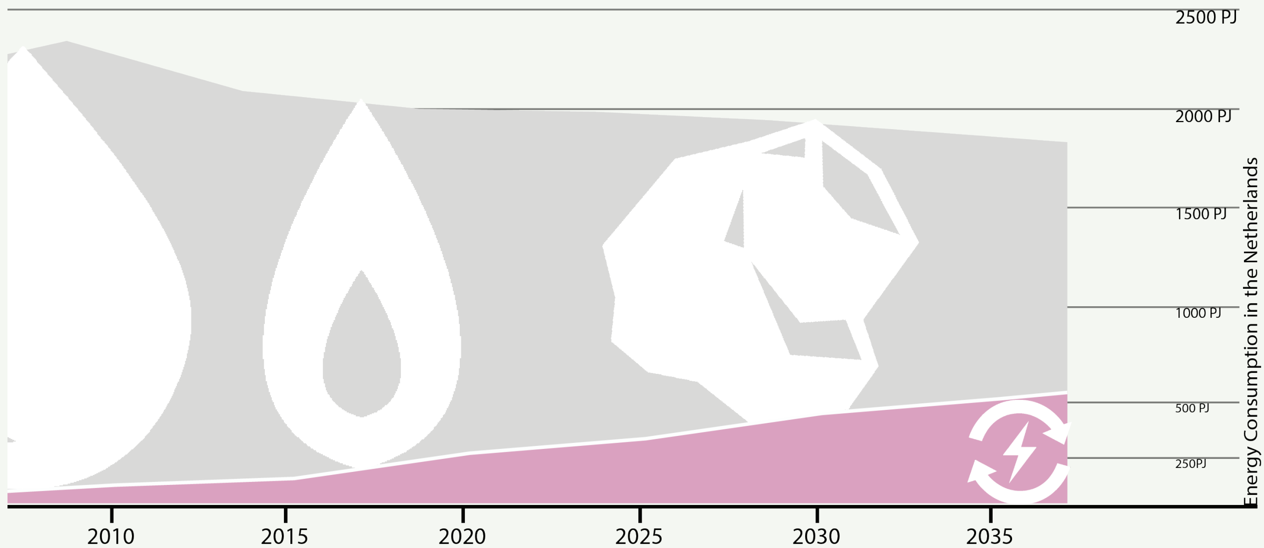
TITLE
DISTRICT EMISSIONS

The build environment plays a minor part in the total co2 emissions figure. However, because the residential dominated area of Amsterdam Zuid-Oost still does play have an impact on the total co2 emissions of Amsterdam, an analyses was performed on the buildings in the district to detemine their current state. A co2 emission mapping was made of each structure in the area based on their produced co2 emissions as can be seen in the maps to the left. The analyses show that the low rise dwelling complexes in the neighbourhoods Holendrecht & Reigersbos produce a particularly high amount of Co2 emissions. Of course, one should take into account that these buildings consist of a greater amount of dwellings than the less polluting rowhouses in the neighbourhood. However, categorising the dwellings based on their energy label together with the analyses of the average consumption of gas and electricity per dwelling typology, show that the low-rise complexes do score the lowest points.

Concluding, the maps give us the ability to predict which existing buildings will be able to thrive in the future and which will not. The low-rise dwelling complexes of the Holendrecht & Reigersbos will not likely have a place in the master plan of 2100.

Figure 1, title. Source (2018).


72 Years Left
42 Years Left
34 Years Left
Energy Reserves (Billion Tonnes oil equivalent)
2021
2031
2041
2051
2061
2071
2081
2091
2101

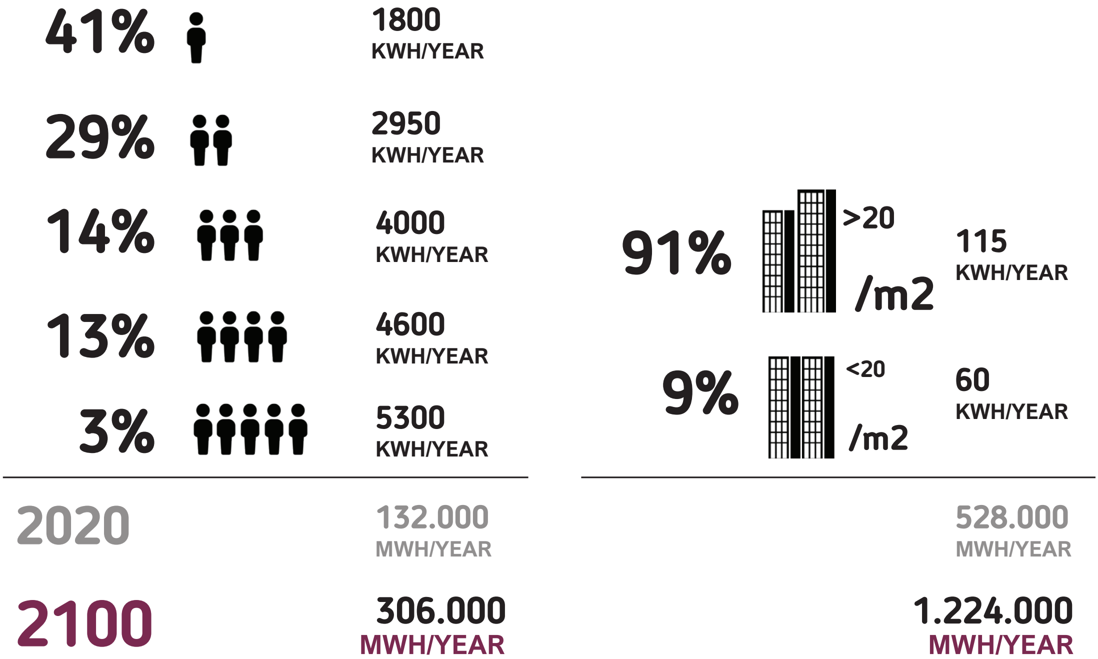

2500 PJ
2000 PJ
1500 PJ
1000 PJ
500 PJ
250PJ
Energy Consumption in the Netherlands
2010
2015
2020
2025
2030
2035

ENERGY CONSUMPTION

By continuing our current global way of energy consumption the … predicted that in the year 2052 the world has depleted its oil resources. Gas will resources will be exhausted by 2060, and the last coal will be mined in the year 2088. The search for alternative energy source has already been growing rapidly over the past decade. However, fossil fuels are still by far the predominant actor in the total amount of primary energy needed for society today. The data on the average energy consumption of a Dutch household shows that they are no exception. Overall the amount of energy a Dutch household consumes has decreased between the year 2000 and 2016.

However, in 2016 still 74% of gas is consumed per household, making by far the greatest source of energy consumed by households in the Netherlands. While the consumption of renewable energy has increased in 2016 towards the beginning of the millennium, the consumption of electricity produced by fossil fuels fuelled powerplants have increased in similar rate.

Figure 1, title. Source (2018).



DISTRICT CONSUMPTION

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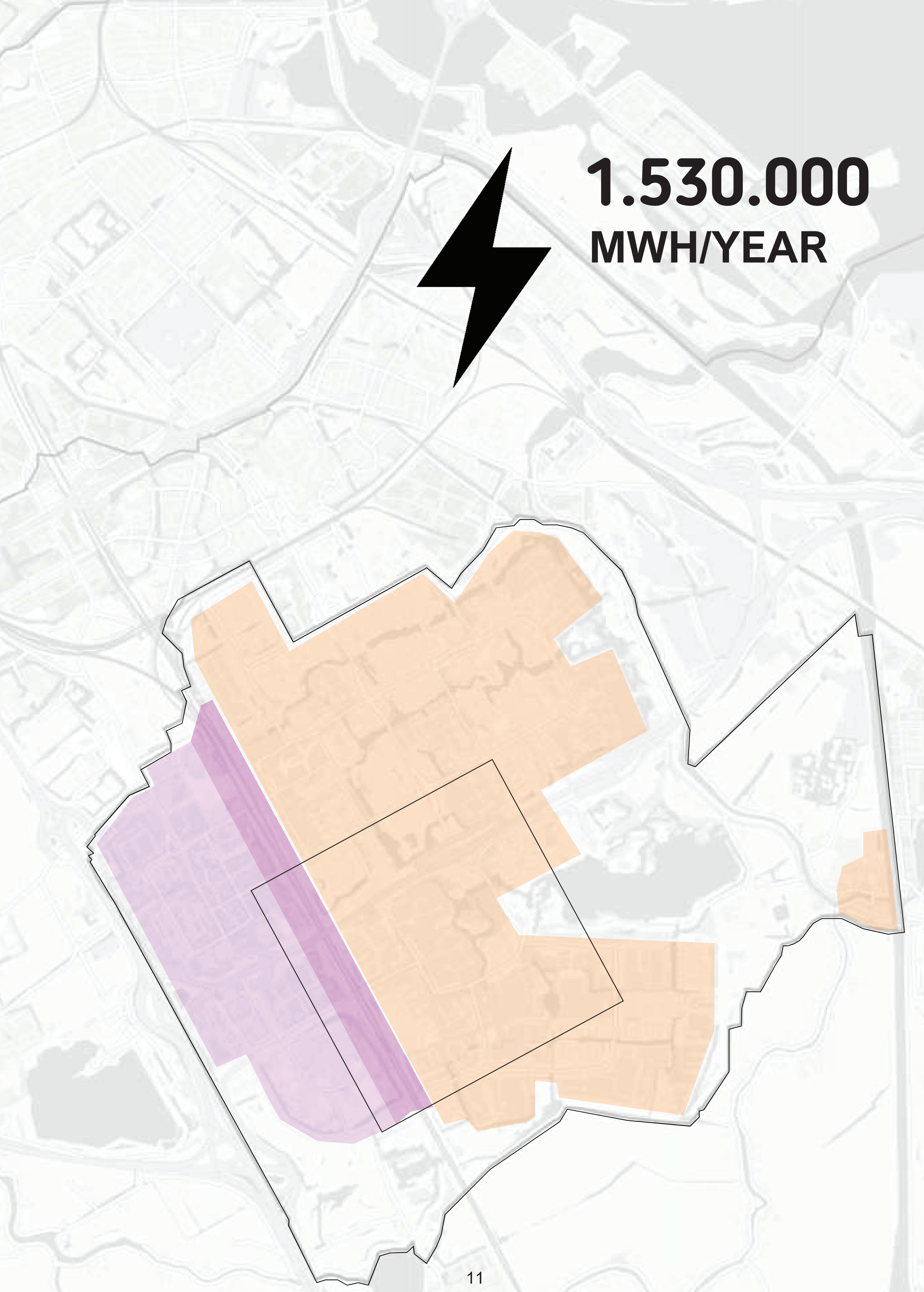
Ficia quam alitat eostrum sinventint utae ditiiss eritati oruntius nossitibus aceaque nus nias mi, netur, occullo rehenis volo everum sum quationseque earum ne que odis adi doluptatatem explis plaborest et occus.

Volo veriam ut volorestibus etus utemqui aborro ma sae consequae conest laborpo repudaesto con pe autaspera santiissed quae dolorit dolecusam, si bea aut expero id quiantia voloribusdam quo conecto rerepra quatem et minctur, soluptaspiet hari ut reius ute pa nos sitem laut volora conse maximust inimaxi magnihil int int re con plabo. Berorruptat enem essedit, quo comnimp ossum, il in perorit, conseque iliqui od mo tet etur rehendel incti doluptatem cor mil es nusdam re voluptatiam invelitat adicatat. voluptatati aut reriore nuscipit in endelitius de que pra int remodis maio temolorest a dolor

Figure 1, title. Source (2018).


1.530.000
MWH/YEAR

70%

CO2 REDUCTION
In 2040, baseline 1990

240.000 MWh

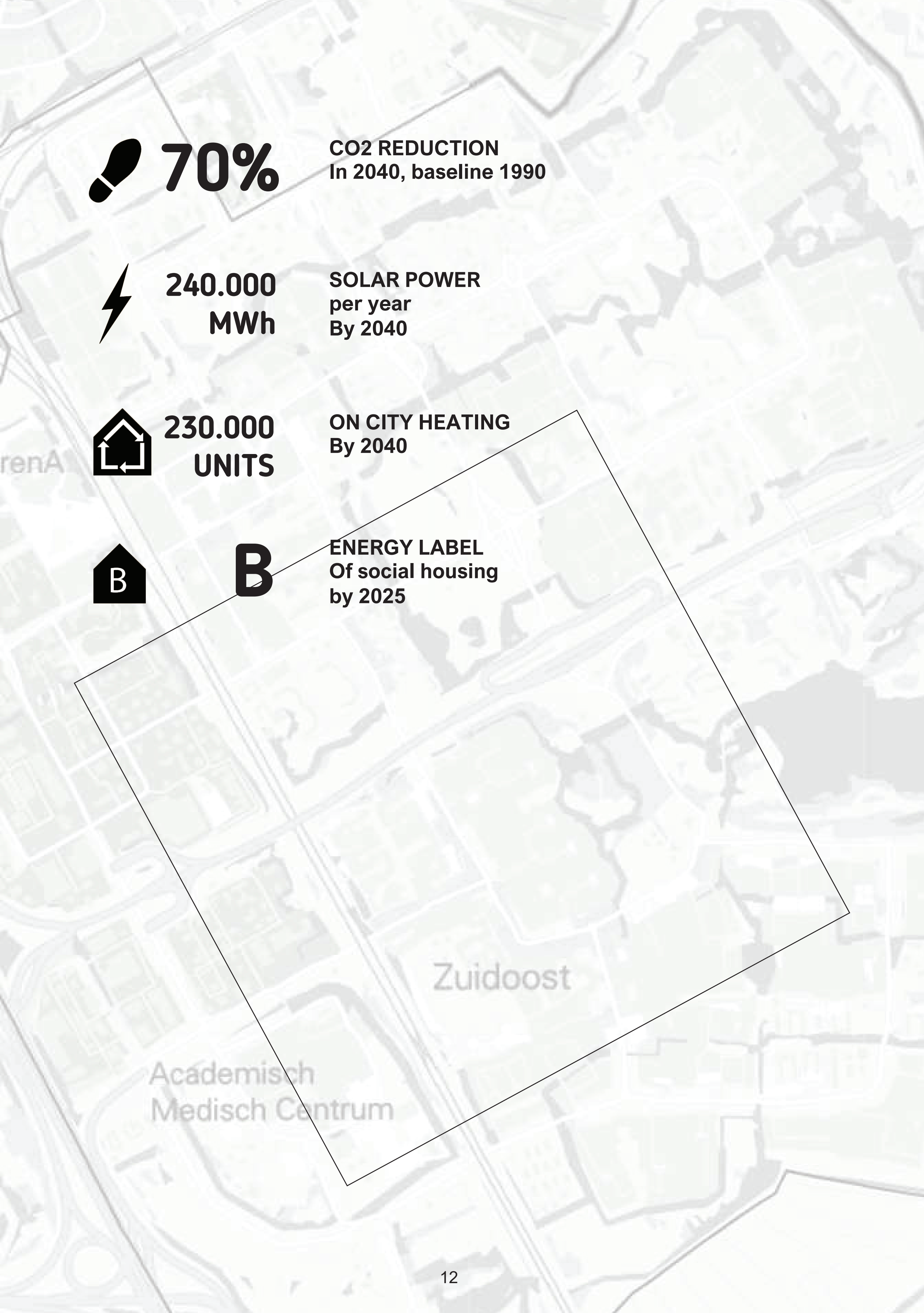
SOLAR POWER
per year
By 2040

230.000 UNITS

ON CITY HEATING
By 2040

B

ENERGY LABEL
Of social housing
by 2025



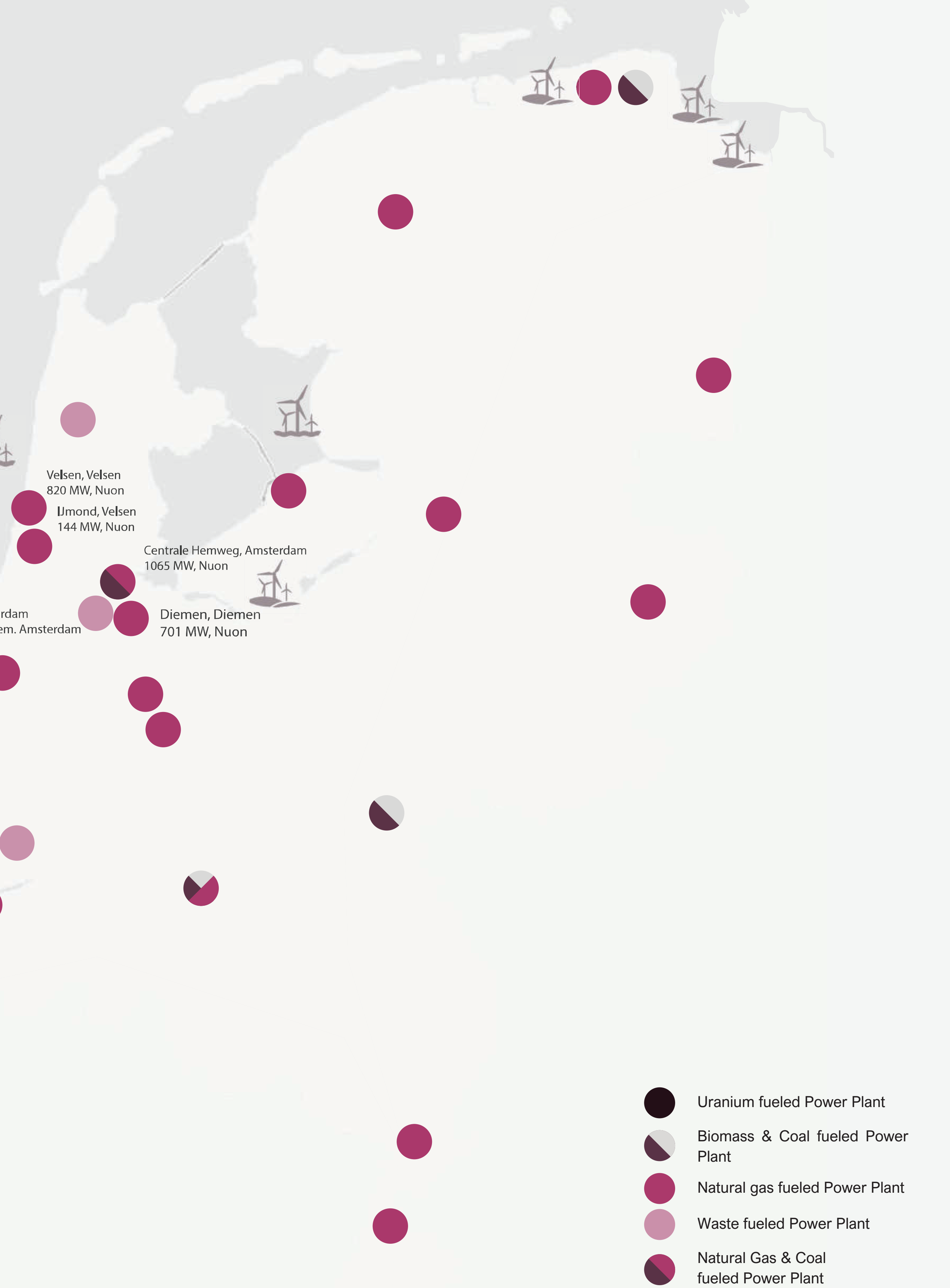
AMSTERDAM ENERGY GOALS

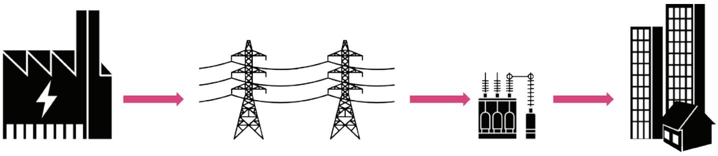
The energy transition has led to a new trend in which nations and in particular large cities to set new energy goals to become the frontrunner on energy, climate and sustainability. In terms of sustainability and the transition to renewable energy the Netherlands, however, is far behind other European countries. Comparing the city of Amsterdam to cities like Vienna and Copenhagen, a significant difference in energy consumption and Co2 emission becomes visible.

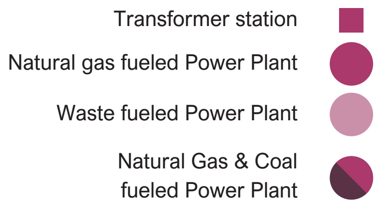
To breach the gap with Europes' sustainable frontrunners, Amsterdam has set energy goals which will have a major impact on its build environment. The goals are set in the city's' new Transformation Agenda Amsterdam and Explanatory paper. The earlier 'Amsterdam Structural vision 2040, Economically vital and Sustainable' (2010) serves as a reference framework. The main reason for these goals is to more sustainability consume energy and increase the outdoor air quality, while overall protecting the climate. The municipalities aims are amongst other to reduce Co2 emissions by 70 per cent towards 1990, to increase its total renewable energy produced from solar power to 240.000 Mwh per year, to connect 230.000 dwelling units to the district city heating systems instead of the gas infrastructure and to have renovate all social housing units to energy label B by the year 2025. This city has set these goals in their new Transformation Agenda Amsterdam and Explanatory paper.

Subsequently, several sustainable projects like building sustainable schools, implementing smart energy grids, more waste separation and emission-free bus transport are being undertaken throughout the city.


Hollandse kust Noord
700 MW, realisation 2023
Prinses Amalia Windpark
130 MW, Eneco/Mitsubishi
Luchterduinen, Noordwijk
120 MW, Eneco/Mitsubishi
Hollandse kust Zuid
2x700 MW, realisation 2022
AEB, Amste
160 MW, Ge


Velsen, Velsen
820 MW, Nuon
IJmond, Velsen
144 MW, Nuon
Centrale Hemweg, Amsterdam
1065 MW, Nuon
Diemen, Diemen
701 MW, Nuon
Uranium fueled Power Plant
Biomass & Coal fueled Power Plant
Natural gas fueled Power Plant
Waste fueled Power Plant
Natural Gas & Coal fueled Power Plant



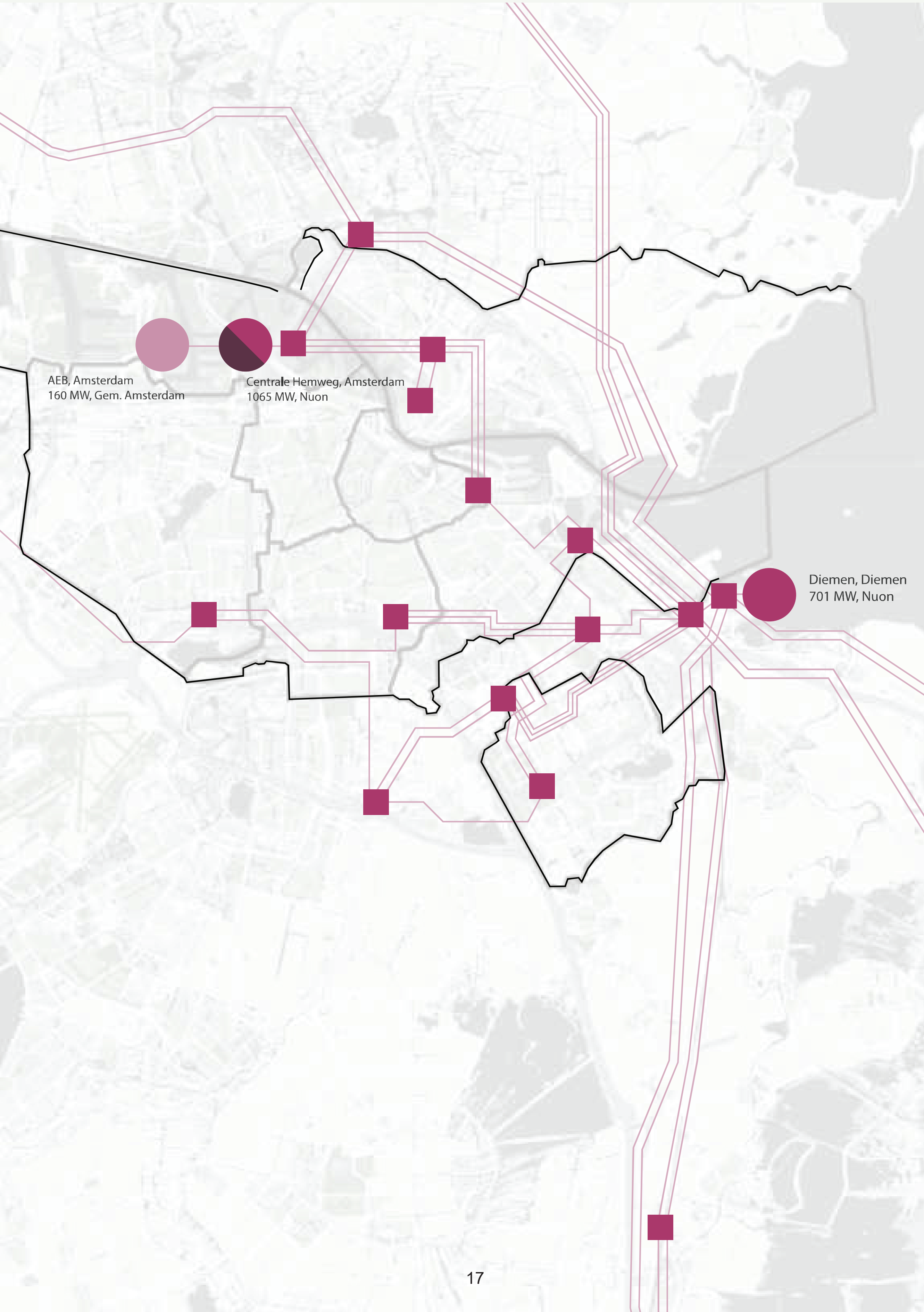


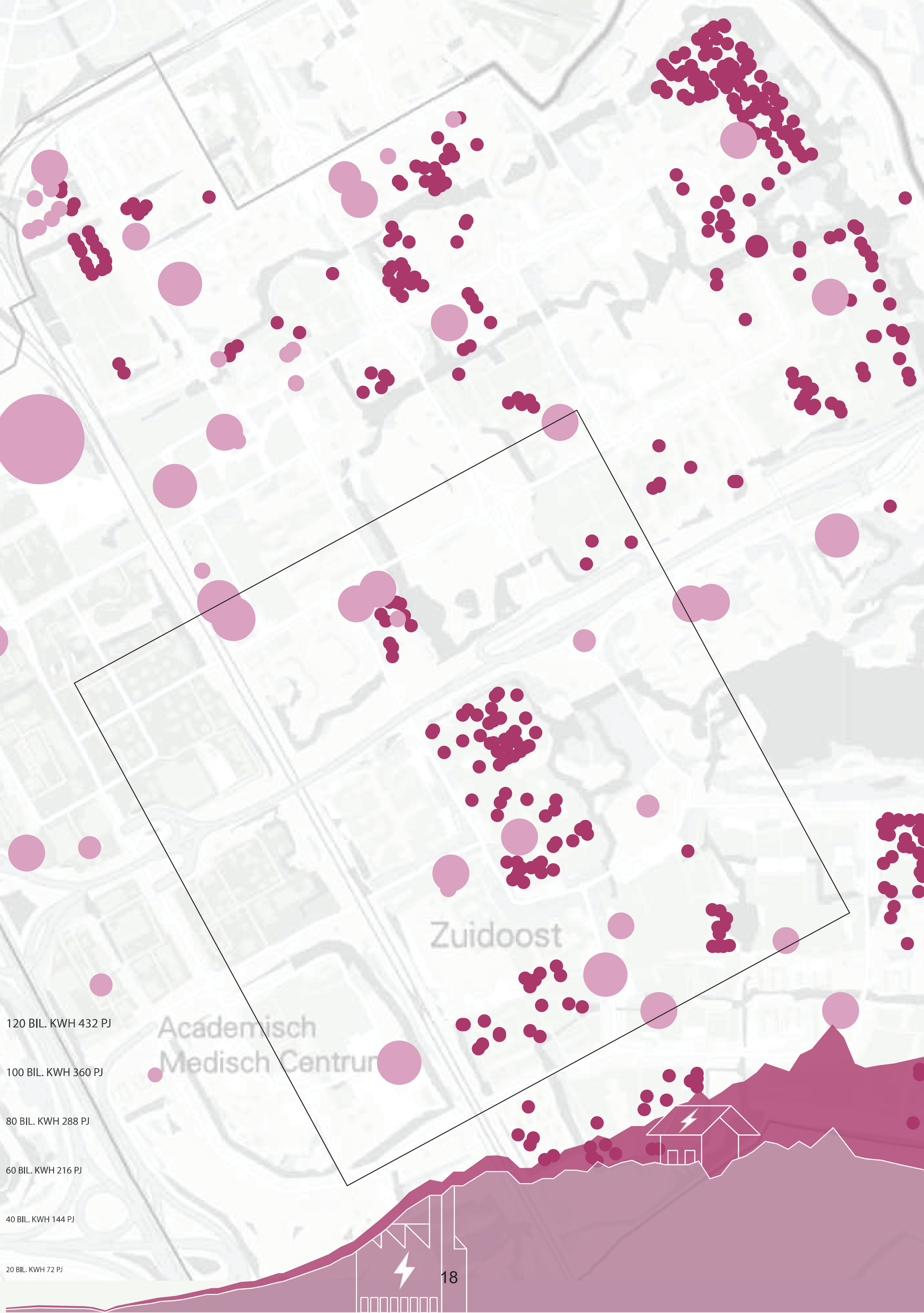
TRADITIONAL PRODUCTION

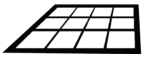
Amsterdam citizens and businesses jointly spend approximately €1.8 billion on electricity bills annually. This massive amount of money flows out of the city, year after year since there is few local energy produced in the city itself. Overall its energy system follows the old principle of centralised production. The main actors are a 1050 MW coal and gas-fuelled power plant located at Westpoort, together with a smaller waste-to-energy plant also located at Westpoort, a gas fuelled 701 MW power plant located in Diemen and a few major windmill parks along the coast west of Amsterdam. Energy is distributed via high-voltage power lines to transformer houses located throughout the city, a linear principle which relies on one central power suppliant.

Amsterdam has one of the largest district heating networks in the Netherlands. The waste-to-energy plant in Westpoort produces most heat. Together they provide heat for approximately 325,000 households, while around 72,000 houses are connected to it. The municipality wants to join forces with partners in the city to invest more in energy efficiency and in the local production of renewable energy. This will simultaneously reinforce the economic structure of the region and contribute to an affordable residential and business environment. In 2013, energy consumption in Amsterdam amounted to 54,500 terajoules, measured at the user level, thus excluding conversion and transmission losses, and excluding geothermal energy.

Figure 1, title. Source (2018).


AEB, Amsterdam
160 MW, Gem. Amsterdam
Centrale Hemweg, Amsterdam
1065 MW, Nuon
Diemen, Diemen
701 MW, Nuon


Zuidoost
Academisch
Medisch Centrum
120 BIL. KWH 432 PJ
100 BIL. KWH 360 PJ
80 BIL. KWH 288 PJ
60 BIL. KWH 216 PJ
40 BIL. KWH 144 PJ
20 BIL. KWH 72 PJ



73% **2213** MWH/YEAR

27% **818** MWH/YEAR

Solar panels on houses

Solar panels on non-houses or mixed

RENEWABLE ENERGY

Besides searching for alternative energy sources, the general consensus is that the amount of energy consumption must be decreased. Amsterdam is slowly managing to reduce its total energy consumption while increasing its renewable energy consumption. The city consumed 60,1 petajoule energy, from which 9,3% is renewable, in 2016 aiming for a total consumption of 58,0 petajoule energy in 2025 from which 27 % will be renewable.

Zooming in on district South East solar panels are the prominent producer of renewable energy in the area. Leading actor in the production of solar energy is the Johan Cruijf Arena. Solar panels on the roof provide in renewable energy to both the stadium and the surrounding entertainment industry. Solar energy production in the residential parts of the district consists of privately installed solar panels and decentralised solar energy production facilities. Solar panels can predominantly be found on the roofs owner owned properties in neighbourhoods Gein and Holendrecht. Subsequently, several wind turbines are operational at natural Oudekerkerplas bordering district South East to the West. The municipality of Amsterdam has appointed several areas with the potential to for the production of wind energy as can be seen in the map to the left. Surprisingly Amsterdam indicated industrial neighboorhood Bullewijk, bordering South East to the west, as an area with potential.

Figure 1, title. Source (2018).

TITLE

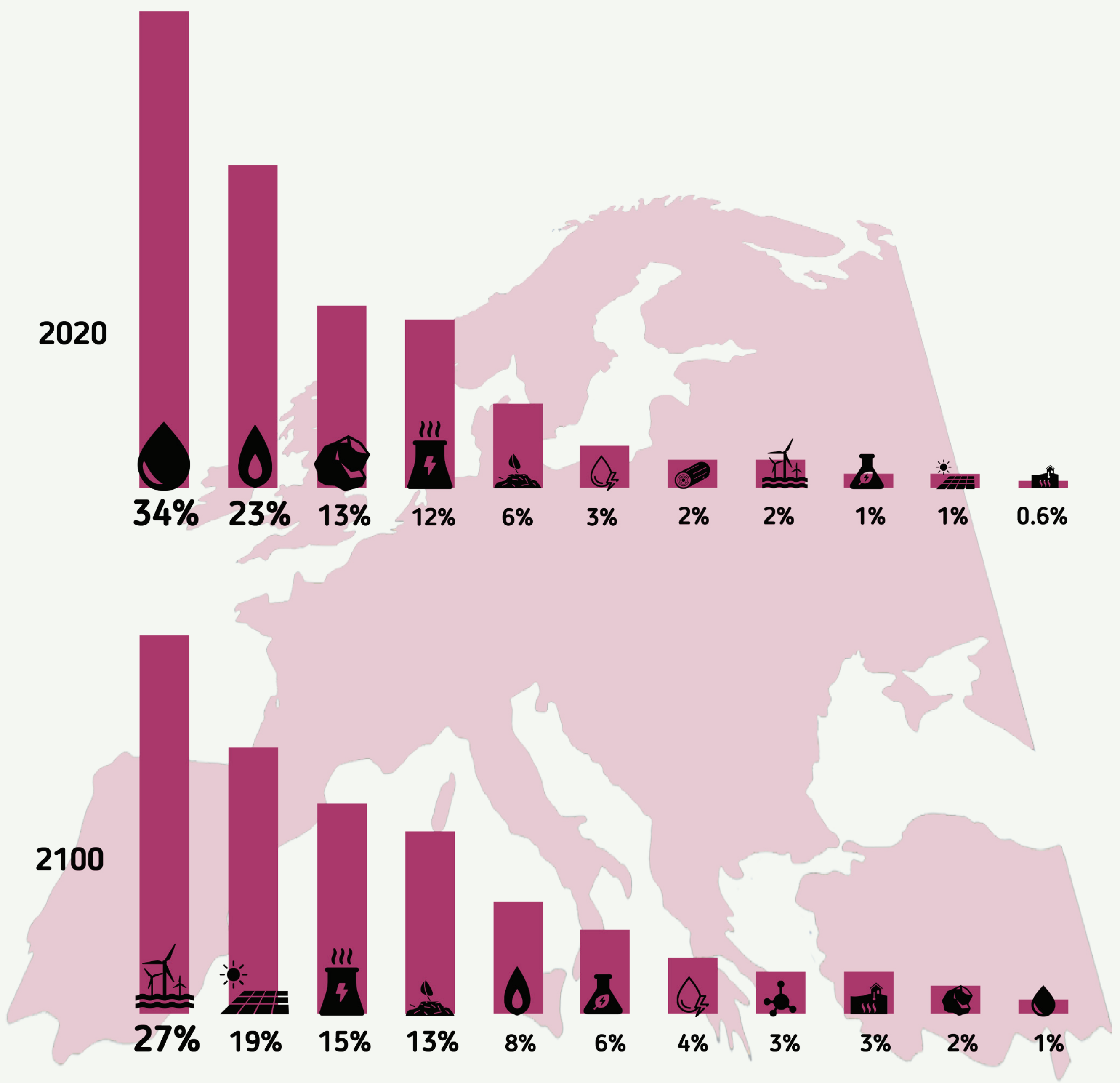
PRIMARY ENERGY

Humanity is currently experiencing an energy transition, a global change in which humanity is making a shift from our reliance on fossil fuels, towards a society reliant on renewable energy sources and therefore more in harmony with our natural resources than before. Our earlier dependence on hydrocarbons to meet economic and societal needs has since recently been established as the cause to environmental changes, including global climate change, acid deposition, urban smog and the release of many toxic materials. Humanity has become much more aware of the impact of our everyday life, compared to the heydays of fossil fuel culture. This paradigm shift, therefore, concerns with the way how humanity deals with energy. Our previous energy systems were intertwined with our way of consuming and producing energy from fossil fuels.

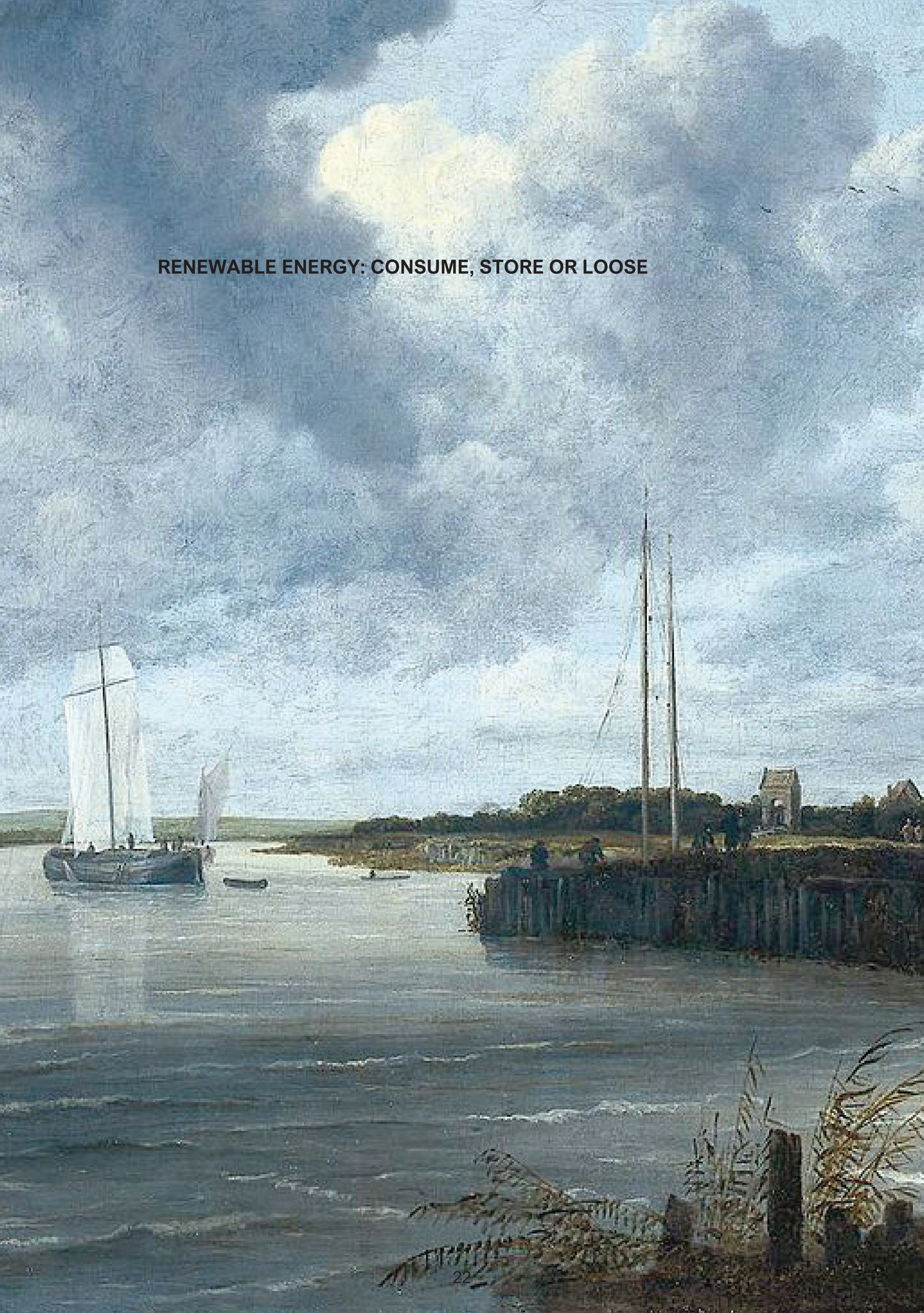
To predict a futural shift in energy consumption and production one should focus on the primary energy needed to a society. Primary energy is the energy required from a source to provide for the final energy demand including the losses of conversion of energy. The primary energy number offers a base to which the future energy production can be assembled. During the analyses, we zoomed in from a global perspective to Europe, to The Netherlands to Amsterdam. The data is then showcased to be able to compare by a historical, nowadays and futuristic perspective.

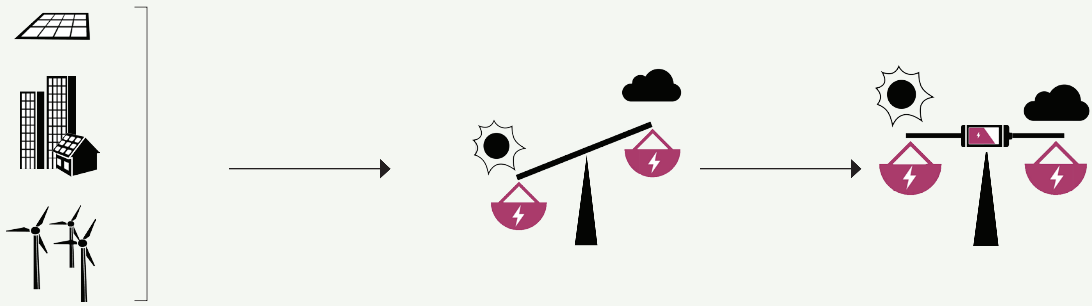
Although based on the prognoses it seems that with the increasing energy production and consumption from renewable energy sources humanity is therefore properly on its way in becoming this post-fossil fuels society, we seem to overestimate the sustainability of the technologies part of the systems producing energy from renewable sources. At least a part of the systems.

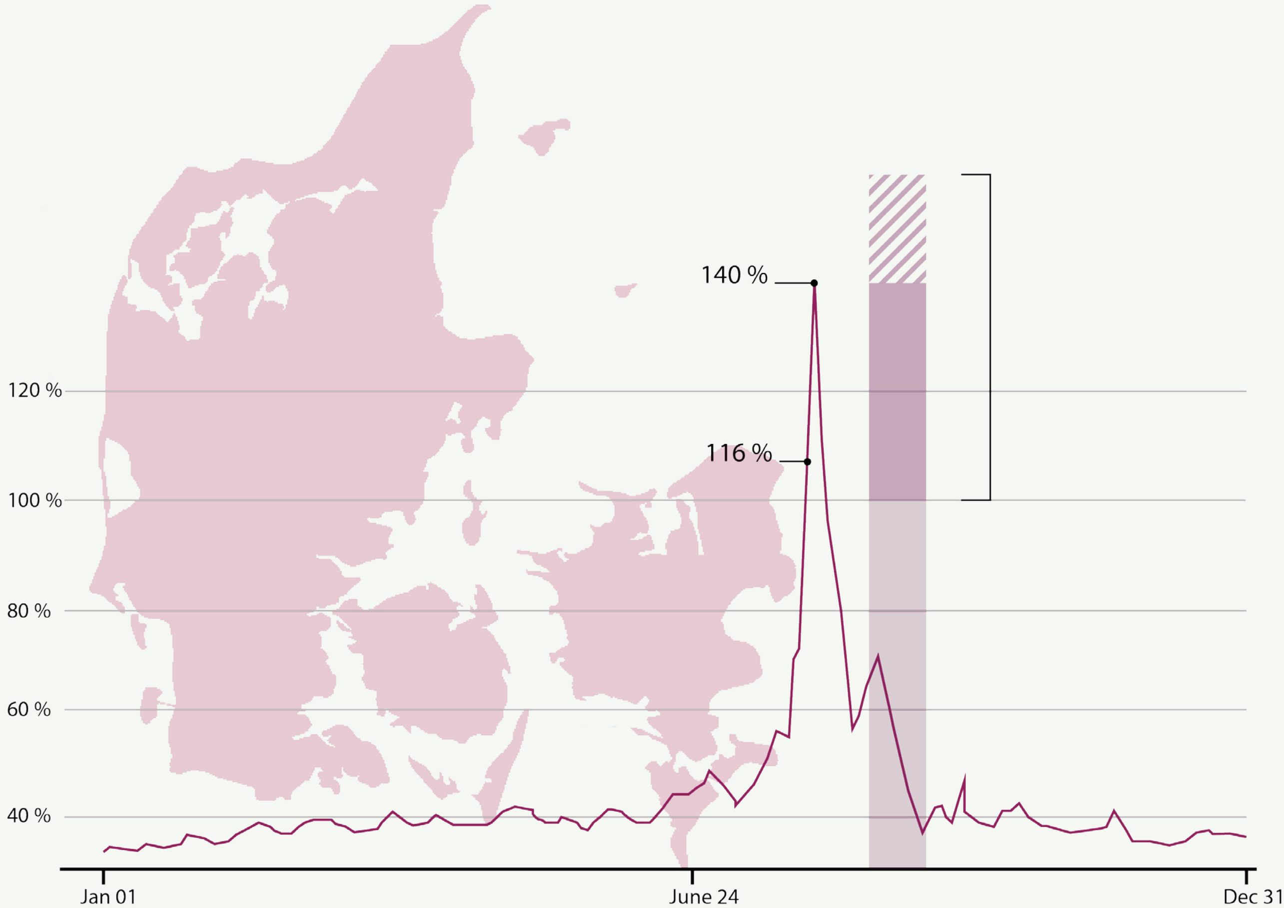
Figure 1, title. Source (2018).


2020
34%
23%
13%
12%
6%
3%
2%
2%
1%
1%
0.6%
2100
27%
19%
15%
13%
8%
6%
4%
3%
3%
2%
1%

RENEWABLE ENERGY: CONSUME, STORE OR LOOSE







140 %
116 %
120 %
100 %
80 %
60 %
40 %
Jan 01
June 24
Dec 31

SUBTITLE

When turning to renewable energy sources our energy systems require a transition into systems intertwined with the characteristics of renewables. As renewable energy sources, in contrary to fossil fuels, have the tendencies to either be directly consumed or stored, else the energy will be lost. Imagine a halted windmill in windy weather: this is energy lost. Thus, unlike a fossil fuel based energy systems, a system relying on renewables will have to increasingly deal with imbalances between the production and consumption highs and lows.

If we take Denmark as an example, one of the most renewable energy fuelled countries in Europe on a regular basis relying on an average of 39 per cent of electricity from renewable sources, we can distinguish the exact issue that renewable energy sources pose. On the ninth of July 2015, when the country experienced heavy winds throughout the nation, Denmark produced 40 per cent more energy from renewable sources that could be consumed at that moment. (Brittlebank, 2015) So the country exported a great part of that surplus of energy.

Denmarks example show that the main issue of the shift to renewable energy sources is that although these sources can supply large volumes of power their energy supply follows, due to the imbalances, quite unpredictable patterns. It is therefore intermittent to the needs of our conventional grid structure. The International Electrotechnical Commission calls this as one of “the biggest challenges facing the renewable energy sector” and therefore a challenge to humanity’s energy shift. (IEC e-tech, 2018) The characteristics of renewable energy sources require ways to smooth out and regulate the energy flows to balance out their unpredictable energy supply. Therefore, means of energy storage are needed interlinked with production from renewables. To quote political economist and journalist Angus Hervey as explanation of the necessity and function of energy storage facilities within a new renewable energy reliant system “They aren’t there for storage; they’re there for lubrication” (Hervey, 2019).

Figure 1, title. Source (2018).

TITLE

SUBTITLE

The storage of energy produced from renewable sources is already being done in many occasions on smaller scales. At the moment the main vessels for storing energy are Off-grid storage, Home Batteries or “stored” on a smart energy grid, which monitors the production and consumption to keep it in balance via distribution. This issue lies with the appliance of batteries as storage as Lithium-Ion batteries dominate the energy storage market. These batteries are built out of the minerals Nickel, Cobalt and Lithium. Here lies the problem when talking about a post-fossil fuels society, more in harmony with its natural resource. The minerals needed for the production of these batteries are, unlike renewable energy, still finite and unsustainable. Not to mention their mere five per cent recyclability (Friends of the Earth Europe, 2013) and reports on human rights violations and formation of producer oligarchies related to the mining business.

With the increasing application of lithium-ion based batteries as vessel to our energy storage humanity seems to transition away from its dependence on fossil fuel for the production of energy, but seems to replace this by dependence on finite minerals for newly required renewable energy storage on a world scale. Therefore, our energy production might be renewable, but the way to store this energy will remain not quite different from our historical dependence on fossil fuels.

Demand for lithium is increasing exponentially. Its price has double between 2016 and 2018. According to consultancy Cairn Energy Research Advisors, the lithium ion industry is expected to grow from 100 gigawatt hours (GWh) of annual production in 2017, to almost 800 GWh’s in 2027. (Cairn Energy Research Advisors, 2016). This growth possess a worldwide issue. As Christina Valimaki analysis at Elseviers calls it: “One of the biggest environmental problems caused by our endless hunger for the latest and smartest devices is a growing mineral crisis, particularly those needed to make our batteries,”. (Katwala, 2018)

Author Simon Harlow argues in his article on Oilprice.com that the future demand of lithium-ion batteries from the automotive industry might become significant, he argues that the real game changer in the demand increase is arguably going to be electrical grid storage. Harlow continues by explaining that “Grid-scale storage battery demand can easily eclipse the need or automotive batteries.” (Harlow, 2016), while emphasising the importance and necessity of lithium in batteries “Battery experts note that although different battery chemistries exist, the energy density of lithium is far superior to other chemistries.” (Harlow, 2016). Harlow concludes that no new battery chemistry will supplant lithium in battery cathodes for decades to come.

Figure 1, title. Source (2018).

5% to 9%
RECYCLABLE

2100 LITHIUM DEPLETED
Based on reserves

TITLE

SUBTITLE

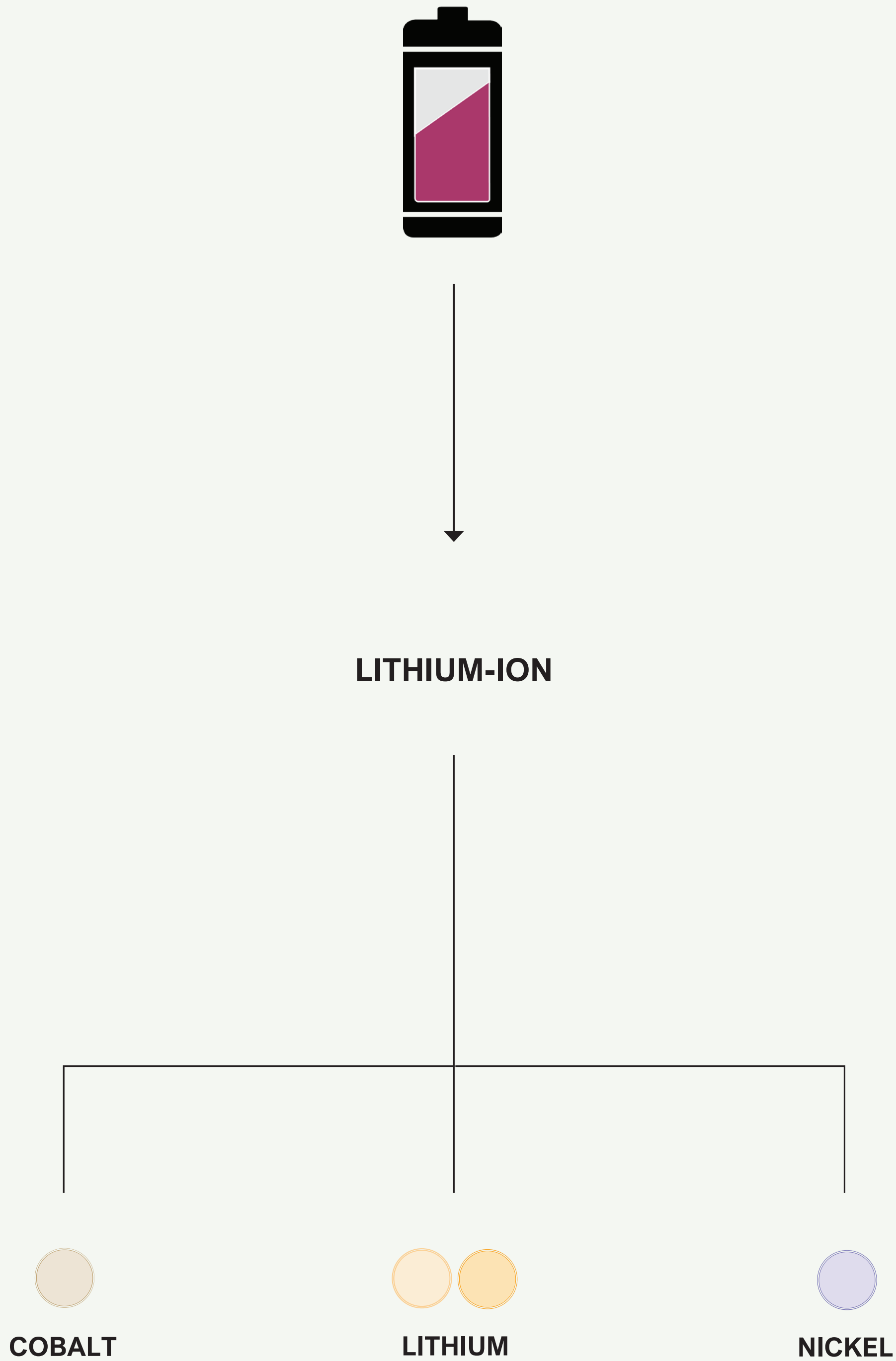
Lithium is thé reactive alkali metal that powers our phones, tablets, laptops, electric cars and since years now used as the vessel for the storage of (the surplus) of renewable energy. As the main component lithium is processed into the positive electrode of the lithium-ion battery, the actual energy carrying vessel of our society. A Lithium-ion battery is made of one or more power-generating cells. Each cell is layered with a positive electrode (cathode), an electrolyte and a negative electrode (anode). All materials in a battery possess a theoretical specific energy, and the key to high capacity and superior power delivery lies primarily in the cathode. For the last 10 years or so, the cathode Lithium has characterised the battery. The exact chemical compound used in the positive electrode is either lithium-cobalt oxide, Lithium Nickel Cobalt Aluminium Oxide, Lithium Nickel Manganese Cobalt or in newer versions, lithium iron phosphate. It is processed in a cobalt solvent. The negative electrode is commonly made out of the carbon (graphite), and the materials used for the electrolyte varies per type of battery.

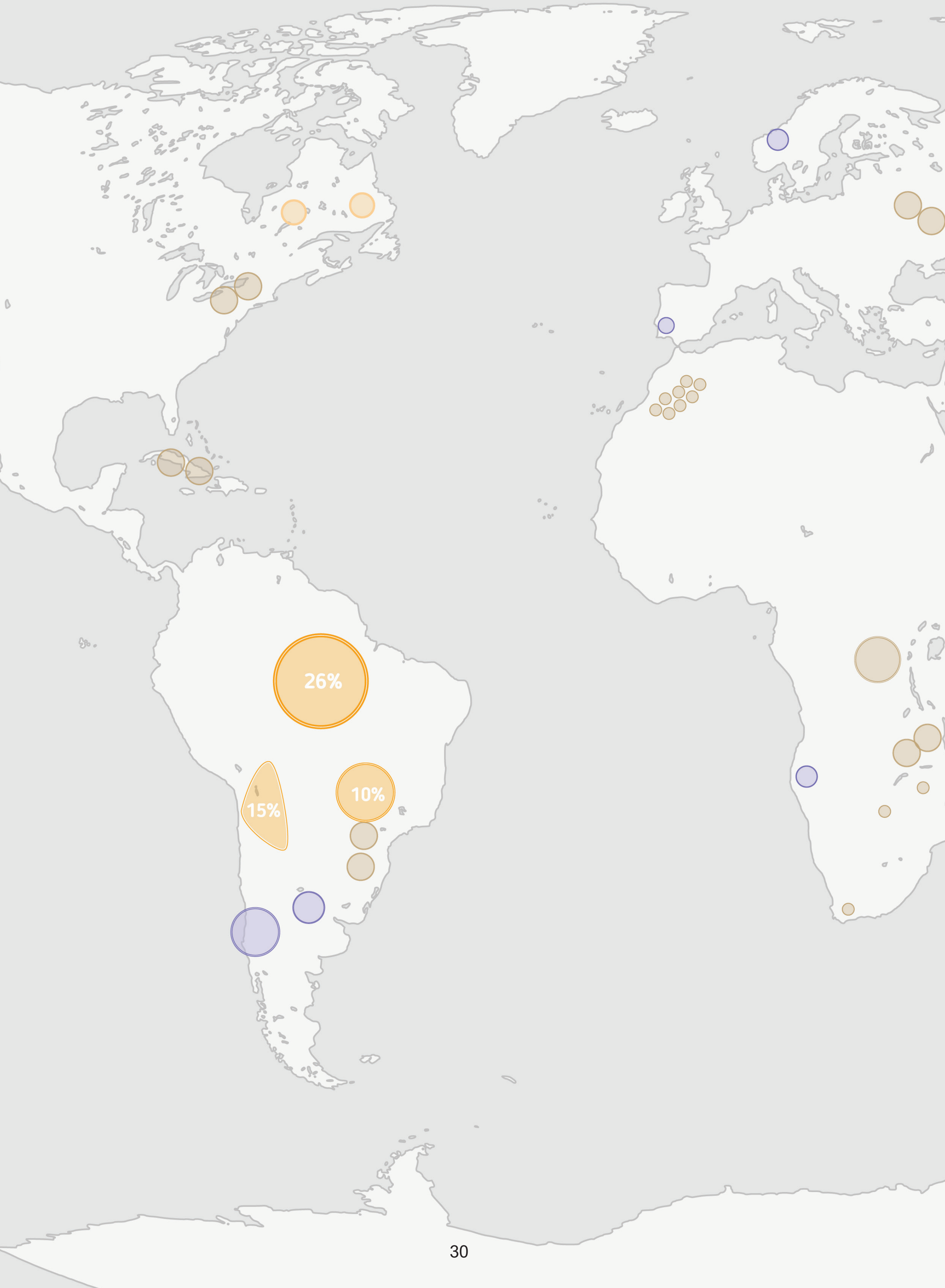
All type of lithium-ion batteries generally operate in the same way. In short, energy is produced due to the movement of ions and electrodes. The process can in general lines be explained as followed. While charging the battery, the positive electrodes, the lithium-cobalt oxide, release part of the lithium ions through the electrolyte to the negative electrode. This process allows the battery to meanwhile store energy.

When the battery is discharging the opposite happens as the lithium-ions move back across the electrolyte to the positive electrode. This process produces the energy that powers the battery. In both cases, electrons flow in the opposite direction to the ions around the outer circuit in the battery. This movement of ions and electrons is an interconnected process. When the ions stop moving through the electrolyte because the battery has been completely discharged, electrons can't move through the outer circuit either—so you lose your power. Similarly, if you switch off whatever the battery is powering, the flow of electrons stops and so does the flow of ions.

The chemical compound of the cathode generally consists out of the materials lithiums, cobalt and in some versions nickel. Cobalt and Nickel are mined in traditional open-pit mines, while lithium is both retrieved in mines and extracted in, so-called, brines. Within a brine, the mineral lithium is obtained from the earth by the use of the surface water in primarily the salt flat-rich continent of South America. It is a relevantly cheap process in which miners start by drilling a hole in the surface of the salt flat, followed by pumping the salty, mineral-rich brine to the surface. What remains as a pool of water on the surface is a mixture of manganese, potassium borax and lithium salts. This brine is then left to evaporate for several months, so ultimately after twelve to eighteen months the lithium carbonate can be filtered out of the mixture.

Figure 1, title. Source (2018).


LITHIUM-ION
COBALT
LITHIUM
NICKEL


26%
15%
10%

TITLE

SUBTITLE

There are several environmental, economic and health issues with the currents ways of extracting all materials used in the lithium-ion batteries. In May 2016, hundreds of protesters plucked dead fish from the Liqi River on the eastern edge of the Tibetan plateau. The nearby Ganzizhou Rongda Lithium mine had leaked toxic chemicals into the river, cause havoc in the local ecosystem. Regarding the brines in Chile’s Salar de Atacama area, for example, mining activities which require 2.273.045 litres of water to extract a tonne of lithium, are reported to have consumed 65 per cent of the region’s water. (Katwala, 2018) As a comparison: a Tesla Model S battery consists of about 12 kilograms of lithium. (Katwala, 2018) A lithium battery expert from the University of Chile Gullermo Gonzalez already told in an interview from 2009 on the lithium brines that “like any mining process, it is invasive, it scars the landscape, it destroys the water table and it pollutes the earth and the local wells. This isn’t a green solution – it’s not a solution at all.” The chemical ridden water from the evaporation pools occasionally leaks into the local water supply. Furthermore, contamination of the water supply around traditional lithium mines in North America and Australia are also reported. Chemicals used in the process to properly extract the minerals from the earth could be found in rivers up to 240 kilometres from the mines.

Figure 1, title. Source (2018).

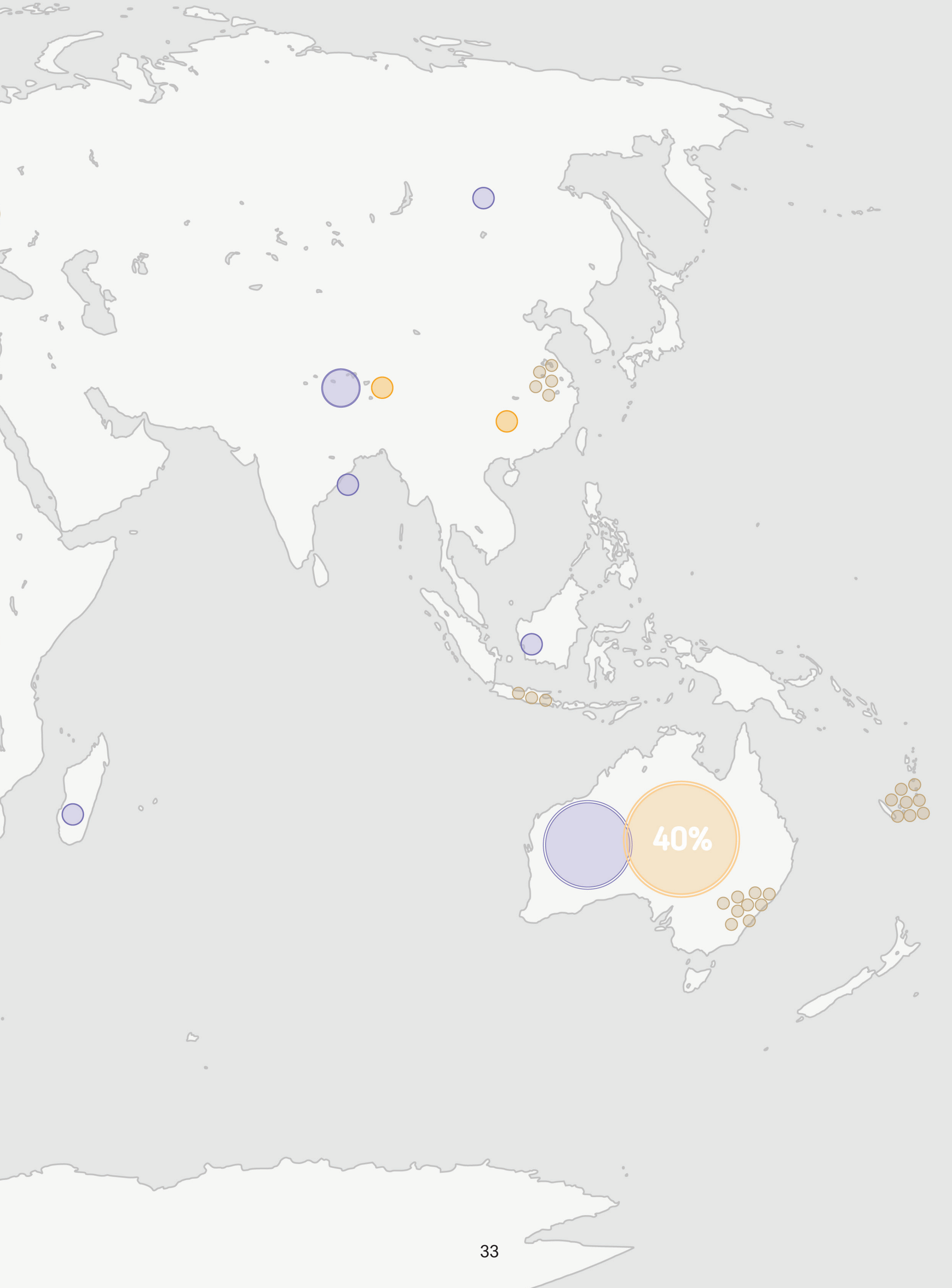
TITLE

SUBTITLE

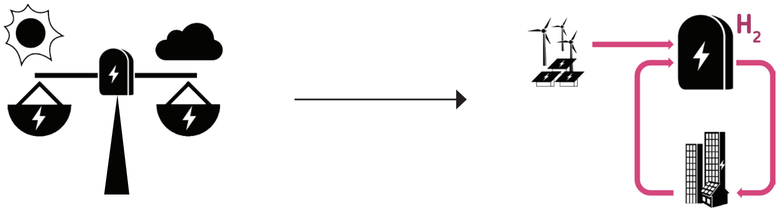
Lithium is, however, not the most problematic ingredient of the batteries, as, for example, sewage water in the future could take over its role in the chemical compound. Cobalt and nickel are considered much more damaging to both humanity and the environment. About 60 per cent of the worlds' cobalt supply is found in large quantities across the Democratic Republic of Congo and central Africa, and hardly anywhere else. In the Congo cobalt is predominantly mined in the so-called “artisanal mines” were the minerals are extracted by hand without protective equipment, often even using child labour. Researchers at the Catholic University KU Leuven and the University of Lubumbashi performed a study on the people affected by the cobalt mines in 2009. Their case study published in Nature Sustainability confirms the health risks due to the mining process. A significant problem are toxic dust clouds, containing cobalt and other metals like uranium, rising from the missing and settling on the ground in the mining district. According to the study, children living in the mining district had ten times more cobalt in their urine as children living elsewhere, while ongoing study suggests the miners' babies have an increased risk of congenital disabilities.

Conclusively, there are economical issues involved with the mining process of all materials. About 90 per cent of the world lithium production is since 2016 controlled by five companies; Albermarle in Chile and Nevada, SQM in Chile, FMC in Argentina and Tianqi and Ganfeng both in China (Harlow, 2016). While minor producers are starting to enter the business, the production of the world's supply of lithium basically operates as an oligopoly.

Figure 1, title. Source (2018).


40%

How renewable energy rightfully be stored?

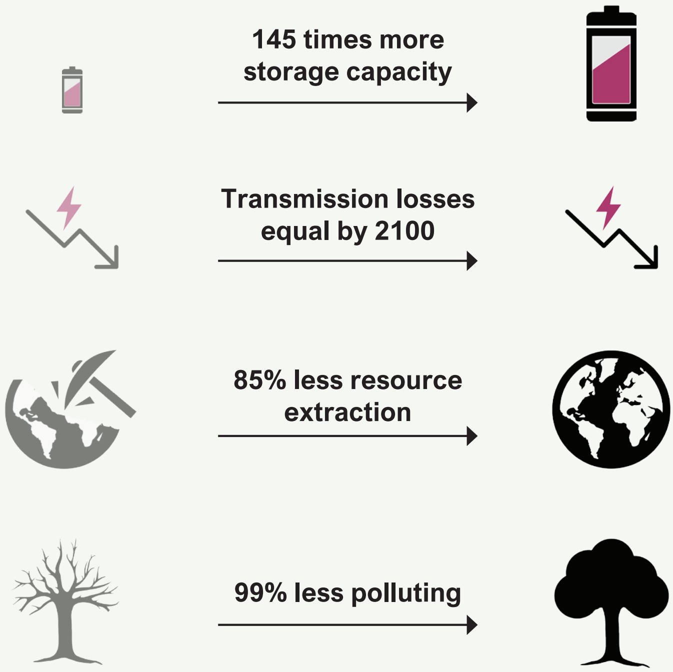


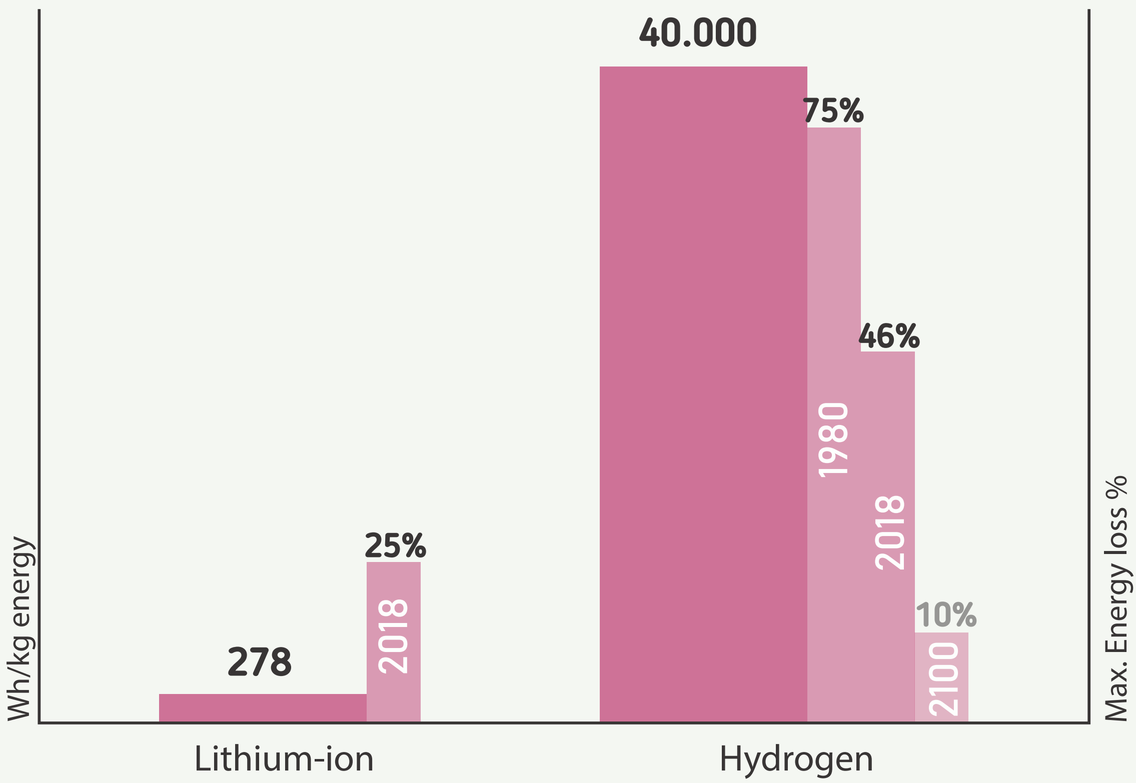
SUBTITLE

There are already several technologies operational that could replace Lithium-Ion batteries as a vessel for energy storage. Also, technological progress is continuously being made to increase Lithium-Ion Batteries recyclability or use different minerals as resources that are less harmful to the natural environment, like the study by Advisory firm Moore Stephens to replace the cobalt by nickel or manganese (Moore Stephens Australia, 2018).

Another solution to the current energy storage issue of the energy transition could be storing energy in hydrogen gas in storage facilities. A hydrogen gas facility is based on balancing renewable energy production and consumption. Therefore it processes the surplus of energy on periods when the production exceeds the consumption by transmitting the energy into hydrogen gas which can be stored. This is a tested and proven concept, already implemented in several places throughout Europe (Hydrogen Europe, 2017). As an answer to the necessary storage of renewable energy to be able to upscale to whole energy principle to hundred per cent renewable, it has already been named by International Renewable Energy Agency as “the missing link in the energy transition” (International Energy Agency, 2018).

Figure 1, title. Source (2018).

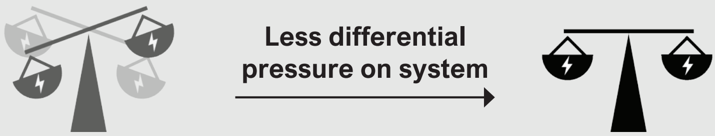

145 times more storage capacity
Transmission losses equal by 2100
85% less resource extraction
99% less polluting


Wh/kg energy
Max. Energy loss %
278
25%
2018
40.000
75%
1980
46%
2018
10%
2100
Lithium-ion
Hydrogen

SUBTITLE

The main catalyser to the use of hydrogen gas as storage is that it right now already can store up to 145 times more energy (source) than lithium-ion batteries, within a system that causes zero pollution. Although, its energy losses during conversion from electricity into hydrogen gas are still quite high, in the future there are expected to be equal to lithium batteries by the year 2100. (source) Storing energy in hydrogen will, therefore, provide a way of energy source extracting 85% less natural resources than lithium-ion batteries required. (source) Resulting in being up to 99 per cent less harmful to the environment when operational. (source)

Another reason to choose for the implementation of renewable energy storage, rather than finding new methods of to consume energy lies in the generally low willingness of people to change the habits that they have gotten accustomed to. Modern humanity relies on a constant, self-evident, supply of electrical energy. Users demand output of power on a regular basis in irregular, flexible patterns. Hydrogen gas as storage to renewable energy, connected to both the producer and consumer, allows the users to continue their modern energy consumption habits. Engineer and doctor in electrochemistry, President of the hydrogen energy startup Ergosup, Patrick Paillère, argues on hydrogen gas energy storage that it “enables users to maintain their usual level of flexibility in terms of power consumption.” (cH2ange, 2016)


Less differential
pressure on system

2100 SCENARIO:

Hydrogen gas storage facilities will be part of our future energy system for the storage of the surplus of renewable energy.

PROBLEM STATEMENT

What are the consequences of the introduction of hydrogen energy storage to the urban environment?

?

TITLE
SUBTITLE

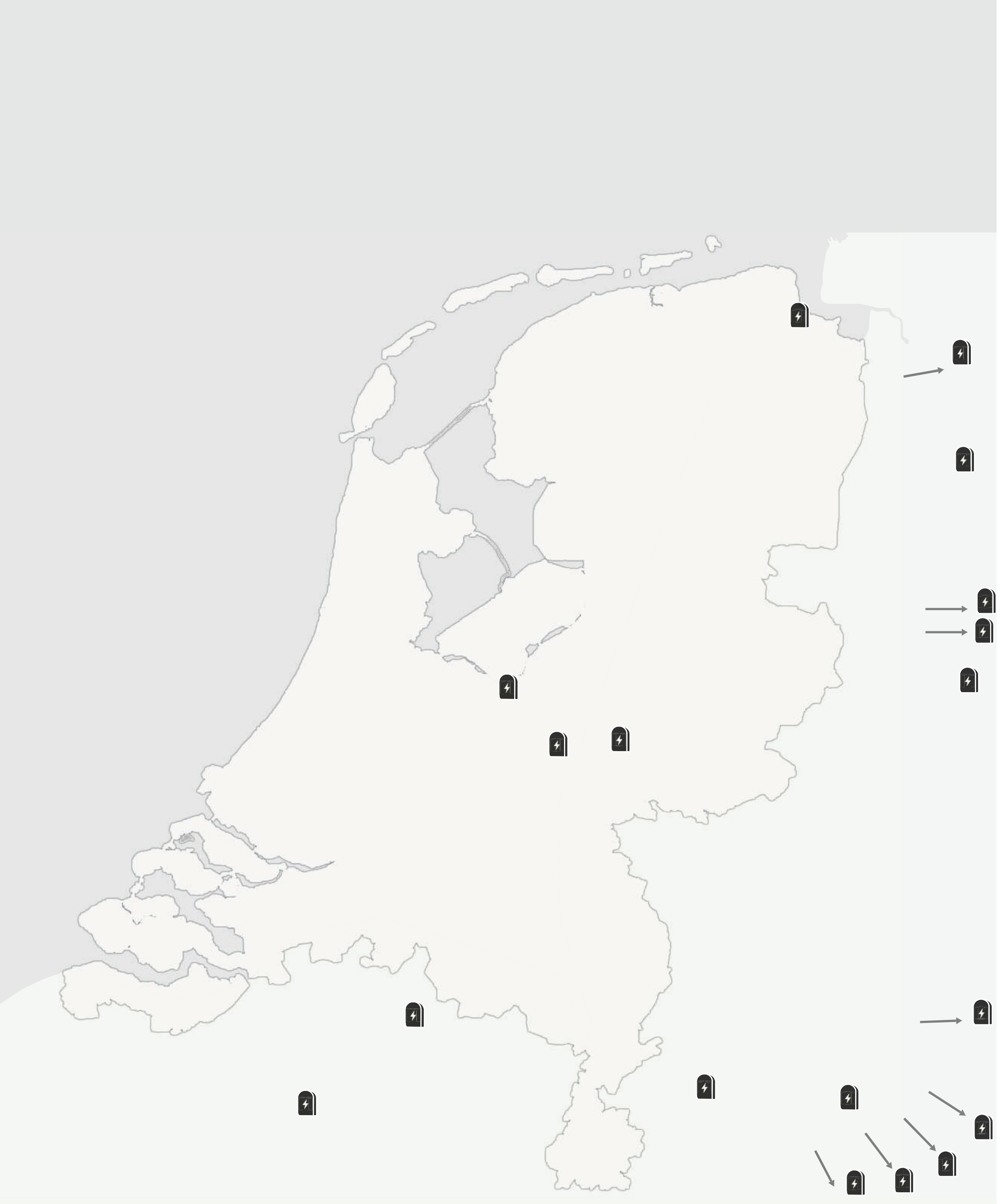
So it is most probable that hydrogen gas energy storage facilities, based on another paradigm shift in humanity thinking about also transitioning to a matter of storing energy sustainably, next to sustainable production, will be part of our future urban context. This therefore pose a new urban question: How to deal with the implications of this paradigm shift in our relation with sustainably storing renewable energy? More specific, What are the consequences of the introduction of hydrogen energy storage to the urban environment? This poses a design question. Hydrogen storage facilities will be implemented on a large scale throughout the country, based on the scenario that they will be an alternative to lithium-ion based off-grid storage batteries and home batteries. This is a scenario that will be laid within this thesis as proposed for the year 2100. However, this development will not happen at once. Therefore, it can be separated into phases.

The first phase is already ongoing. Right now only several facilities are operational in Europe. These facilities generally have the function to process a surplus of renewable energy into hydrogen gas for either storage or direct consumption. The exact techniques applied vary per facility. Many of them right now are mere testing or pilot initiatives to uncover the potential of hydrogen storage. The scenario that I pose within this thesis is that these facilities will be further developed to become more efficient and hold more tank storage capacity. Not only the process of transforming renewable electrical energy into hydrogen gas will become more efficient, but also based the process of converting it back into electrical energy via fuel cells.

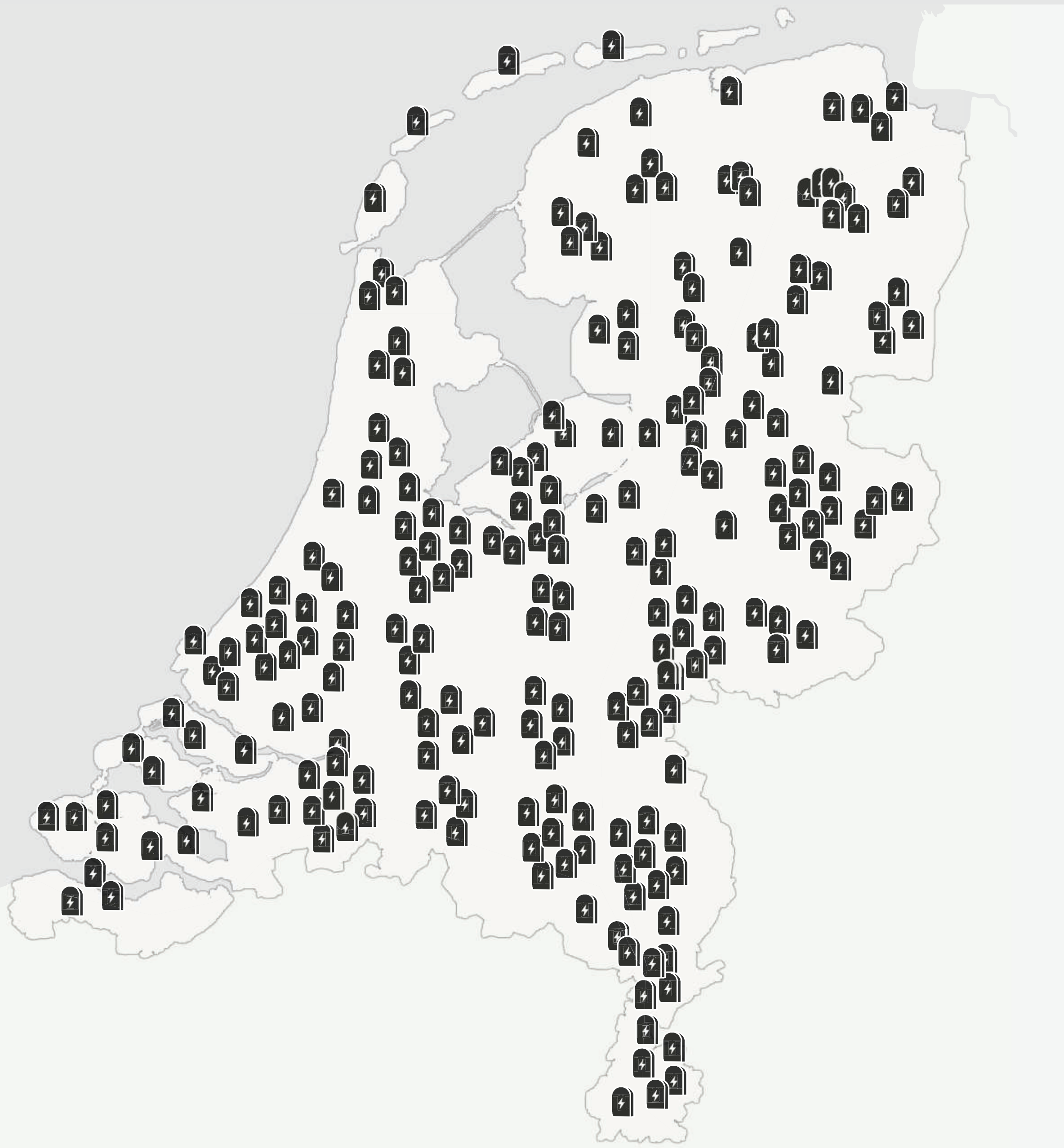
At the time of writing, nearly all operational facilities lack the capability to transfer gas back into electricity. Simply because of the relatively low efficiency of the fuel cells, together with the prime focus of the facilities to deliver hydrogen gas itself as an end product. The hydrogen gas is then either mixed into the current natural gas infrastructure or used in fuel cells in hydrogen driven engines.

The second phase starts around the year 2050. Based on development of both the process of transforming electrical energy into hydrogen gas by ,for example the Technical University Delft with its so-called 90 per cent efficient Battolyser (Middelkoop, Weninger, Mulder, Schreuders, & Ooms, 2017) and back in the future Hydrogen Gas facilities will be able to turn renewable energy, with minimal losses in to hydrogen gas and back. The facilities will be situated on location that have already been housing functions regarding energy production and distribution, as the world will be in the energy transition so, therefore, our energy system will still be a hybrid.

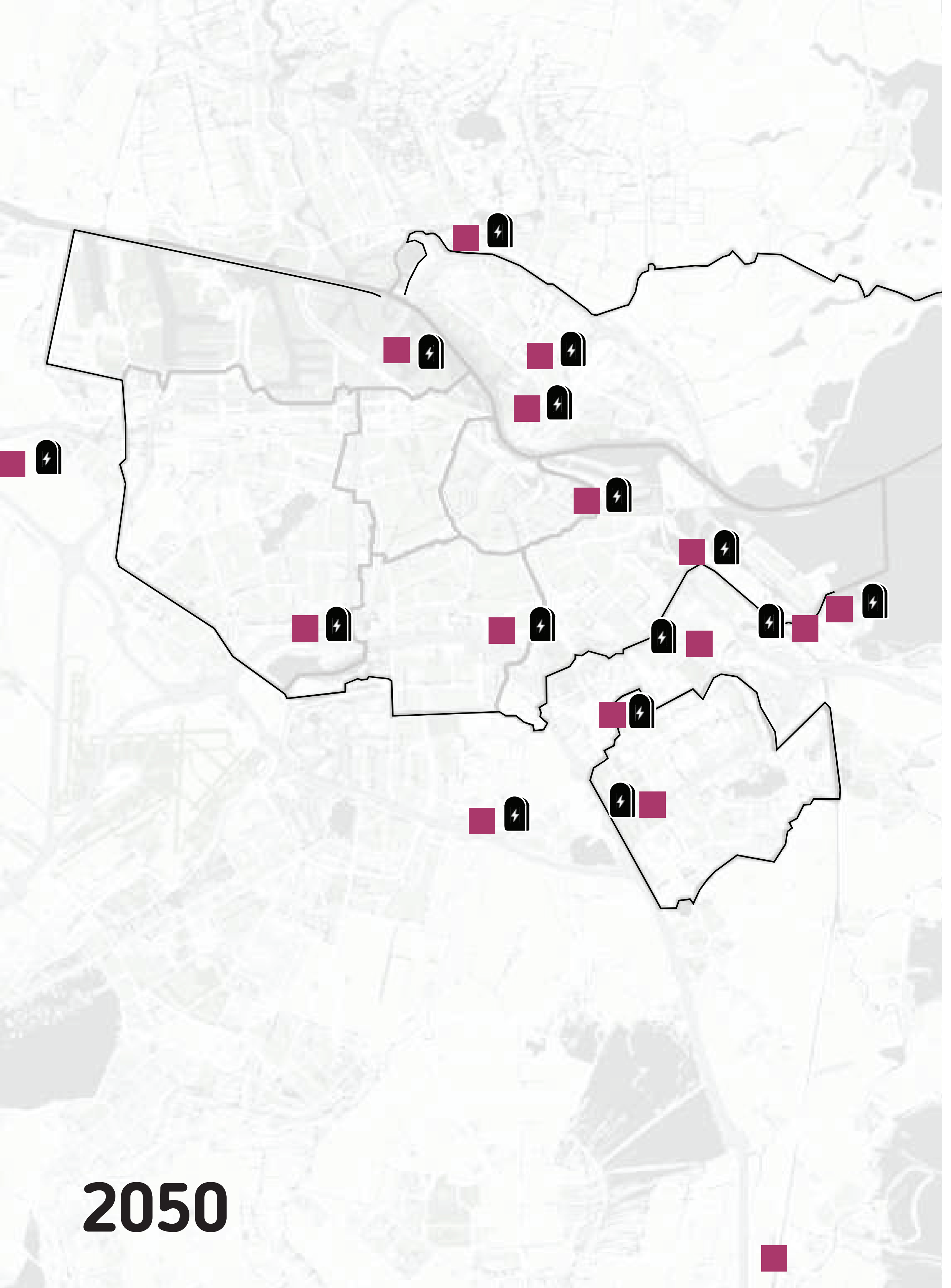
As argued earlier, in a one hundred per cent renewable energy powered world, the production of energy itself will be much more decentralised. Energy can be produced in places like the façade of an office, to massive solar farms and the roofs of row houses. By the year 2100, this is the world that we live in. When lithium storage is made a thing of the past, hydrogen storage facilities will completely take on the role of storing energy. Therefore, we will see an implementation of facilities throughout all kinds of urban districts; from the edges of city centres to residential neighbourhoods.



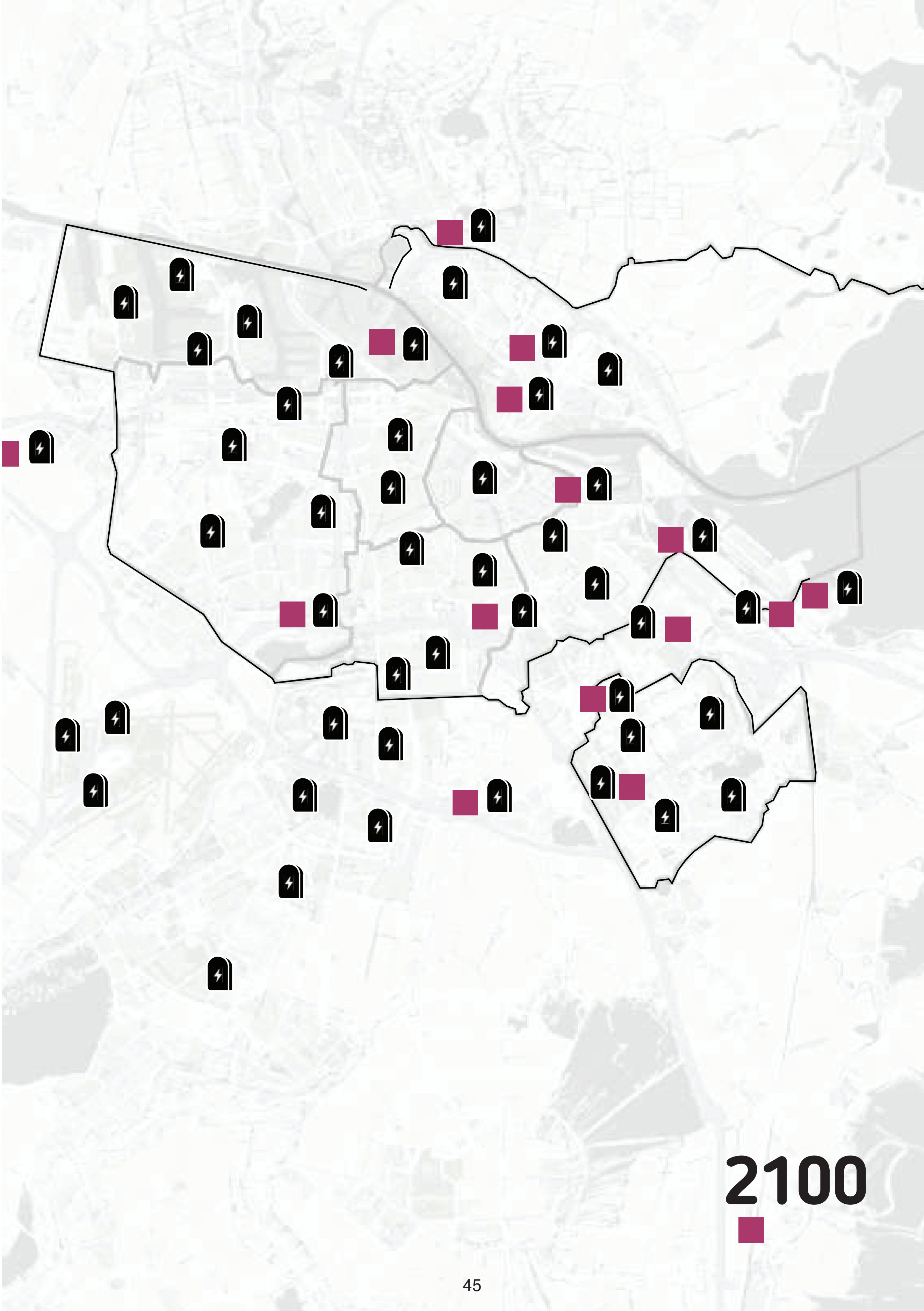
2050

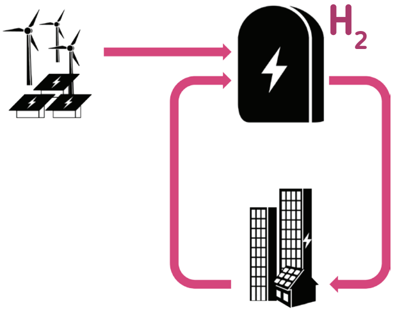


2100



2050


2100



SUBTITLE

A hydrogen gas facility operates based on the principle of balancing renewable energy production and consumption. Therefore it processes the surplus of energy on periods when the production exceeds the consumption by transmitting the energy into hydrogen gas which can be stored.

But what is hydrogen exactly? Hydrogen gas is the most abundant element on earth. However, almost always exists in the shape of a chemical compound. Hydrogen gas (H2) is produced by extracting it from its compound. This extraction can be done in numerous ways. When the extraction is powered by renewable energy or carbon-free electricity, it can be regarded as sustainable. As an element hydrogen gas can serve as a highly efficient, low polluting fuel used for transportation, heating and power generation.

Current hydrogen gas production if primarily fueled by natural gas, about 70 per cent (Hydrogen Europe, 2017). The common technique applied in the process is steam reforming, mainly in the chloride industry. To date, only small amounts of hydrogen are being generated from renewable energies, although that amount is set to increase. The sustainable way to produce hydrogen gas is via electrolysis, in which H2 is extracted from water by an electric current to split H2O into its constituent parts from which one is hydrogen gas. Since hydrogen's production translates into extracting it from its compound by using energy from other primary sources, it is an energy carrier, which is used to move, store, and deliver energy produced from these sources.

Figure 1, title. Source (2018).

TITLE

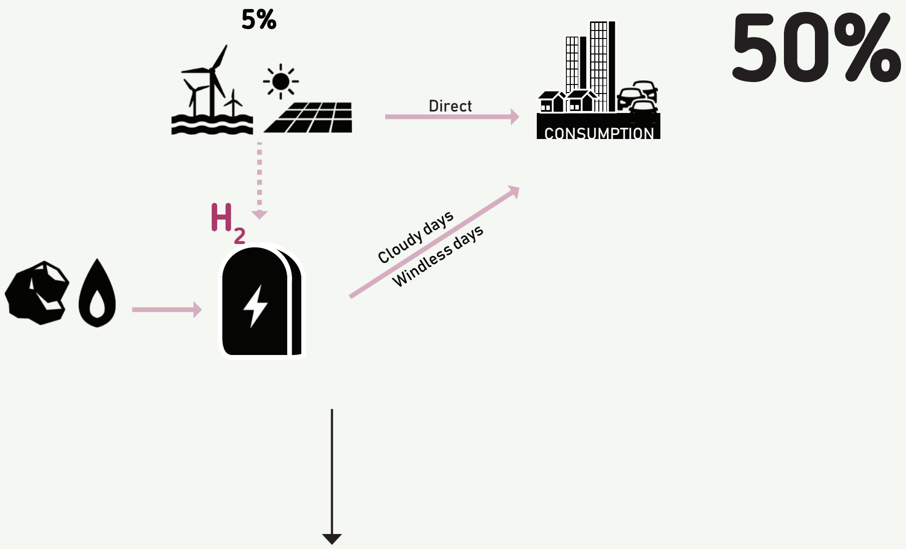
SUBTITLE

Hydrogen gas is currently being applied in several sectors. Its applications vary from being combined with nitrogen to form a fertiliser, to industrial metalworking and cooling and transportation. From these applications, regarding the district of Amsterdam-Zuidoost, most interesting are its application as fuel in transportation and of course its use in the energy sector.

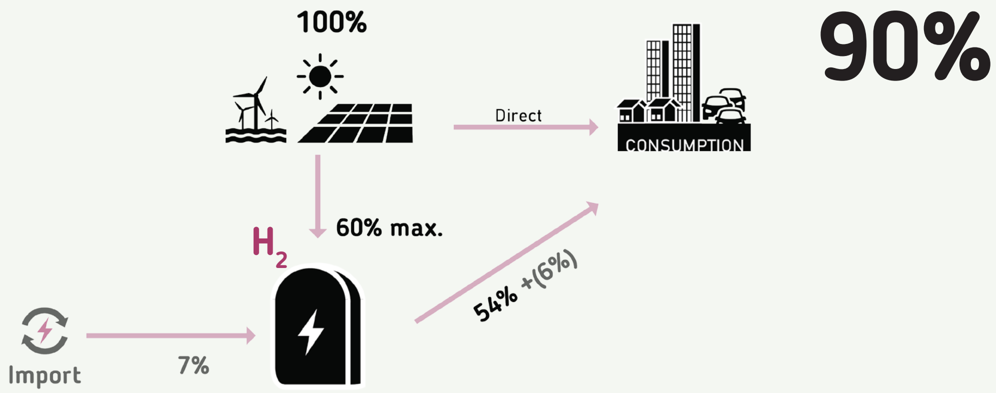
The principle to store renewable energy in hydrogen gas is as followed. Local renewable energy production is connected to the Hydrogen gas facility supplying it with the surplus of renewable energy. This surplus of renewable energy is used to power electrolysers producing hydrogen gas. The hydrogen gas is then either stored on site, in the earth or directly consumed. To take on the function of an electrical battery to a district, hydrogen gas must be kept stored near the location where the renewable energy was produced. When required for local consumption, hydrogen gas is burned in fuel cells to generate again electrical energy ready to power the local electricity demand. This cycle can be continuously repeated. Three case studies will further elaborate on the various methods to produce hydrogen gas and set up of a hydrogen gas facility.

Currently hydrogen gas is in many cases used as an energy carrier to support renewable energy production and consumption. During cloudy or windless days the energy consumption is supported by stored hydrogen gas, which will be consumed via the gas infrastructure as mixed with natural gas. Its production in these cases is often fuelled by fossil fuels. The overall efficiency of this process remains quite low; up to 50 per cent. In the future, this efficiency of the total process has the potential to grow to 90 per cent (Middelkoop, Weninger, Mulder, Schreuders, & Ooms, 2017). By the scenario described earlier, the electricity that humanity consumes will be hundred per cent renewable. Based on the case study of Denmark, the hydrogen storage facility need to have the capacity to store up to 60 per cent of the consumed electrical energy. Ideally, to prevent shortages due to the 10 per cent energy loss during the process, a minor part of renewable energy must be imported.

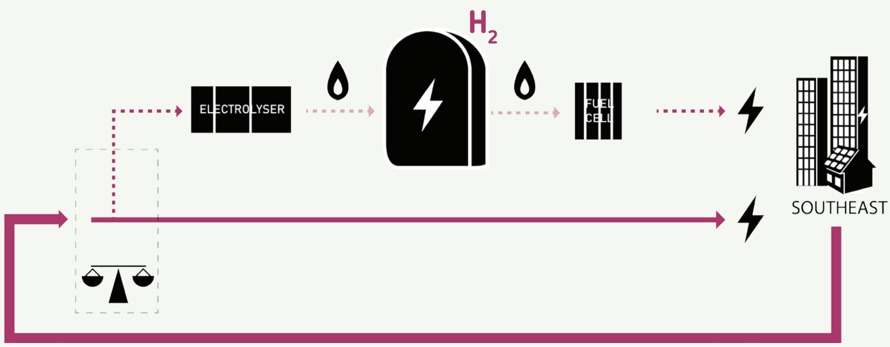
Figure 1, title. Source (2018).



5%
Direct
CONSUMPTION
H_2
Cloudy days
Windless days
50%

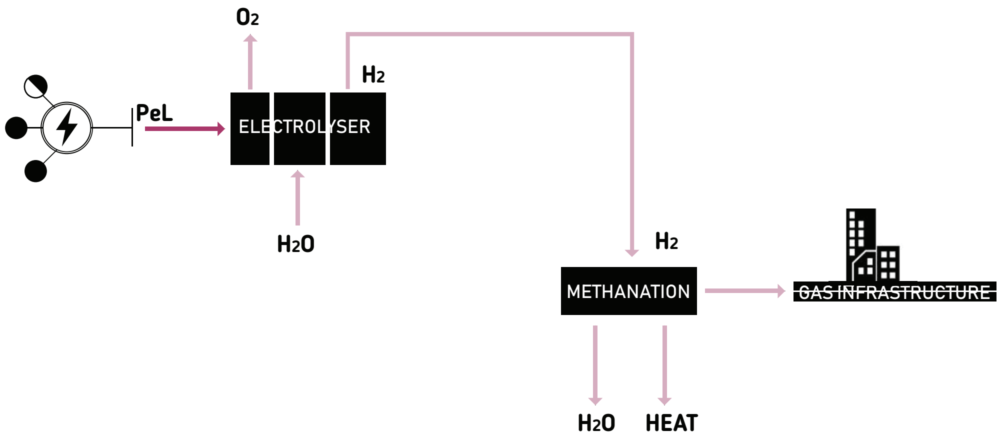


100%
Direct
CONSUMPTION
90%
60% max.
H_2
54% +(6%)
Import
7%



H_2
ELECTROLYSER
FUEL CELL
SOUTHEAST


AMS ZUID-OOST



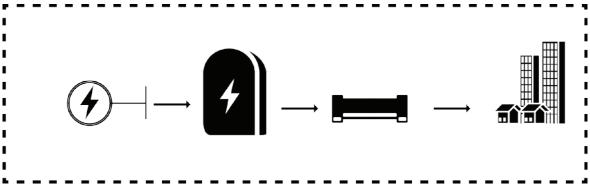
TITLE

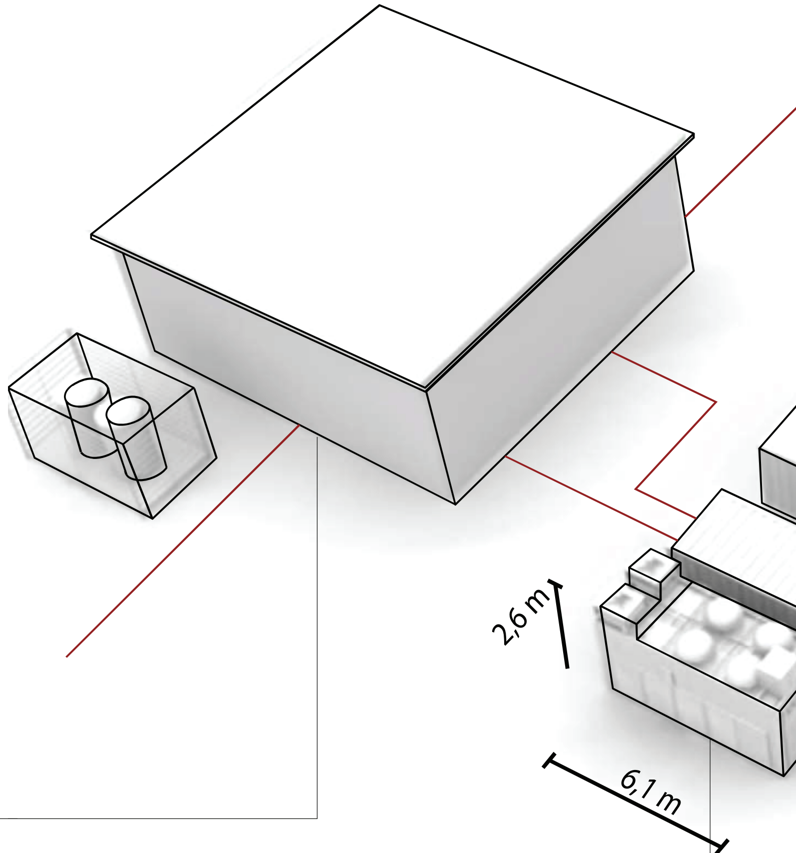
SUBTITLE

The Thüga Power-to-Gas plant is deployed in Frankfurt Am Main by the Thüga Group gas company. It is established to show the possibility of converting grid electrical energy into hydrogen gas to consume mixed with natural gas. The facility itself is, therefore, a tiny example with only 0.3 MW power. The structures found at the facility consist of a combination of an old natural gas pressure station, a visitors centre and the essentials to make the power to gas principle happen; an electrolysis container and a gas mixing plant. The visitor centre is built to bring awareness to the public via demonstrations, following the main purpose of the facility.

The facility is connected to the district electricity grid. The electricity powers one electrolyser, capsuled/compressed into a 20 feet sea container, which produces hydrogen gas. Because of its volatility, the hydrogen gas is then mixed with methane gas while being put under pressure. When put under the right pressure, the mixed gas is injected into the existing gas infrastructure ready for consumption.

Figure 1, title. Source (2018).





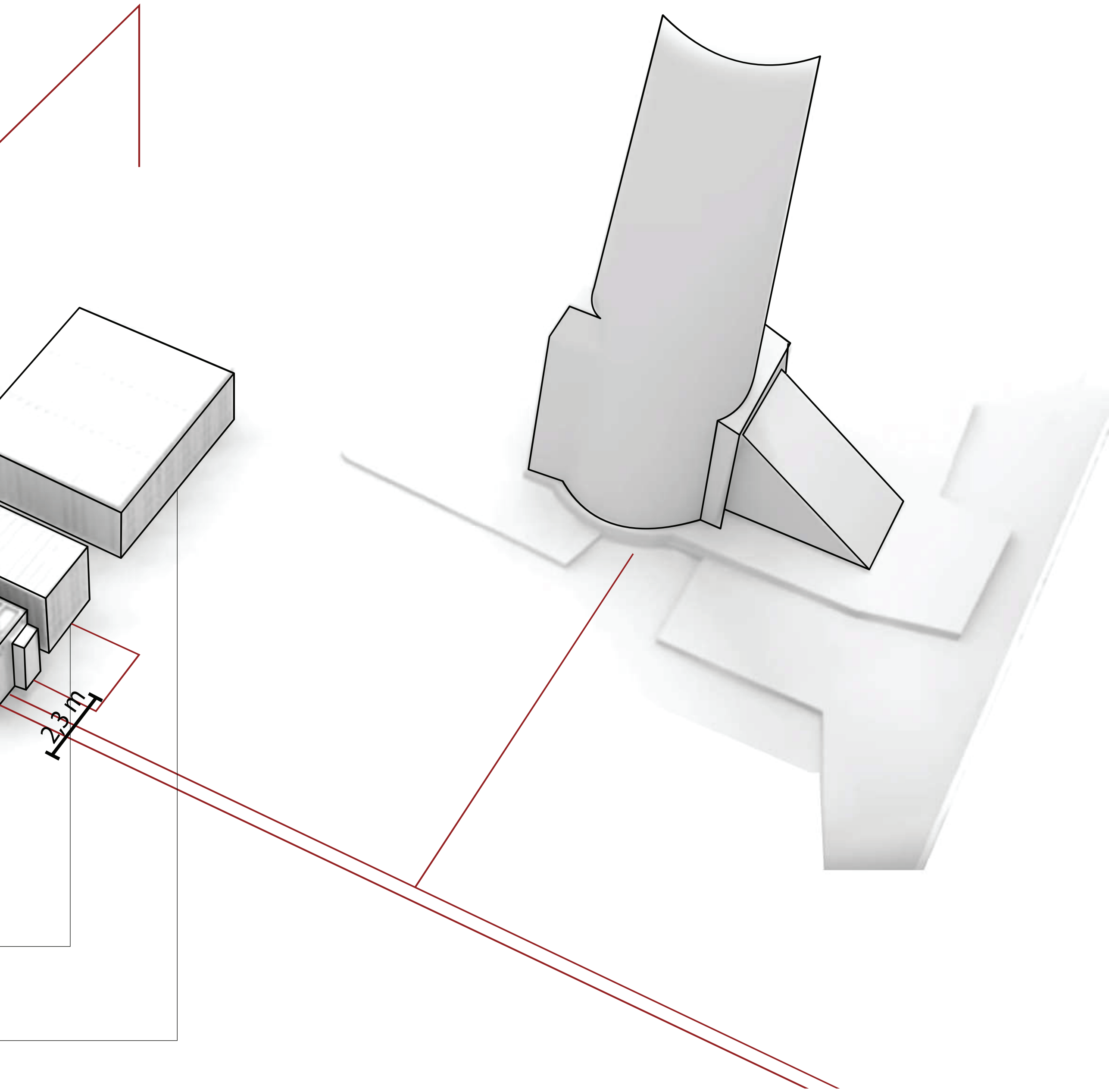
GAS PRESSURE
REGULATOR STATION

ELECTROLYSER
SYSTEM 1x20ft

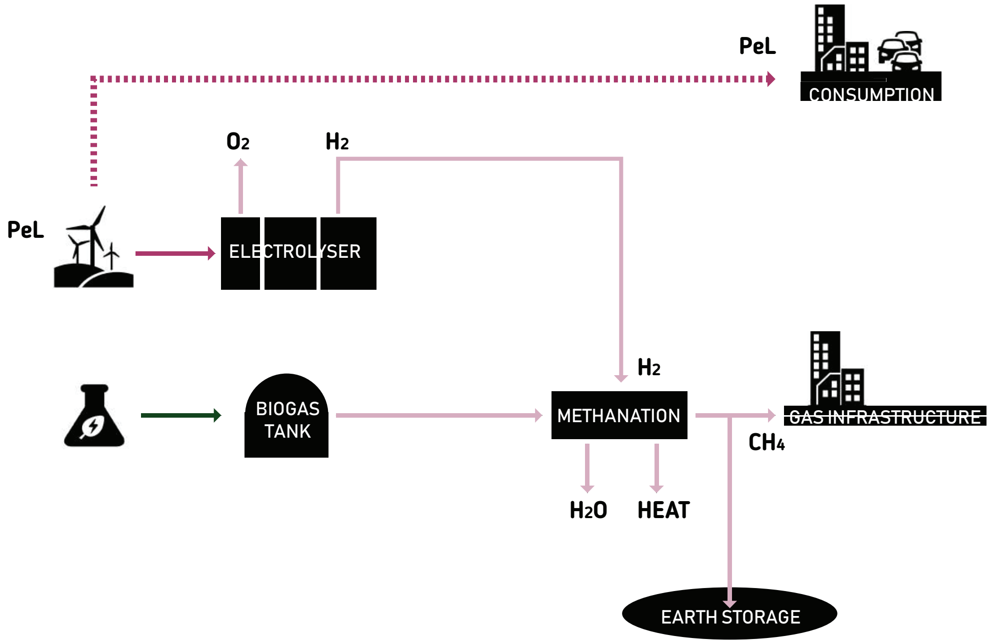
GAS MIXING
PLANT 1x20ft

VISITORS
CENTRE

FACILITY SUFACE:
750 m2


2.3 m


HYDROGENICS
Advanced Hydrogen Solutions
Shift Power | Energize Your World
Power
to Gas
uni
per
SWISSGAS
JPSU 200694 3

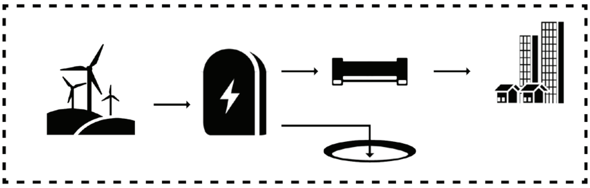


TITLE
SUBTITLE

Windgas Falkenhagen is a medium-sized facility located in Prignitz Germany operated by E.ON facilitated by Hydrogenics technology. The 2,0 MW facility is established to use the surplus of wind energy from a nearby windmill park to produce hydrogen gas. The structures seen on site are all constructed by Hydrogenics technology, which assembles hydrogen machinery in 20 to 40 feet sea containers for easy deployment. The facility has a distinct and uniform appearance due to the Hydrogenic sea containers housings around the machinery. However, it does not hold any strong architectural expression.

The wind energy powered facility uses six PEM electrolysers in 20 feet long sea containers to generate hydrogen gas. The gas is mixed in a mixing plant with locally produced biogas to either be directly injected into the gas infrastructure or stored in earth storage. The facility itself does not hold any capacity to store hydrogen gas on site.

Figure 1, title. Source (2018).



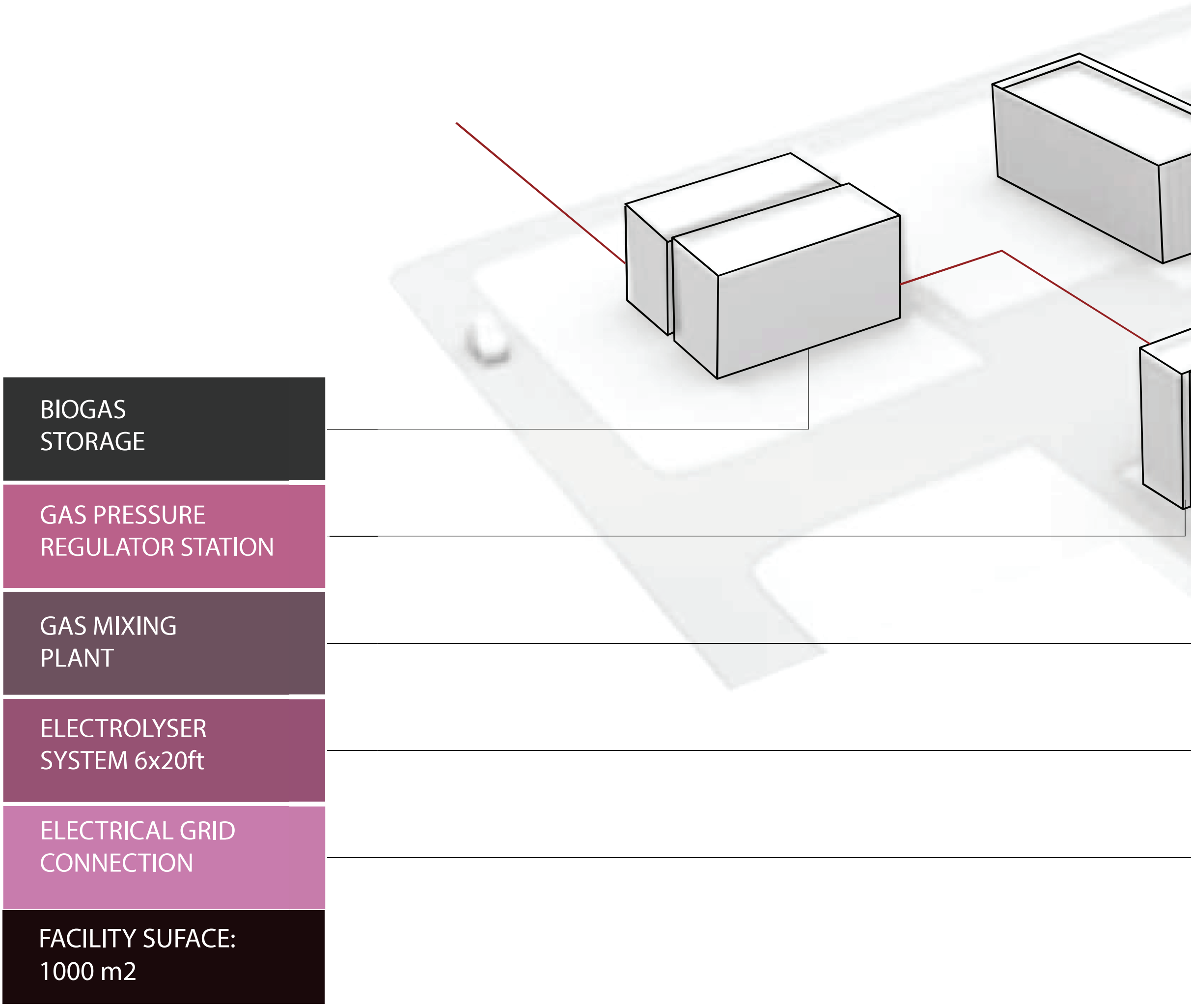
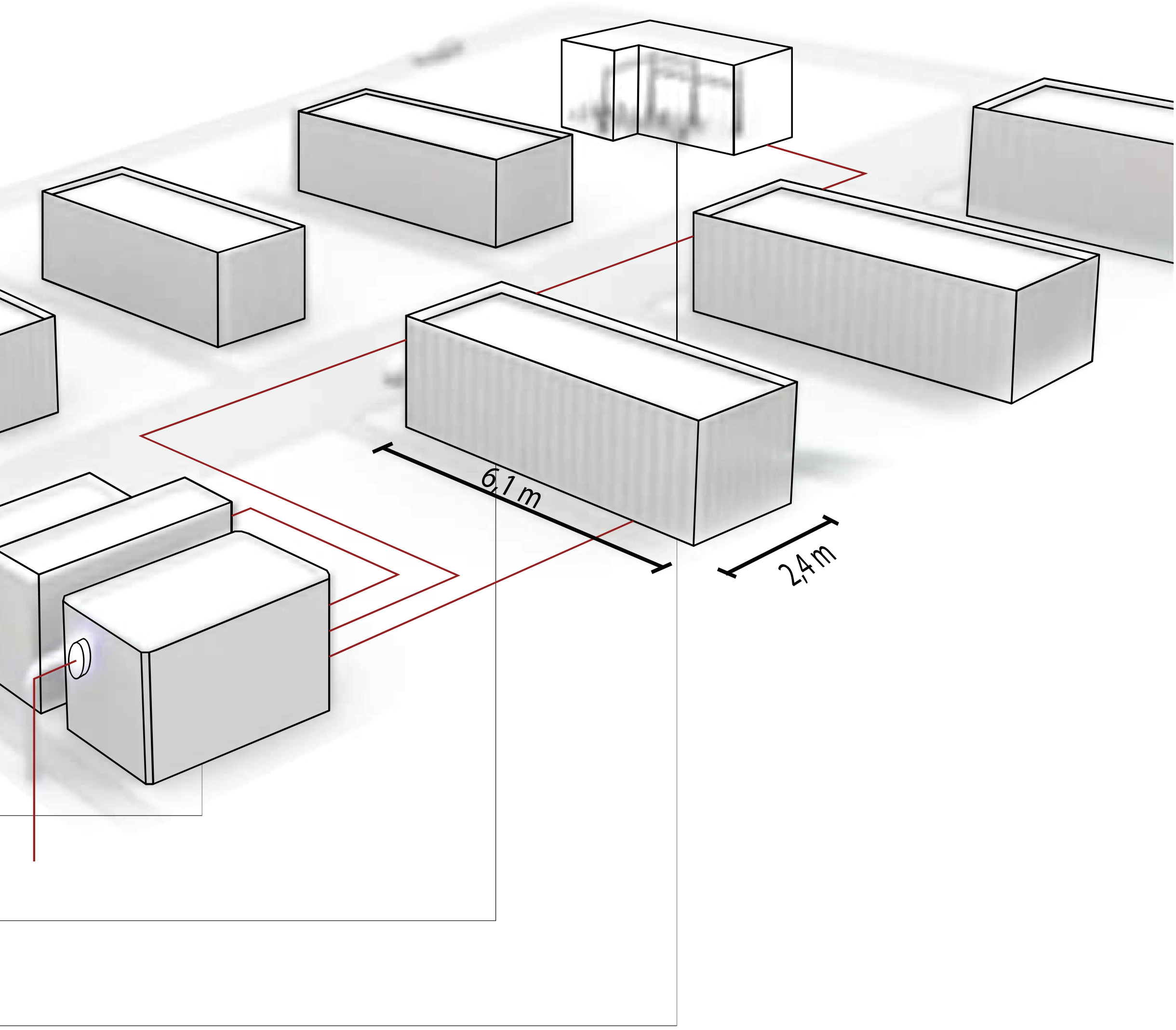
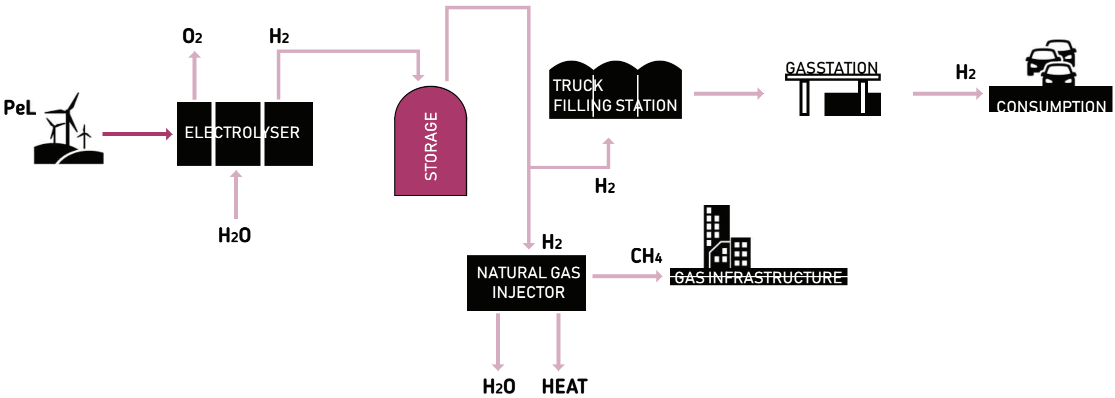


Figure 1, title. Source (2018).


6,1 m
2,4 m



TITLE

SUBTITLE

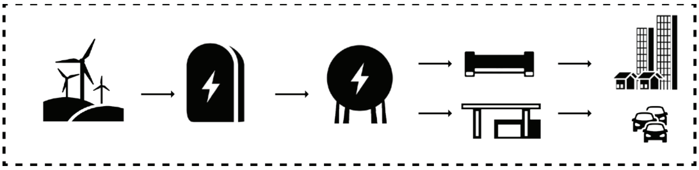
Energiepark Mainz is a larger facility operational since 2017, located in the outskirts of the city of Mainz in Germany. It is developed as a joint venture between Siemens, The Linde Group, RheinMain University of Applied Sciences and Stadtwerke Mainz to find out the possibilities and limitations of power to hydrogen gas storage on a large scale. Its primary objective is, therefore, the development, testing an application of innovative technologies for the production of hydrogen utilising electrolysis powered by renewable energies. The facility aims to be part of the solution of balancing out the production and consumption of renewable energy, by producing and storing hydrogen gas.

Like the other case studies, Energierpak Mainz produces hydrogen gas with electrolysers. The energy necessary for this is partially supplied by excess power of adjacent wind energy plants. The 6MW electrical power of the facility is estimated to be enough to compensate capacity shortages in the district electricity grid. The organisation sees to potential to employ similar plants in various locations to stabilise the grid.

The electrolysers used in this case study are also the so-called PEM type (Proton Exchange Membrane). Three of them are positioned in a hall. Each has a peak power of 2.0 MW. The operation of PEM-electrolyzers in this performance category is a worldwide first because until now PEM-based systems were only used for small scale hydrogen production. Other essential system components include a two-stage ionic compressor, the gas feed, filling appliances and the switchgear. The “ionic compressor” is essential to this variant of the hydrogen facility, because it enables compression of the produced hydrogen so that it can be filled into storage tanks, gas pipes and tank trucks. This is a unique feature of the facility, because it incorporates a truck filling station to distribute hydrogen gas a fuel to the transport sector. Furthermore, this facility actually stores hydrogen gas at the facility in tanks. It, therefore, comes quite close to the future where a facility of this kind completely replaces lithium-ion batteries as storage vessels.

Figure 1, title. Source (2018).


THE LINDE GROUP
Linde



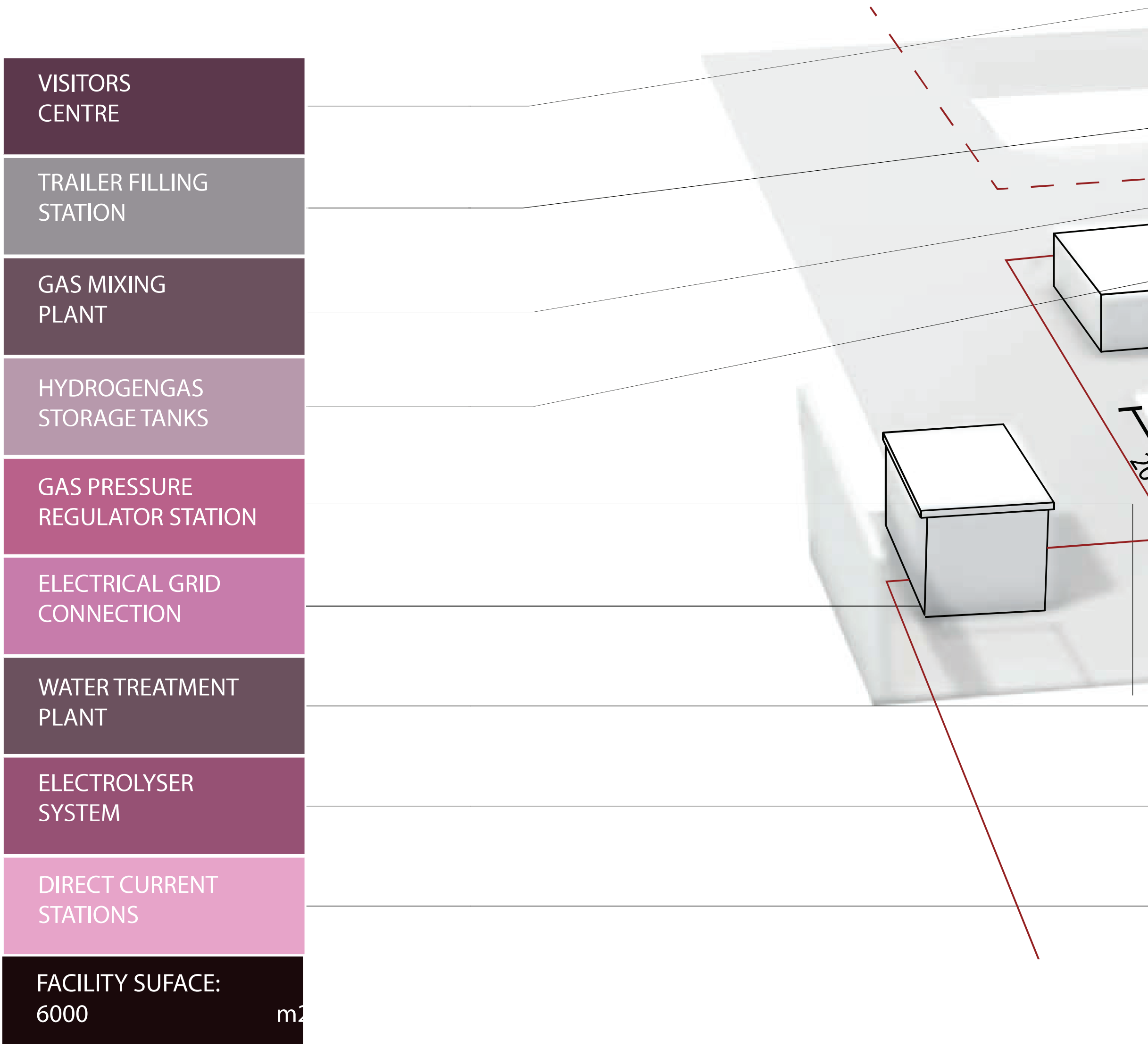
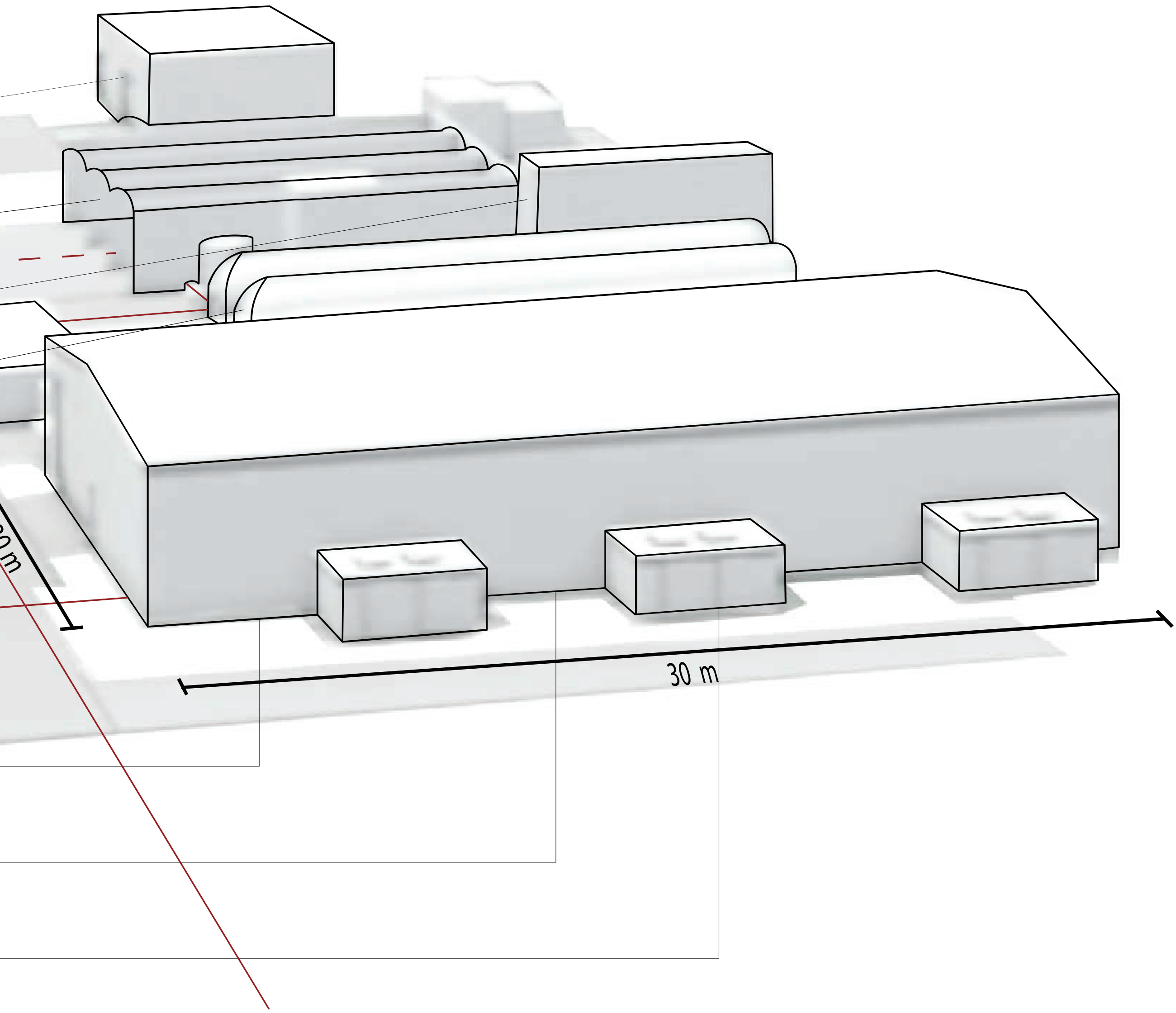
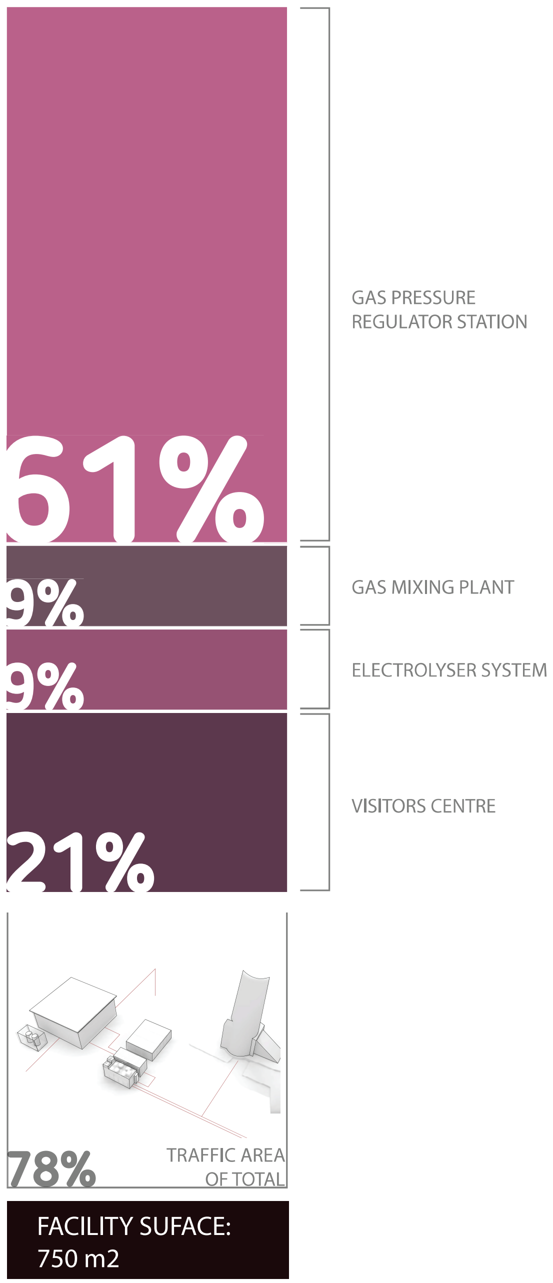


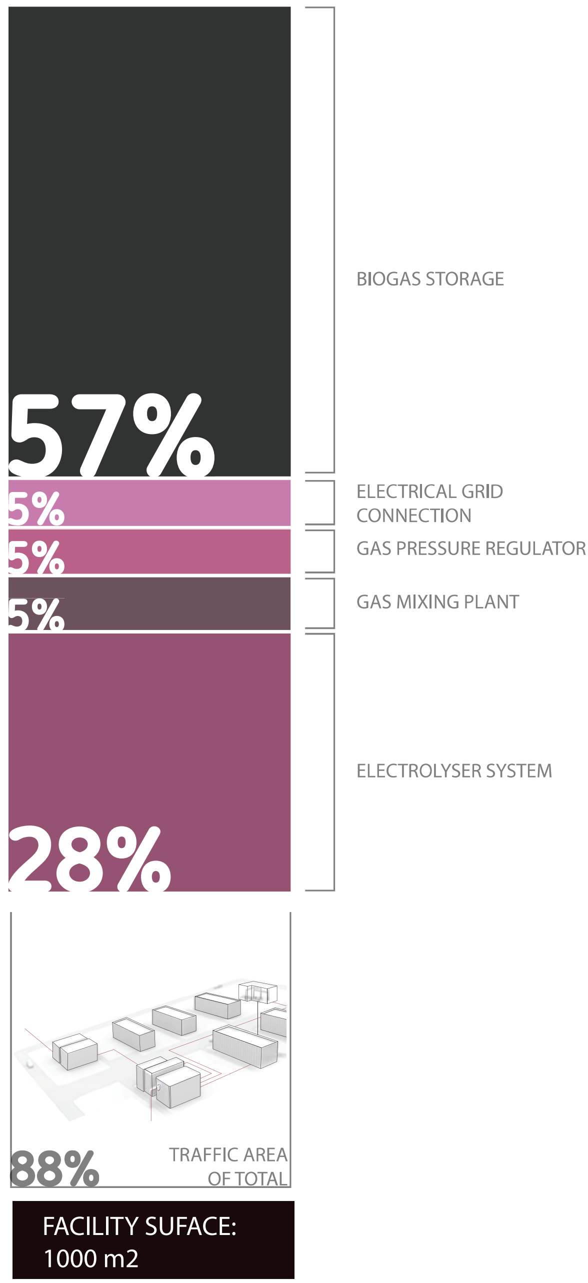
Figure 1, title. Source (2018).


30 m

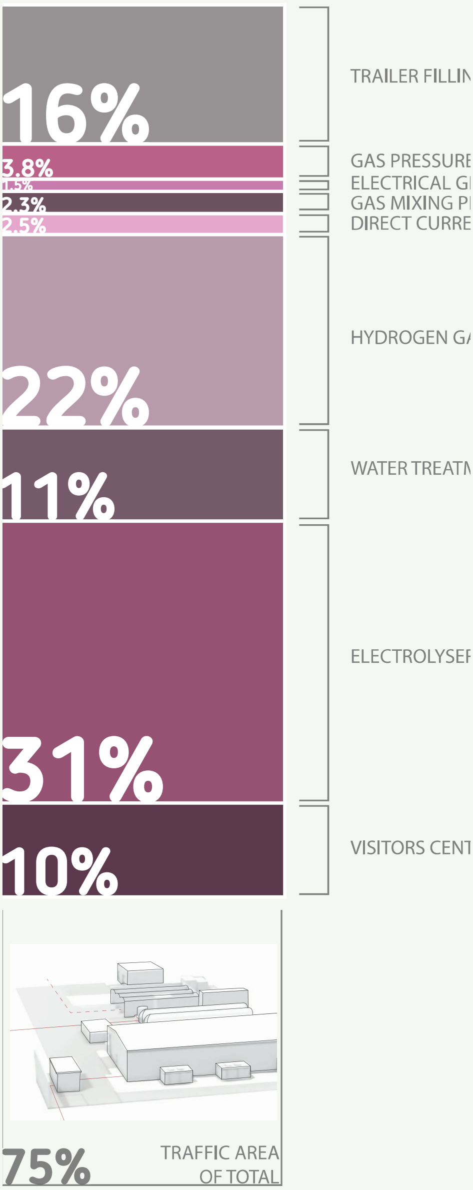
THÜGA POWER-TO-GAS
0,3MW



WINDGAS FALKHAGEN
2MW



ENERGIEPARK MAINZ
6MW

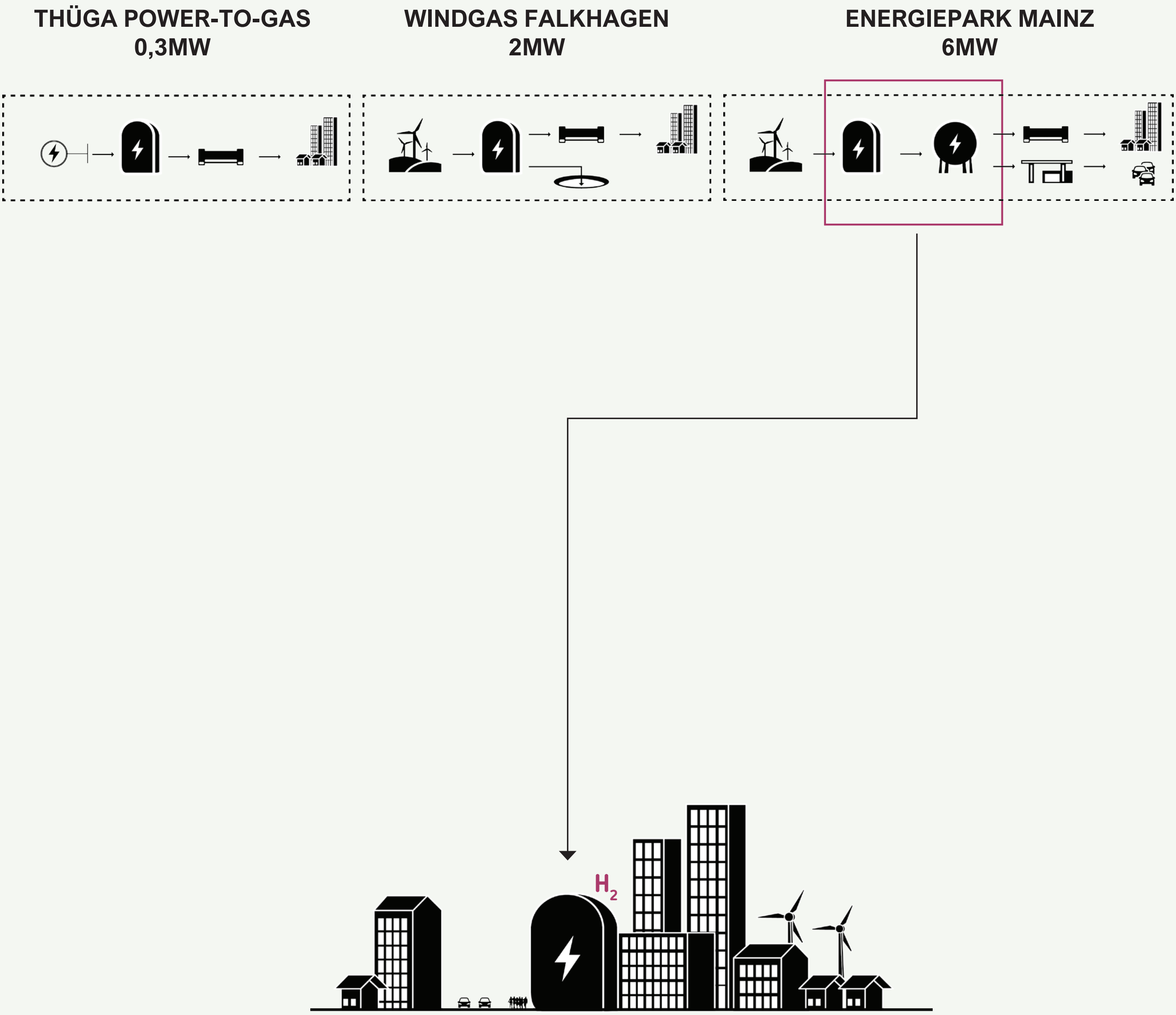


FACILITY SUFACE:
4300 m2

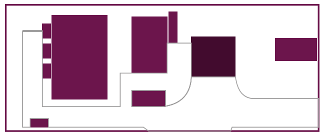
SUBTITLE

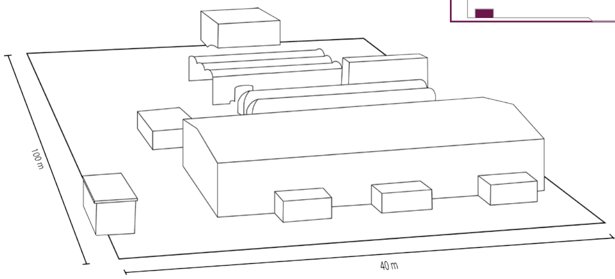
Based on the future scenario to replace lithium-ion batteries as a vessel to store the surplus of energy produced by renewable sources, the capacity to store energy lies at the heart of the future hydrogen gas facility. Secondary are the electrolysers for the production of hydrogen and the fuel cells to again produce electrical energy. The Energiepark Mainz case study shows the most potential to use a base for further future development of this type of facility; it already has some gas storage capacity, it produced 6 MW power with only 3 electrolysers, and it operates entirely on renewable wind energy.

Figure 1, title. Source (2018).


THÜGA POWER-TO-GAS
0,3MW
WINDGAS FALKHAGEN
2MW
ENERGIEPARK MAINZ
6MW
H2

100%





6 MW

6 MW * 1,9 =

Efficiency

SUBTITLE

Torum fuga. Nequo quatur autame vendella con eritae. Oluptat explabore dolut quam eturior aut asit omnimodis nimus et aborum ut arunt aceperrovit et eatempore, apelige nisquuntia quunt maximet dolorae vernate ctoria porehendia verorum utatur aditasp ernatur, occulpa riaepelit ratur res que pel ea ne conem reperest, solut volupta sperfero et a quiaes as sectae eiciisciatia consed quunt quo et aut excestiis am debis veritas eum ilitae. Suntur?
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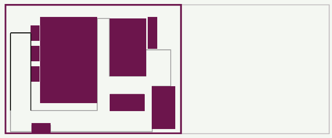
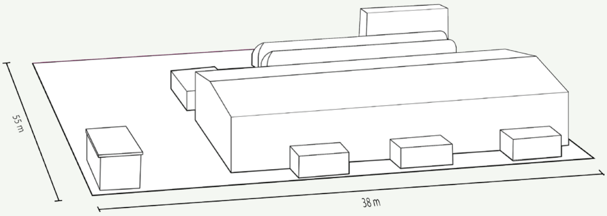
Figure 1, title. Source (2018).

52%

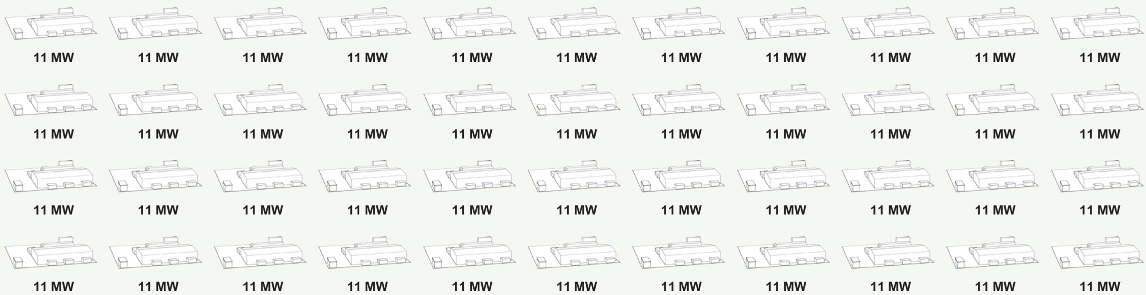


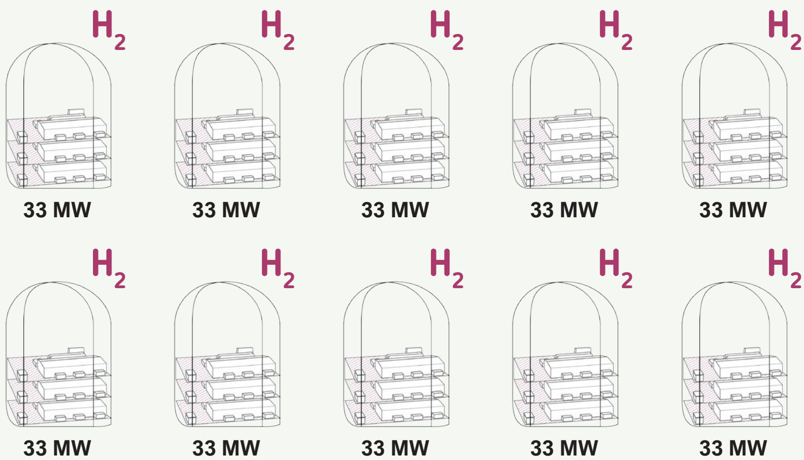
10,8 ≈ 11 MW

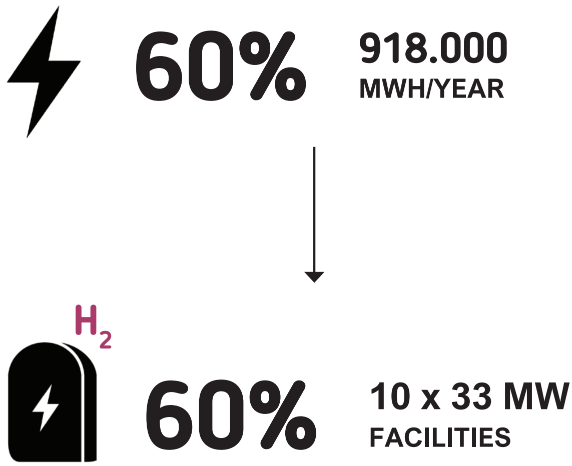
increase



11 MW







Business district
Innovation Axis
Residential district

SUBTITLE

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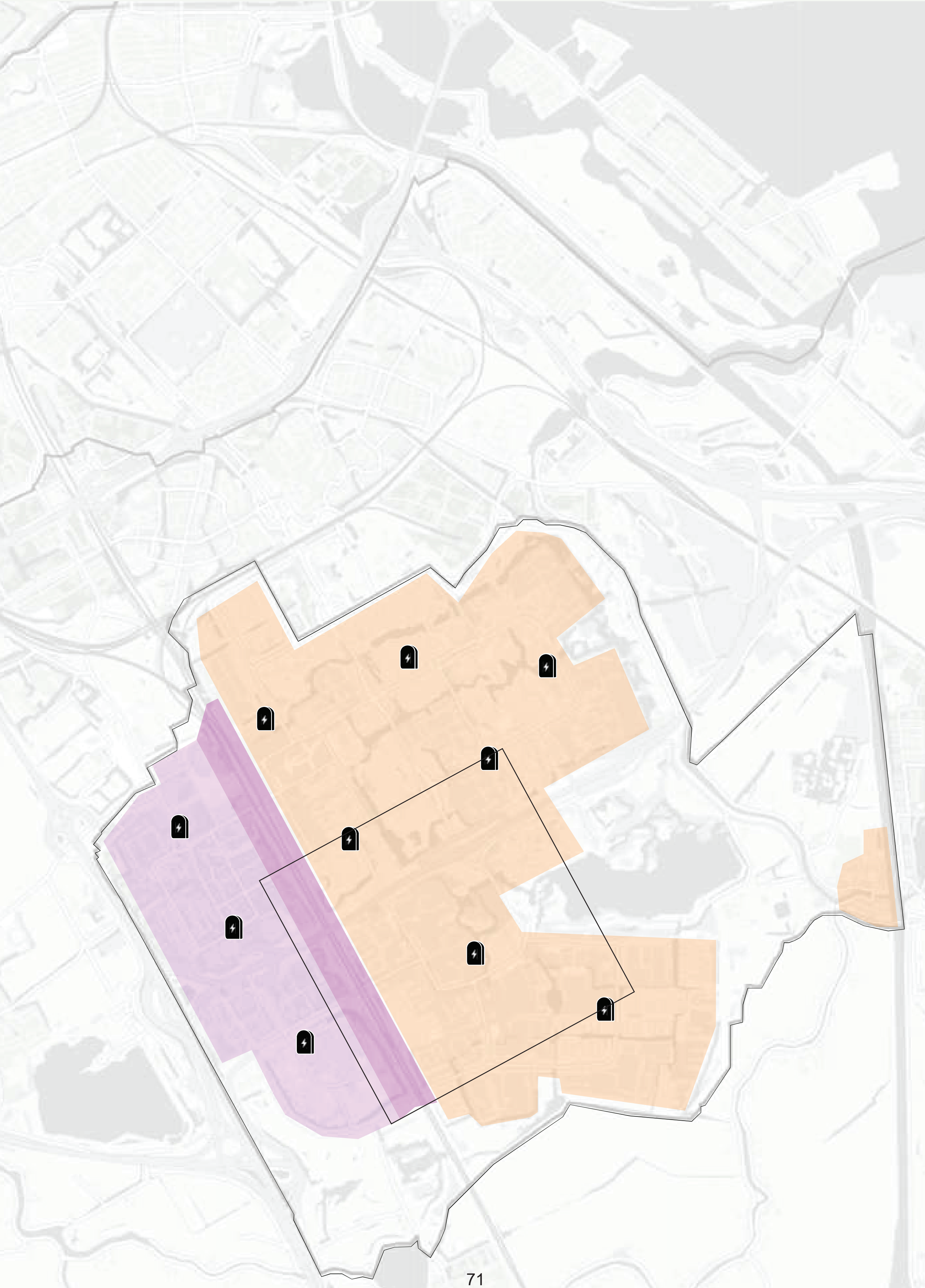
Figure 1, title. Source (2018).

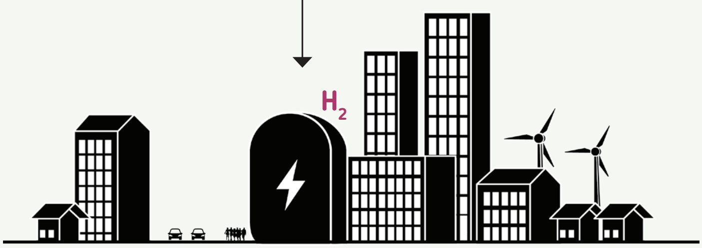


MISCONCEPTION

A (H)Bomb

CHALLENGES

Safe Storage
Overcoming Stigmas
Spacial integration within context



TITLE
SUBTITLE

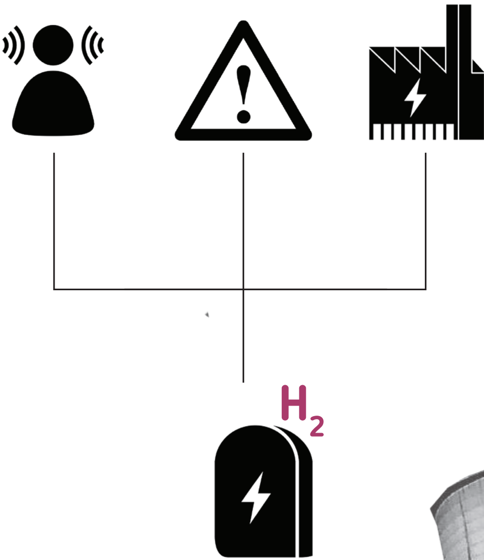
Hydrogen energy storage facilities will be part of our total urban context, to be able to serve in its function as a local battery to excess renewable energy storage. Therefore, facilities will be situated in a great variety of districts throughout the city. Amongst these districts are residential areas like Amsterdam-Zuidoost, in which smaller initiatives like domestic solar panels will predominantly produce renewable energy. This poses the question how hydrogen gas storage facilities can properly be implemented within a residential area. In such a task regarding the characteristics of a building like this, one must deal with both misconception and challenges.

One of the main challenges to the implementation of hydrogen as a technique itself is related to the costs, which today are far higher than those of existing systems. This issue is already being tackled by research and development studies aimed to optimise equipment efficiency and decrease operational costs. Generally speaking, the large the electrolyser unit, thereby producing larger quantities of hydrogen, the better the price/performance ratio. In essence, the cost of electricity also strongly determines the feasibility of producing hydrogen gas from renewable energy.

Hélène Pierre, treasurer of the French Association for Hydrogen and Fuel Cell, forecasts in an interview with the Paris Tech Foundations, however, that in the long term massive production of renewable electrical energy will lower the costs considerably. (Paristech Review, 2015)

Societal acceptance by the public of implementing hydrogen energy storage facilities is essential to their future success, according to Pierre. There are many preconceived ideas about the level of risk associated with hydrogen. Amongst them is the idea that hydrogen gas storage relates to destructive hydrogen bombs and the LZ129 Hindenburg zeppelin accident. The “hydrogen bomb” idea leads to the misconception that hydrogen as gas would transform a vehicle or structure into a bomb. However, the hydrogen economy uses the isotope, Protium, the most common type of hydrogen, while hydrogen bomb technology uses the rare isotope Tritium. Tritium is radioactive and does not occur naturally, but has to be made in a nuclear reactor. This technology, therefore, bears no resemblance to the simple chemical reactions in the hydrogen production, storage and distribution related to renewable energy storage or electrical energy powering.

Figure 1, title. Source (2018).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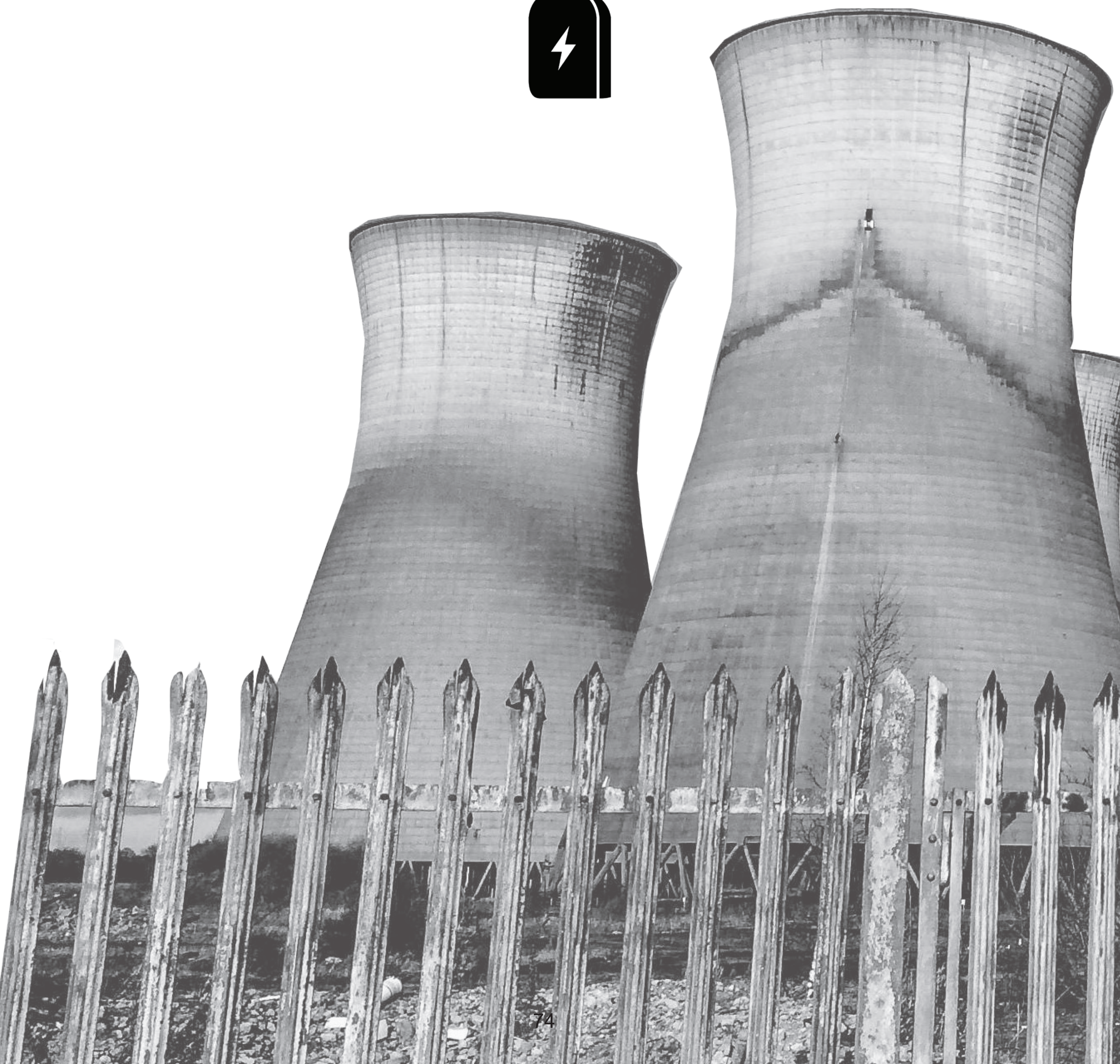

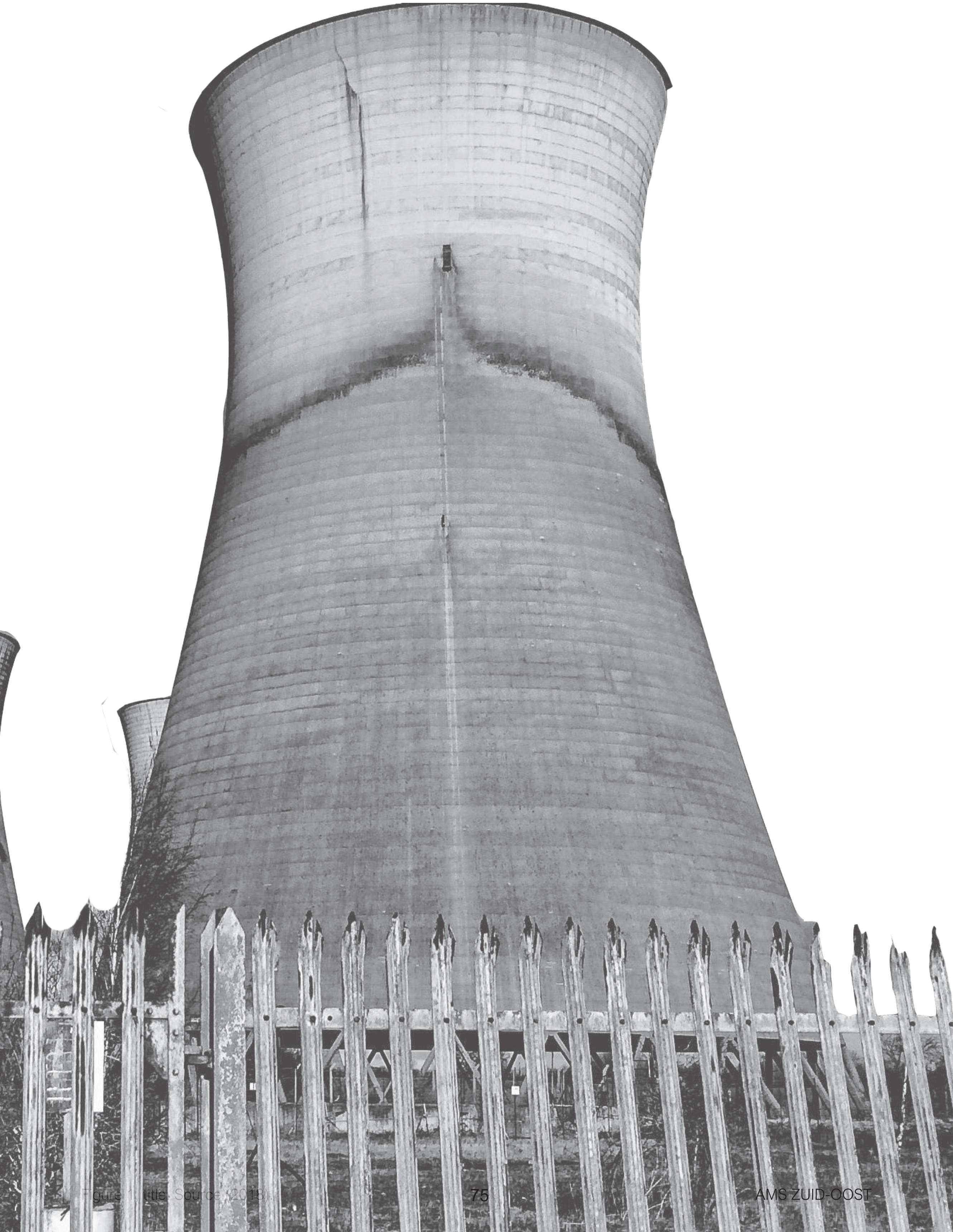

Figure 1. title. Source (2018).


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How might hydrogen gas energy storage facilities become part of our urban context?

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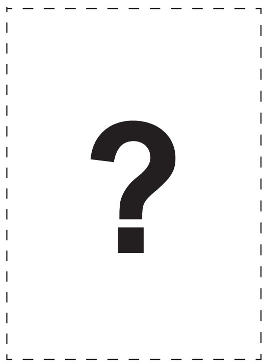

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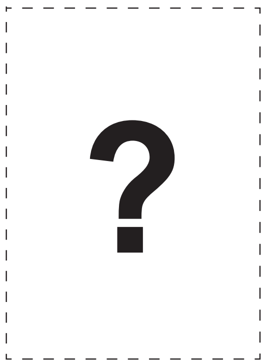

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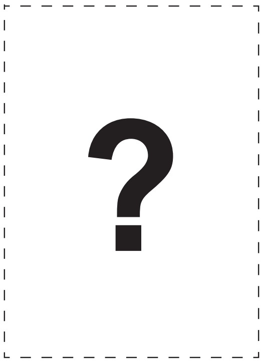

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