T-shore

Technical Skills for Harmonised Offshore Renewable Energy

Co-funded by the European Union

Skive College

HYDROGEN VALLEY®

Intro to Power-To-X

T-shore module theory

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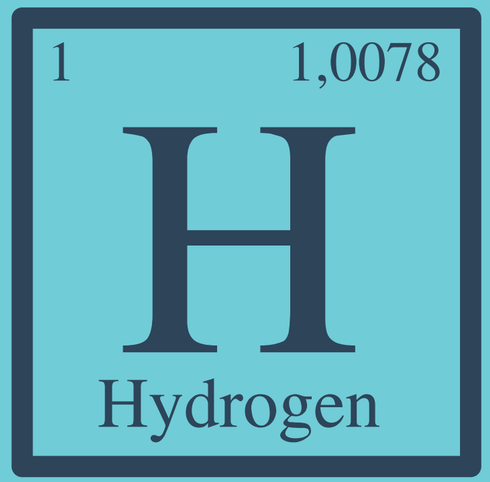
Power-to-X



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01	14.03.2025	New presentation created	Jens Høffner, Heidi Katrine Rosenberg
02	30.04.2025	Adjusted and added context	Verner Johnson, Heidi Katrine Rosenberg, Dennis Nørbjerg

Aims and Objectives of Intro to Power-To-X theory

Main Aim

The purpose of this theory material is to provide an introduction to the technical knowledge related to Power-To-X. In addition, it contains elements of electrolysis and risks of using the various substances that can be used in Power-to-X, including carbon monoxide (CO), and CO2, hydrogen (H), as well as an understanding of safety aspects of using Power-to-X.

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Content

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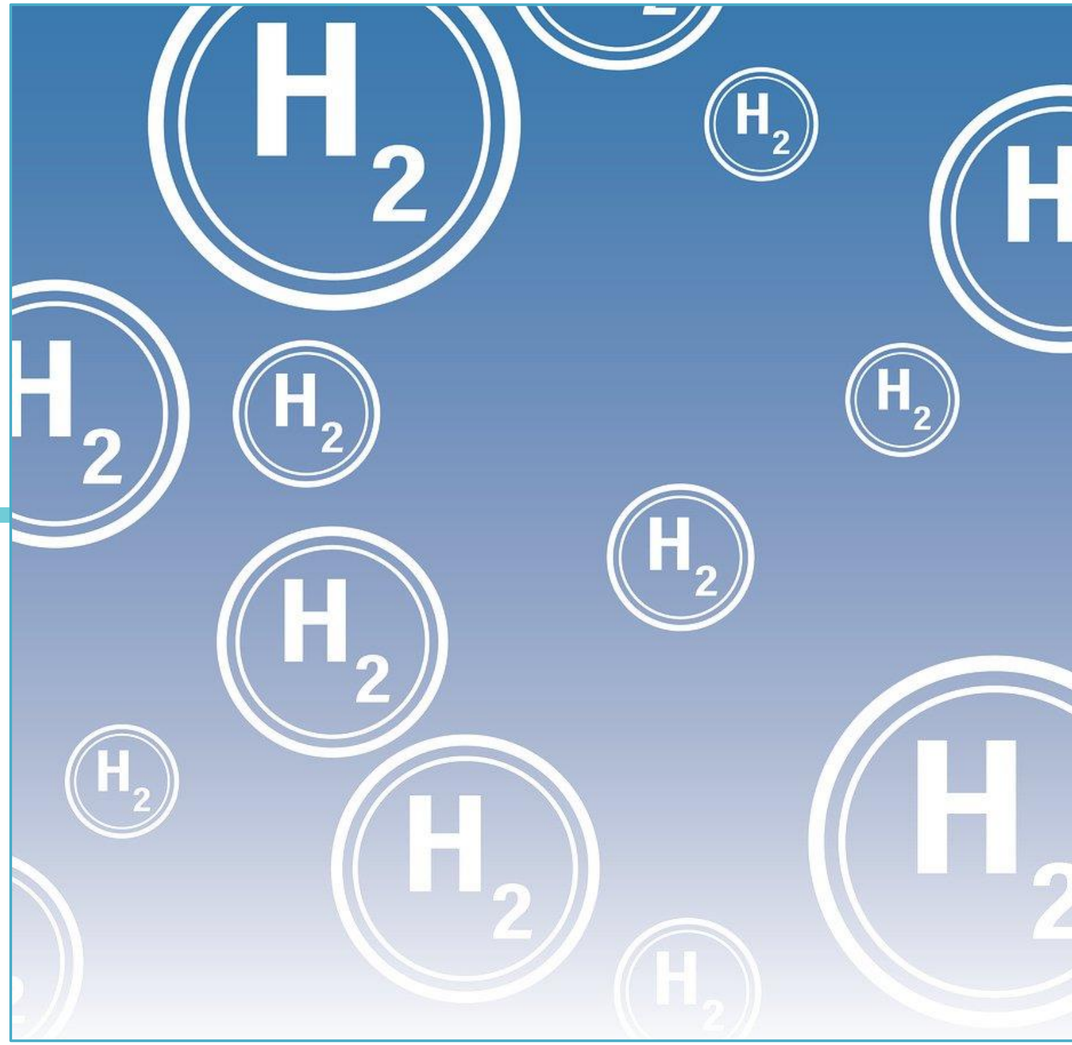
Intro to Power-To-X

Lesson 1



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Power-To-X

Let's "dive" in:

Energy for something we don't know what is yet!

What is POWER to X?

Why POWER to X?

How to POWER to X?

What about ATEX?

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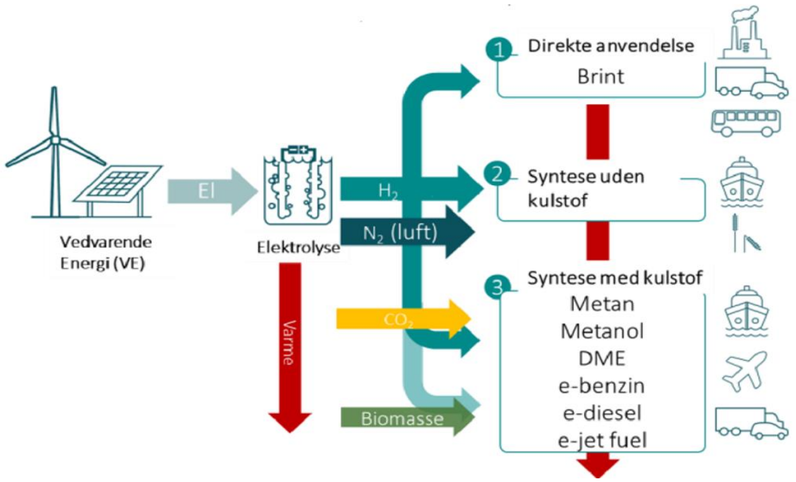
Power-To-X

The Danish Energy Agency assesses that PtX can become an important piece in Denmark's future energy system.

Power-to-X (PtX) covers a number of technologies, all of which are based on the fact that electricity is used to produce hydrogen.
In Denmark, they talk about Power-to-X, while abroad they call it green hydrogen or: Electrofuels or E-fuels.

Both concepts describe the process by which electricity and water are converted into green hydrogen through electrolysis.
The hydrogen can be used directly in e.g. trucks, ferries or industry, but it can also be further converted into other fuels.



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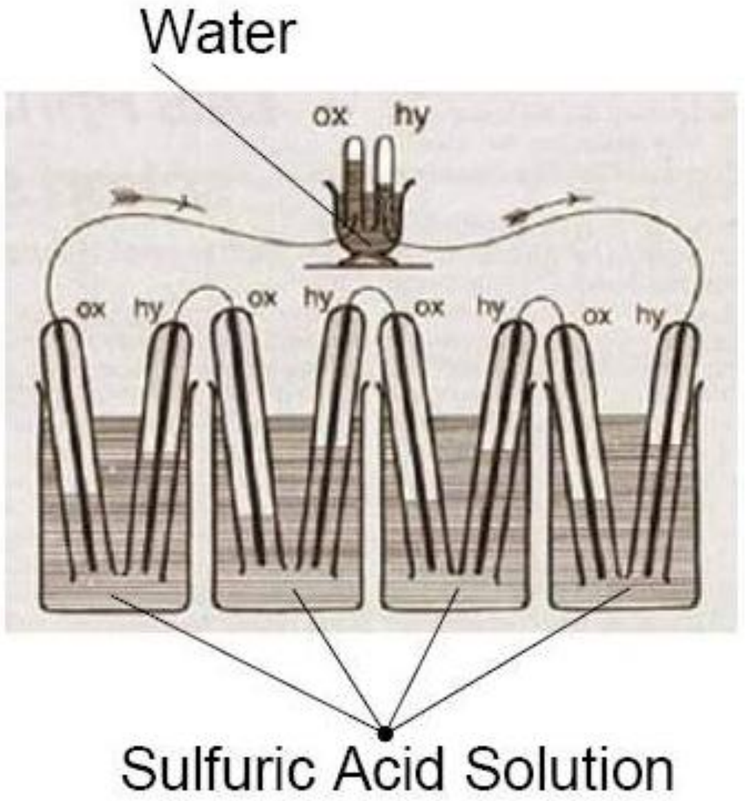
The history of Power-to-X

The story behind the development of Power-to-X from the first electrolysis experiments to the first Power-to-X plants in Denmark and the future for Power-to-X.

- **Electrolysis** As far back as **1839**



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What can we learn from Denmark's first Power-to-X factory?

The HyBalance Project in Hobro

- The demonstration plant produces hydrogen via PEM electrolysis using electricity and water
- The plant will continue producing hydrogen for many years to come

Production and Technology

- Since mid-2018, 120,000 kg of hydrogen has been produced (as of 1 September 2020)
- Hydrogen enables greater capacity for storing electricity
- Electrolysis technology is well-known, but here applied on a large scale
- Large-scale storage of surplus wind power makes wind energy more economically attractive

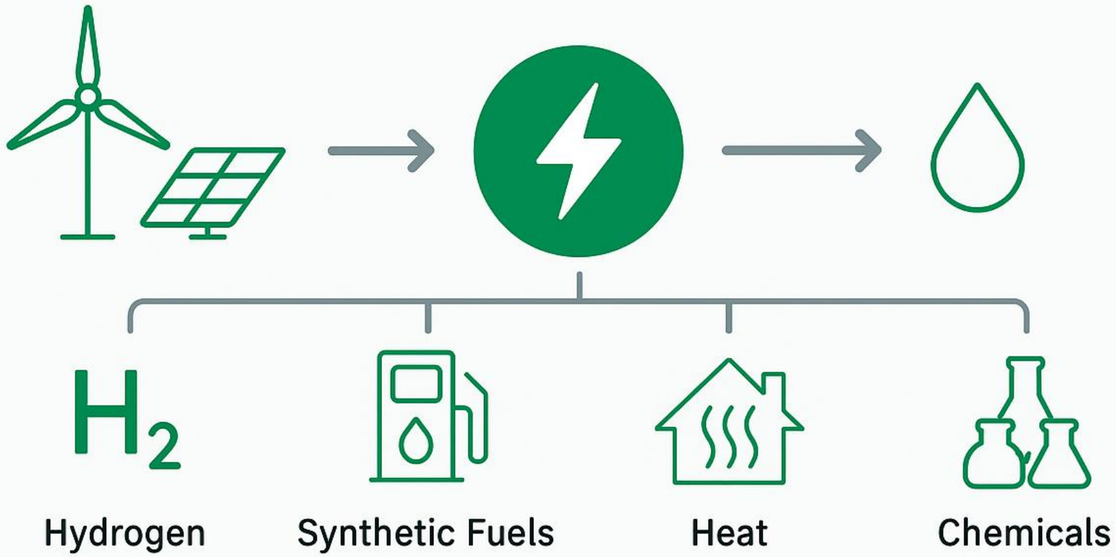
Contribution to the Power Grid

- The plant demonstrates how hydrogen production can help balance the electricity grid
- HyBalance is approved by Energinet (the Danish supply grid) to participate in all electricity markets
- Provides system services to help maintain balance in the power grid

What is Power-to-X?

Power-to-X (PtX)

technologies that convert green electricity into other energy forms or products. This includes hydrogen, synthetic fuels, heat, or chemicals. PtX enables storage of surplus power from wind and solar. The technology connects electricity with transport, industry, and heating sectors. It is a key solution for the green transition and CO_2 redu-



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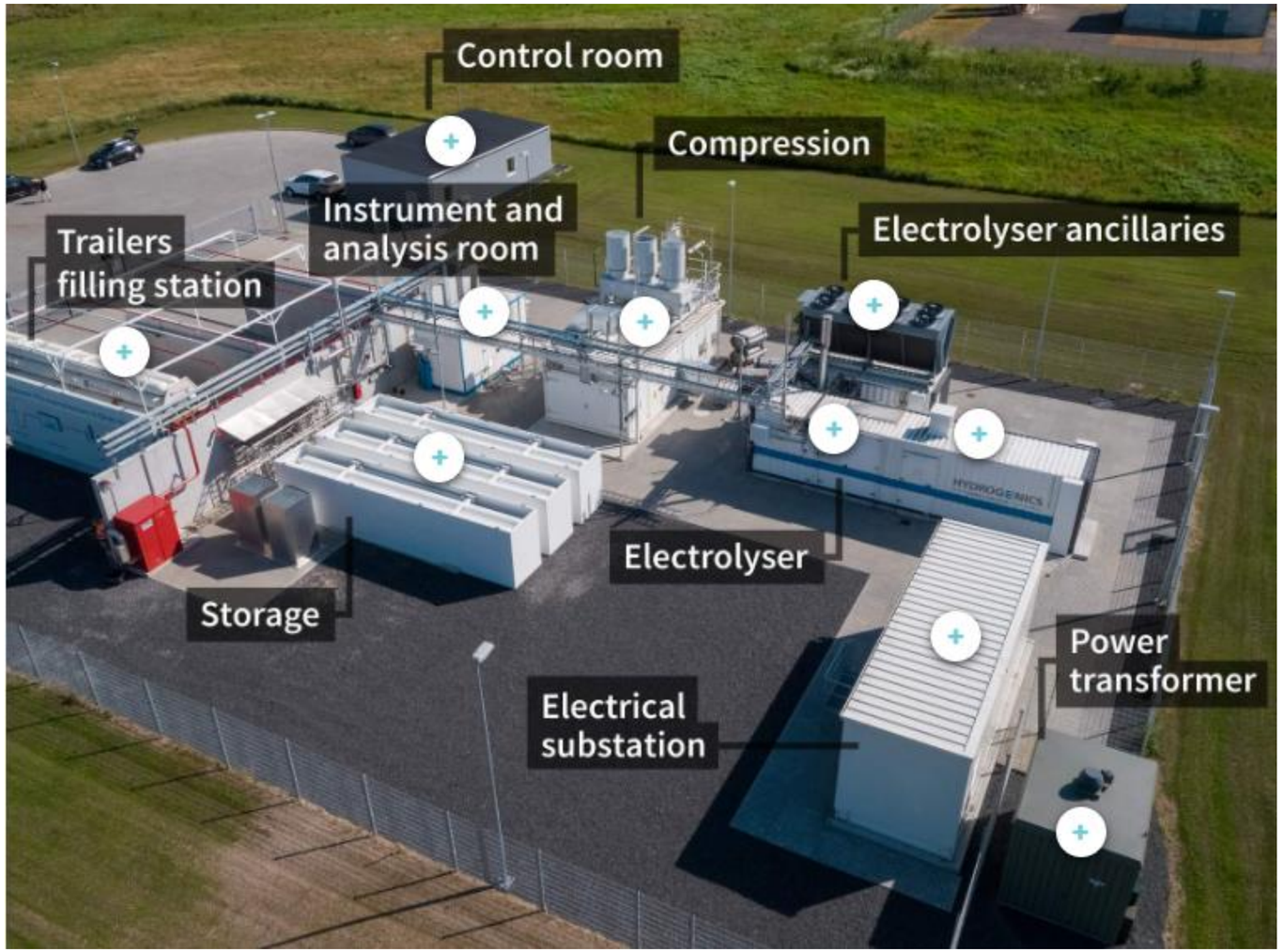
Power-to-X system

Power-to-X systems typically consist of several key components that work together to convert electricity into other energy carriers or fuels. The main components of such a system include the elements in the picture.

Do you know them?



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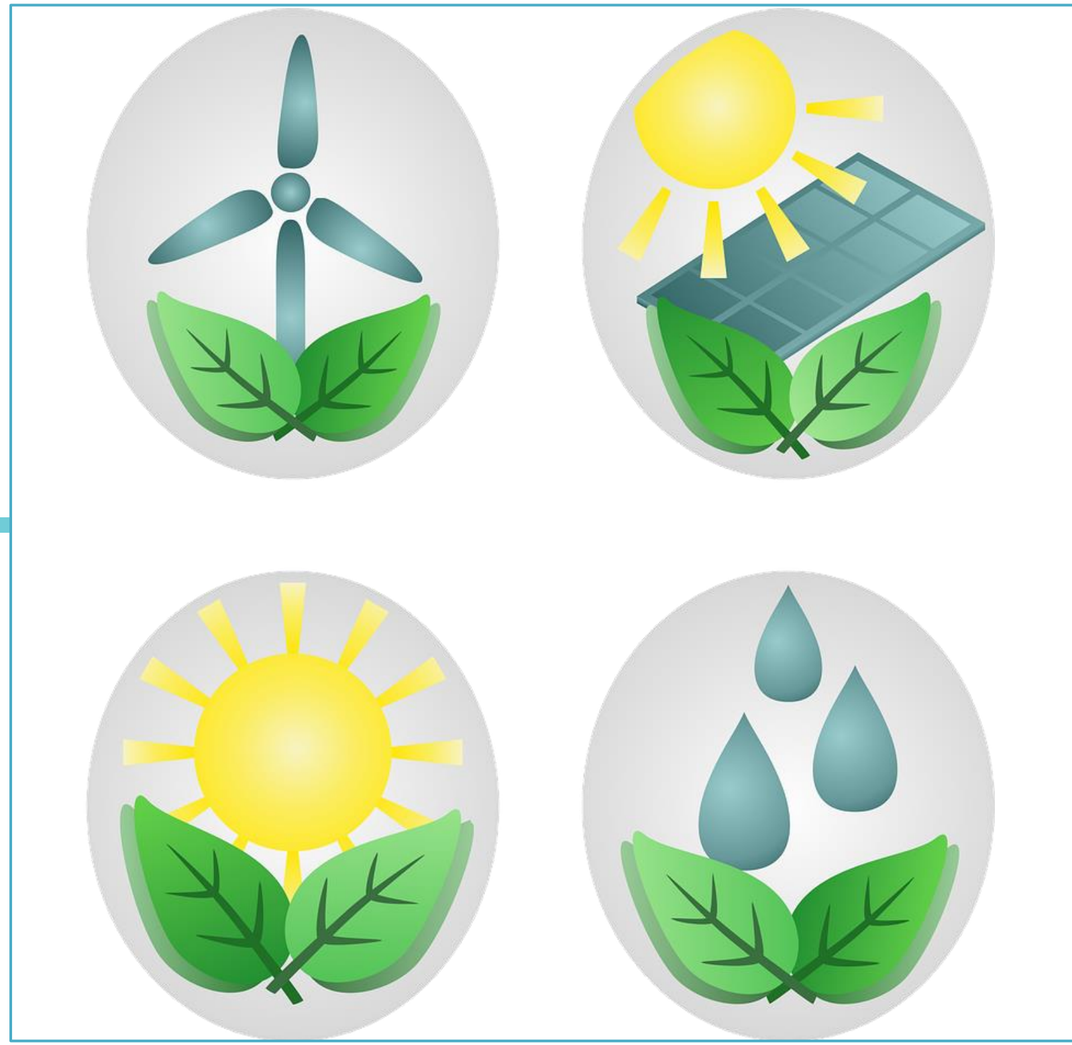
Supply for electrolysis

Lesson 2



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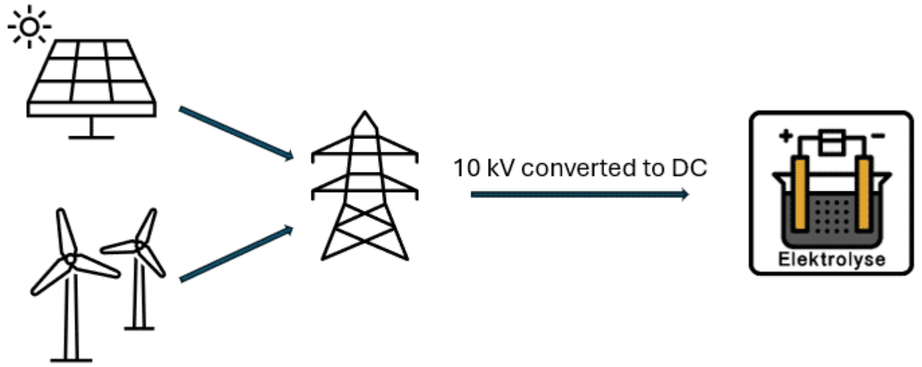
The energy supply for the Power-to-X process

Power-to-X Energy Supply

- Requires stable and large electricity supply for electrolysis
- Typically powered by renewable energy (wind, solar)
- Ensures green and sustainable fuel production

Backup and Stability

- Can use grid electricity as backup during low renewable output
- Energy storage systems help balance supply and ensure stable operation



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Green renewable energy

The green renewable energy sources such as solar energy, wind power and hydropower, have in common that they emit minimal CO_2 compared to the fossil energy sources.

Learn more about renewable energy by watching the video →

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Electricity grid

The electricity grid in Denmark

- Green energy is connected to the electricity grid, which consists of transmission and distribution networks
- **Transmission network** (electric highways):
  - 100 kV and above, owned by Energinet
  - Enables import/export of power between regions and countries
  - Transports power from production to consumption areas
- **Distribution network** (local electric roads)
  - Below 100 kV, connecting consumers and transmission networks
  - Connection point for local electricity generation (CHP, solar cells, wind turbines)

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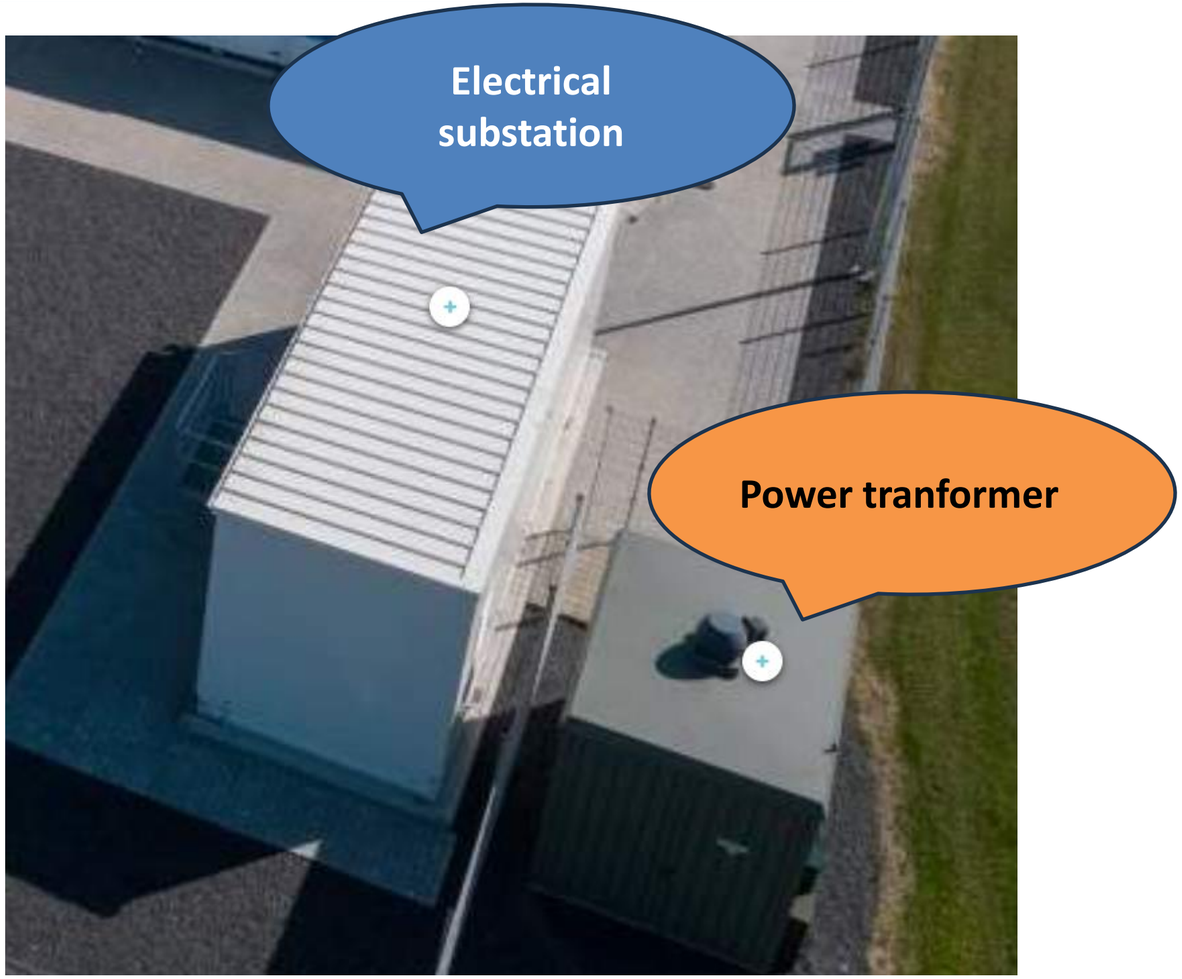
Transformer / Converter

A Power-to-X facility is supplied with electricity through a transformer connected to the distribution grid. The transformer ensures that the electricity from the grid is adjusted to meet the facility's energy conversion requirements.



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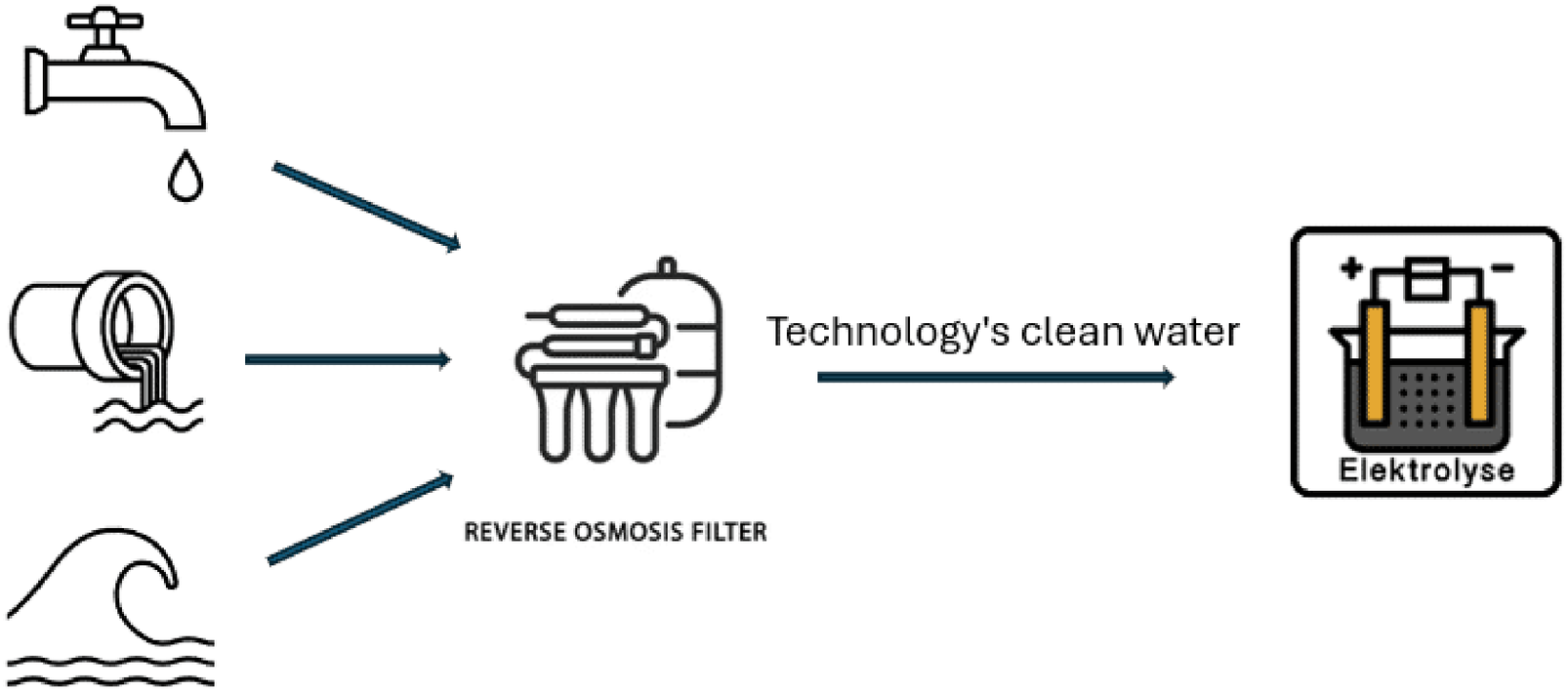
The water supply for the Power-to-X process



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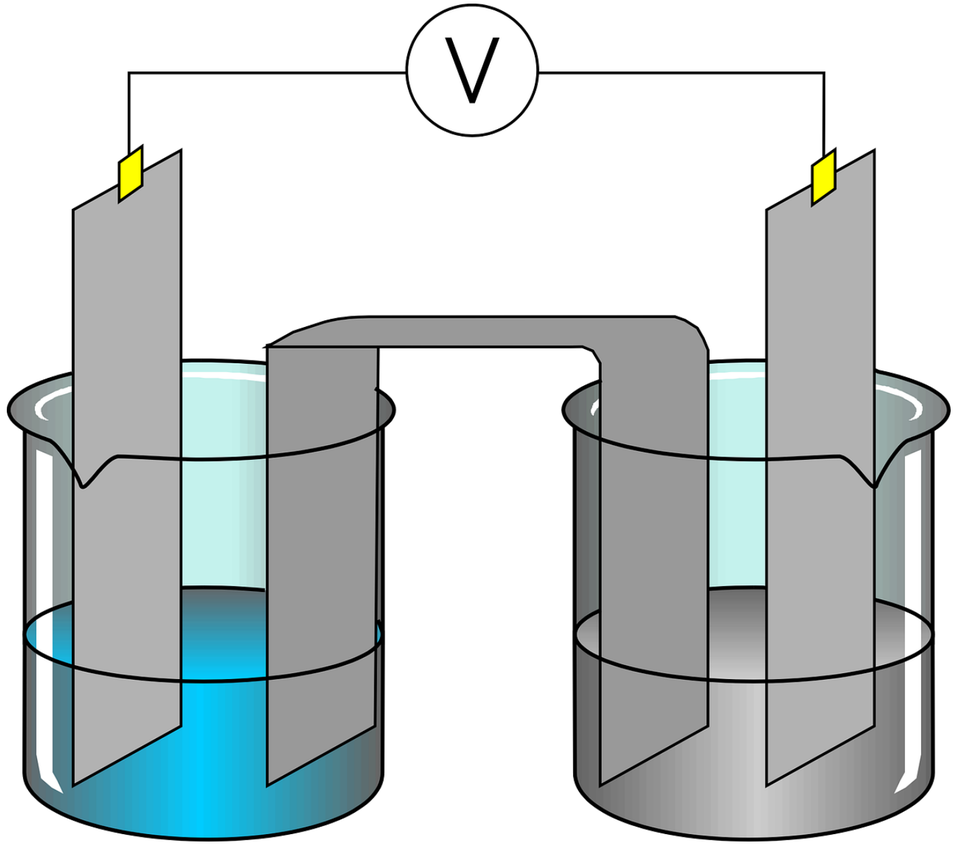
Forms of electrolysis

Lesson 3



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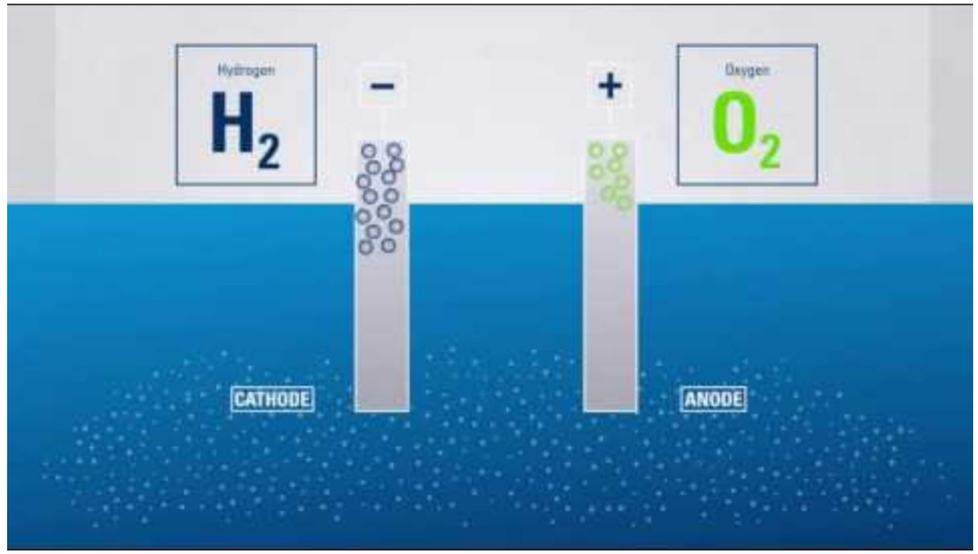
What is Electrolysis and Its Types?

- Electrolysis uses electricity to drive non-spontaneous chemical reactions
- Splits compounds into elements in an electrolytic cell
- Uses an electrolyte and two electrodes: cathode (–) and anode (+)
- Commonly splits water into hydrogen (H_2) and oxygen (O_2)
- Core technology in Power-to-X for green hydrogen and synthetic fuels



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Types of Electrolysis

- **Alkaline Electrolysis (AEC)**: An electrolysis process that uses a liquid alkaline electrolyte (KOH or NaOH) and porous separators to separate hydrogen and oxygen. It is a well-established technology with relatively low costs.

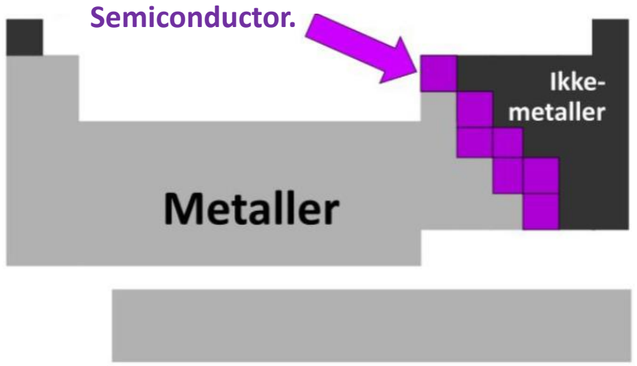
- **PEM Electrolysis (Proton Exchange Membrane)**: An electrolysis method where a proton-conducting membrane acts as the electrolyte. It has high efficiency, fast response time, and is well-suited for integration with renewable energy. (e.g. this technology is used in Hybalance in Hobro and at Greenlab Skive)

- **SOEC Electrolysis (Solid Oxide Electrolysis Cell)**: A high-temperature electrolysis method that uses a ceramic solid oxide electrolyte to achieve very high efficiency. It can utilise excess heat from industrial processes.

Universe “Building blocks” - Elements

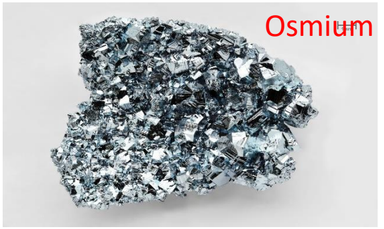
118 Different elements.

94 (98) Naturally occurring.
24 (20) Artificially produced.



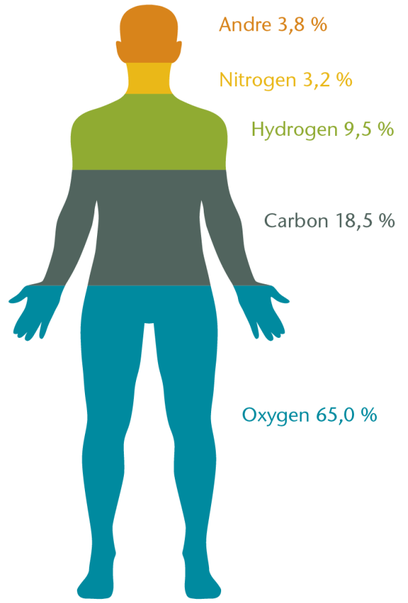
Universe “Building blocks” - Elements

Element number 1, Hydrogen is the lightest.
Element number 76, Osmium is the heaviest.
The company name OSRAM (1906) is formed by: OSmium and WolfRAM (element no.



Element number 3, Lithium (Li), is best known as an ingredient in batteries.
Lithium is also used in psychiatry to treat mental disorders.

Humans are made up of 28 elements.



An average smartphone contains about 30 different elements, of which 0.03 grams is element number 79: Gold (Au).

Element number 87, Francium (Fr), is the rarest element on Earth.
Francium is also highly radioactive, but decays as quickly as it is formed.
It is believed that no more than a few 100 grams exist at a time at any given time.

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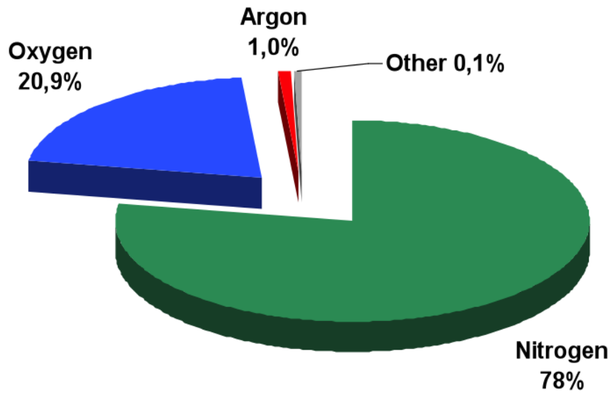
Universe “Building blocks” – In the atmosphere



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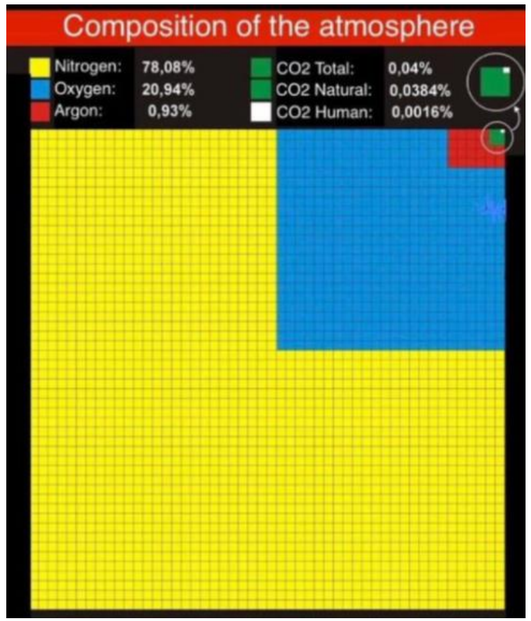
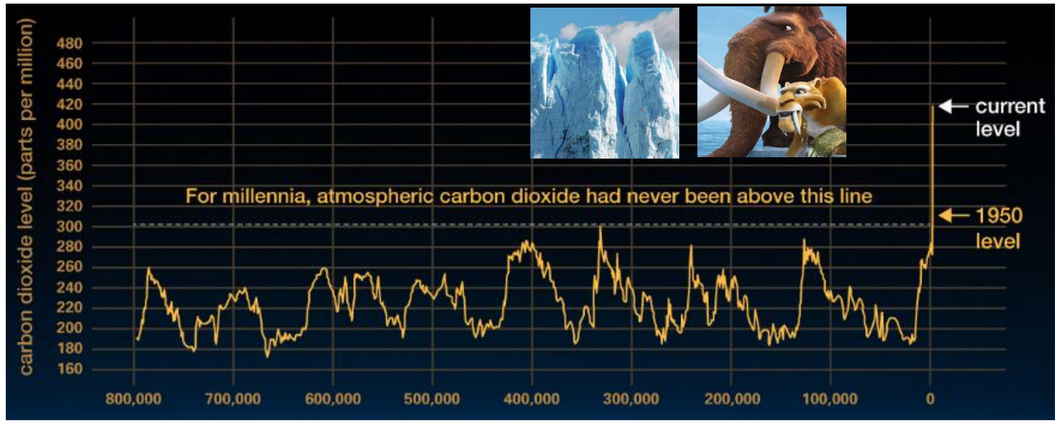
CO2 in the atmosphere !

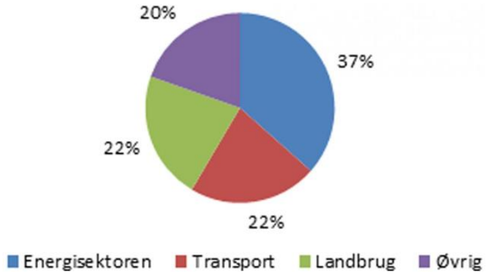
The quantity
against
The concentration



CO2 is the chemical name for carbon dioxide, which is also called carbon dioxide. The chemical name CO2 indicates that carbon dioxide consists of one carbon atom and two oxygen atoms.

So CO2 is not an element, but a mixture of different substances!





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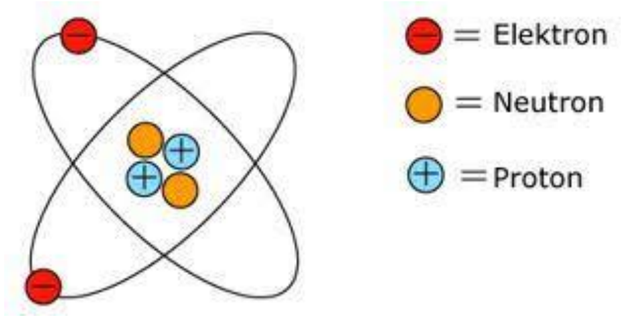
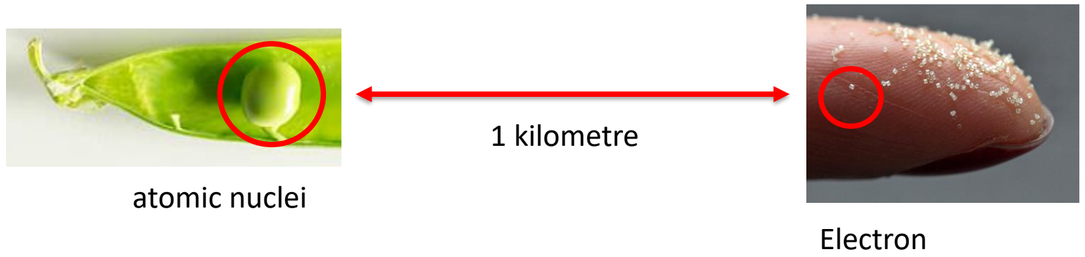
Atomets struktur

An ATOM is the smallest unit of an element.
Both the Protons and the Electrons are electrically charged.
An electron and a proton have an equal charge, but the charges are opposite.
The electrical charge of electrons is negative and that of protons is positive.
Since the atoms are electrically neutral outwardly, there must be an equal number of electrons and protons in each atom.





atomic nuclei

Electron

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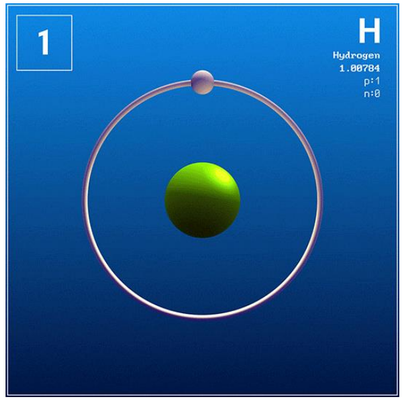
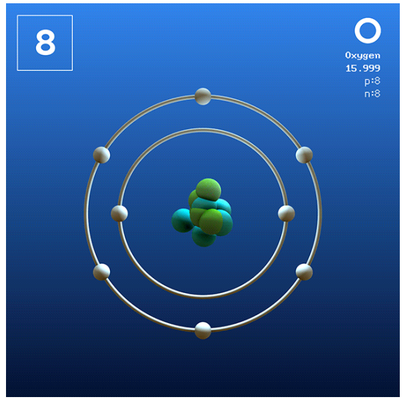
Atomets struktur

The atom can have up to 7 electron shells around the nucleus.
There can be from 1 to 32 electrons in the shells

1. Up to 2 electrons.
2. up to 8
3. up to 18
4th to 7th up to 32

The outermost electrons in the shells are the ones that binds atoms together to form molecules.





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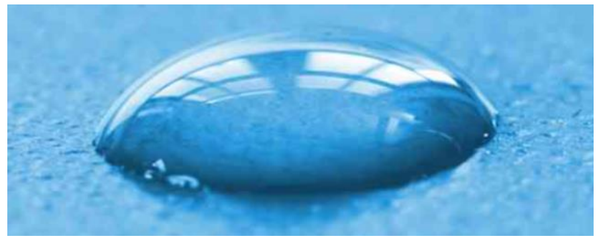
Atomets struktur

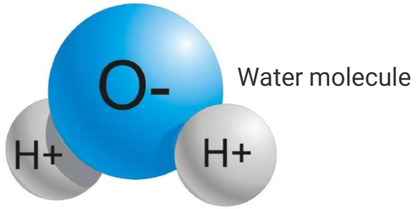
Tabel 4.6 – Sammensætningen af nogle atomer for forskellige grundstoffer

Grundstof	Symbol	Atomnummer	Massetal	Antal protoner	Antal neutroner	Antal elektroner
Hydrogen	H	1	1	1	0	1
Nitrogen	N	7	14	7	7	7
Oxygen	O	8	16	16	8	8
Chlor	Cl	17	37	17	20	17
Jern	Fe	26	58	26	32	26
Guld	Au	79	197	79	118	79

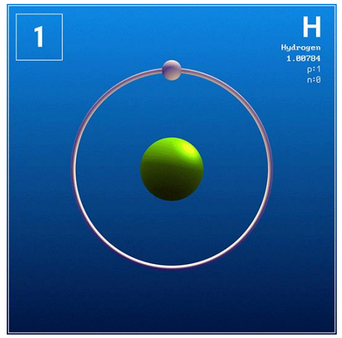
Atom vs molecule An atom is the smallest unit of an element. All atoms in a single element contain the same number of protons. Atoms cannot be further divided using any chemical method. In contrast, a molecule is the unit of a pure substance. A molecule is made up of more than one atom.

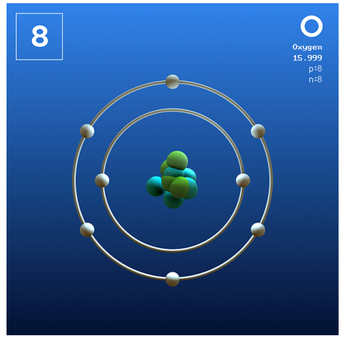
Electrolysis





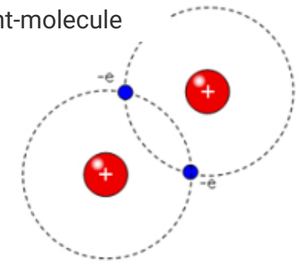
Water molecule

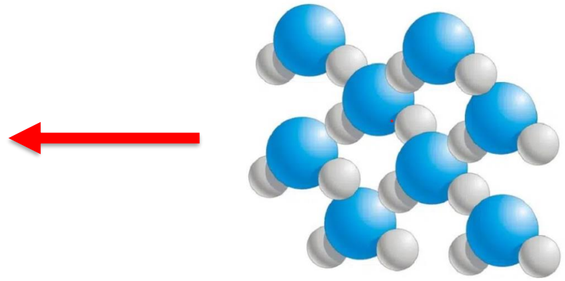




H_2

Brint-molecule





Oxygen molecule

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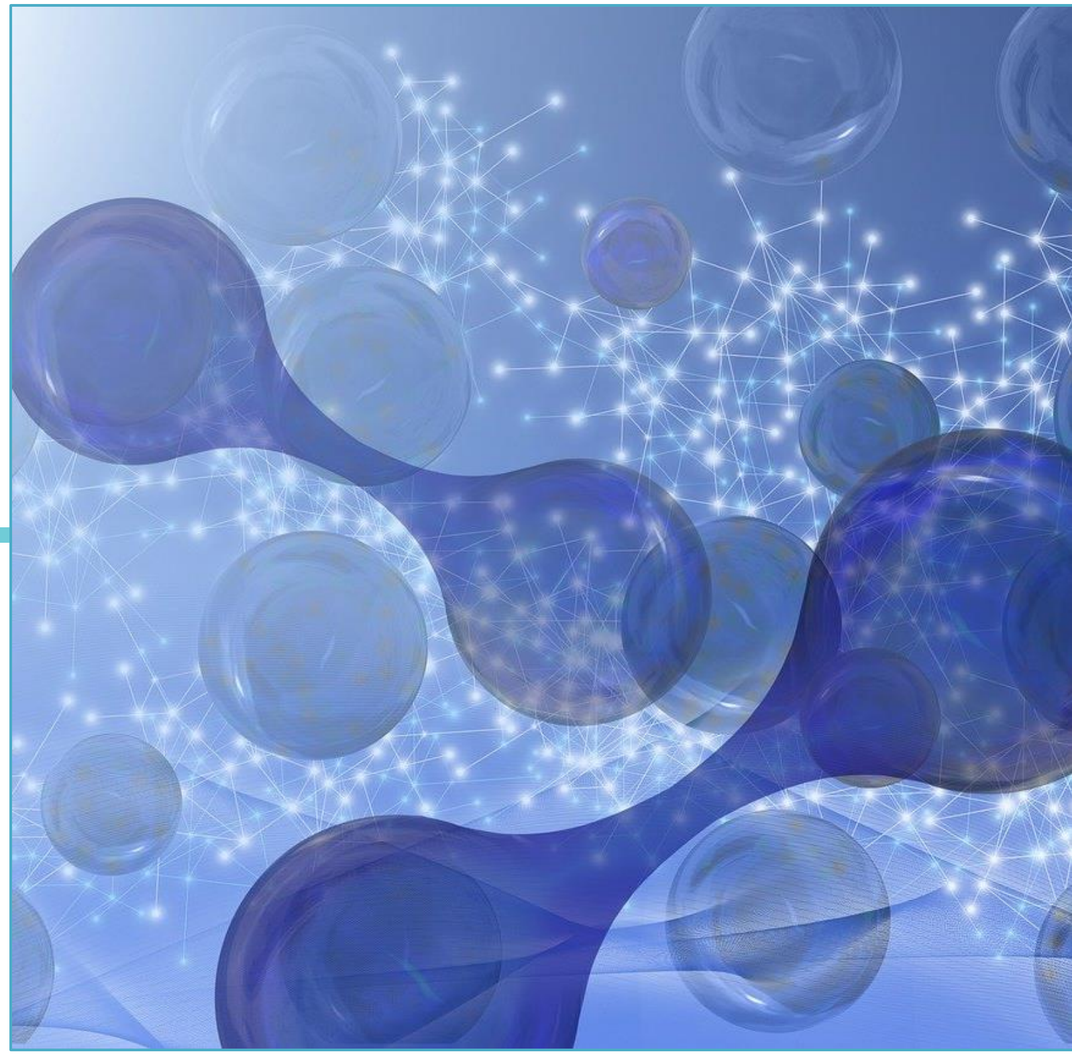
Cooling of electrolysis – residual heat

Lesson 4



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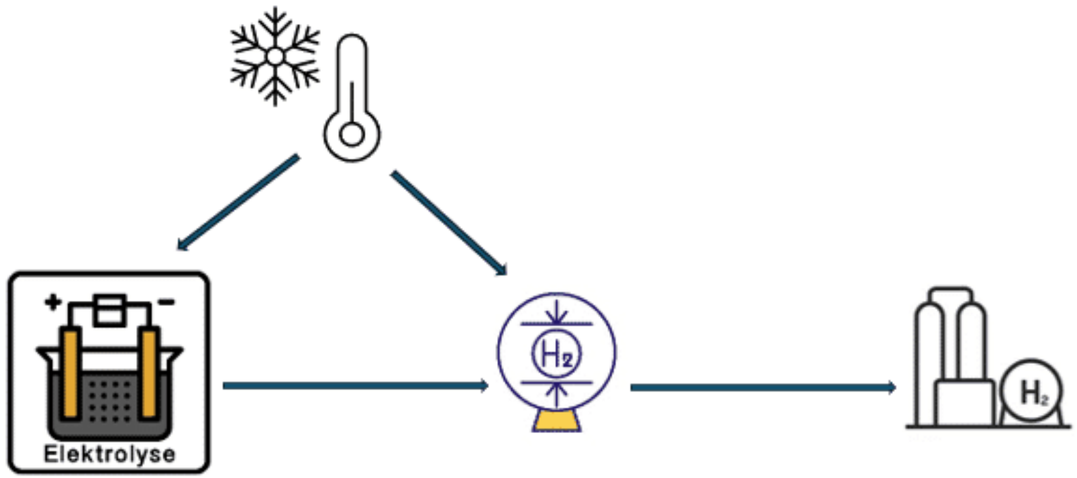
Cooling in Electrolysis and Hydrogen Compression Systems

Electrolysis systems and **hydrogen compression systems** require effective **cooling** to maintain optimal operation, prevent overheating, and ensure the longevity of the equipment. **Cooling** is critical because both the **electrolysis process** and the **hydrogen compression** generate significant amounts of **heat**, which must be removed to avoid **thermal stress** on the components.



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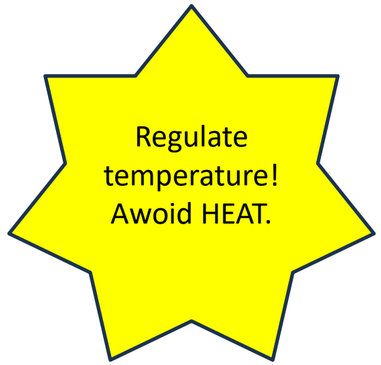
Cooling in Electrolysis and Hydrogen Compression Systems

Electrolysis systems convert **electricity** and **water** into **hydrogen** and **oxygen** through an **electrolytic process** that produces **heat** during energy conversion. To regulate the **temperature** and maintain an efficient **electrochemical reaction**, various **cooling strategies** are employed:



- **Internal Liquid Cooling**
- **External Heat Exchanger**
- **Active Temperature Control:**

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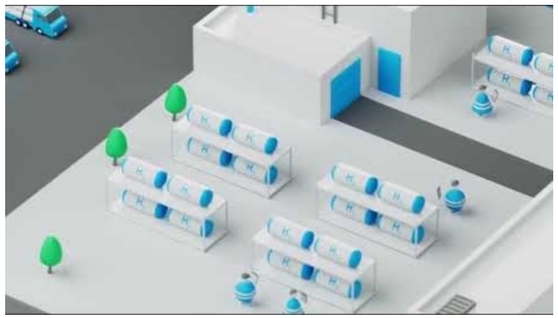
Storage of Hydrogen (H_2)

In order to utilise **hydrogen's energy** for later use, it is necessary to store the gas in an efficient manner. One of the biggest challenges in storing hydrogen is its very low **mass density**. This means that hydrogen in gas form requires large volumes to store sufficient amounts of energy. To make it possible to store hydrogen efficiently, several methods are used.



- Compression of Hydrogen
- Cooling Hydrogen to Liquid Form
- Storage in Hydrogen-Containing Chemicals
- Storage Using Complex Hydrides

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The products of electrolysis

Lesson 5

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Products of Power-To-X

Power-To-X is an umbrella term for a set of technologies that enable the conversion of **electrical energy**, particularly from **renewable sources**, into various forms of **energy carriers**, **fuels**, or **chemicals**.

The Importance of Energy Density in Power-To-X Product Development

- Power-to-Gas (PtG)
- Power-to-Liquid (PtL)
- Power-to-Heat (PtH)
- Power-to-Chemicals (PtC)
- Power-to-Fuel

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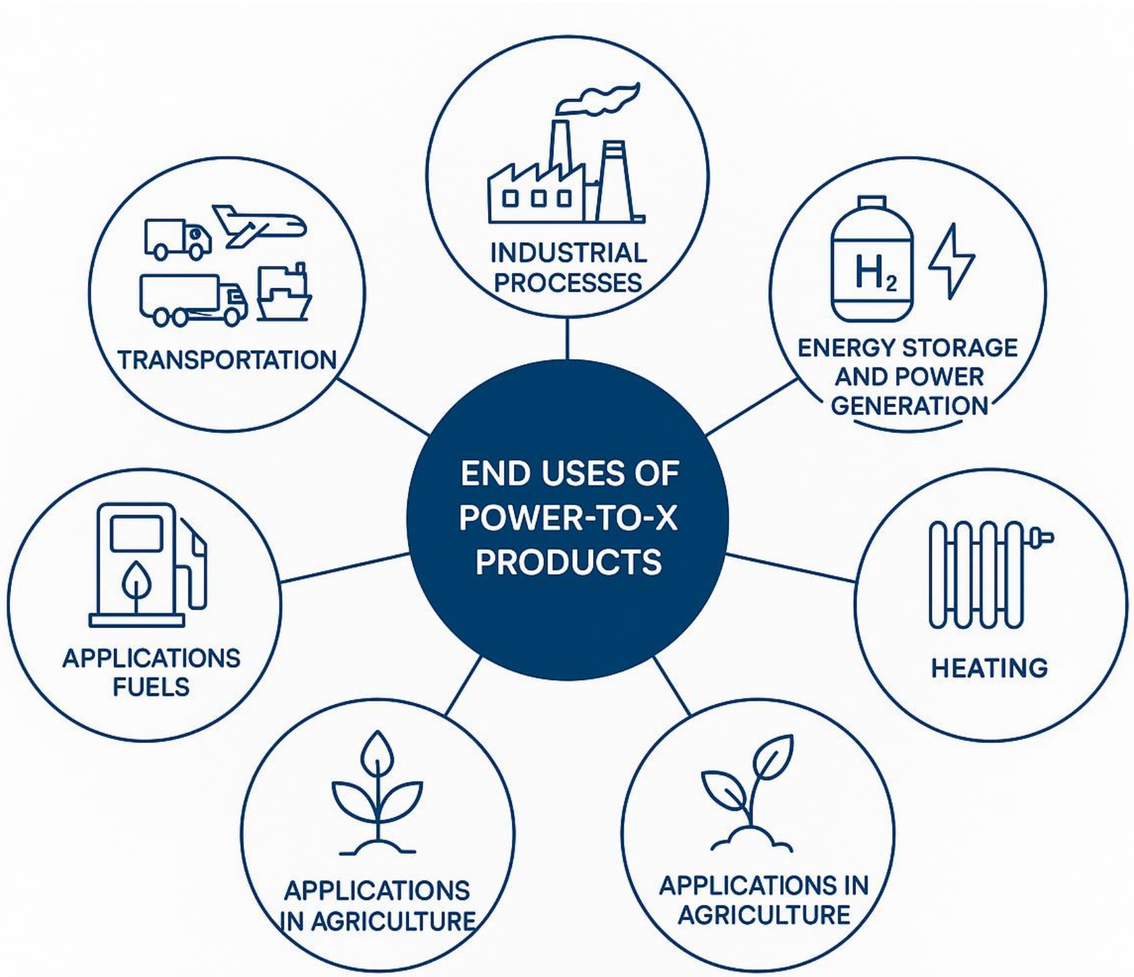
Typical End-Users of Power-to-X Products

Power-to-X products such as **hydrogen**, **methanol**, and **synthetic fuels** are essential components in the transition to sustainable energy systems.



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Technological and Economic Considerations

- **Cost Competitiveness**
  Green hydrogen and other **Power-To-X** products are currently more expensive than their fossil-based counterparts. Scaling up production and advancements in **electrolysis**, **synthesis**, and **storage technologies** are essential to reduce costs.

- **Infrastructure Development**
  Infrastructure for **hydrogen transportation**, **refueling**, and **storage**, as well as facilities for **synthesising** and **handling methanol** and **e-fuels**, needs to be expanded to support **large-scale adoption**.

- **Policy Support**
  Governments and **regulatory bodies** play a critical role in accelerating the adoption of **Power-To-X** products by providing **subsidies**, setting **mandates** for **renewable fuels**, and funding **research** and **development**.

Safety, laws, regulations, and standards

Lesson 6

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What is EX atmosphere?

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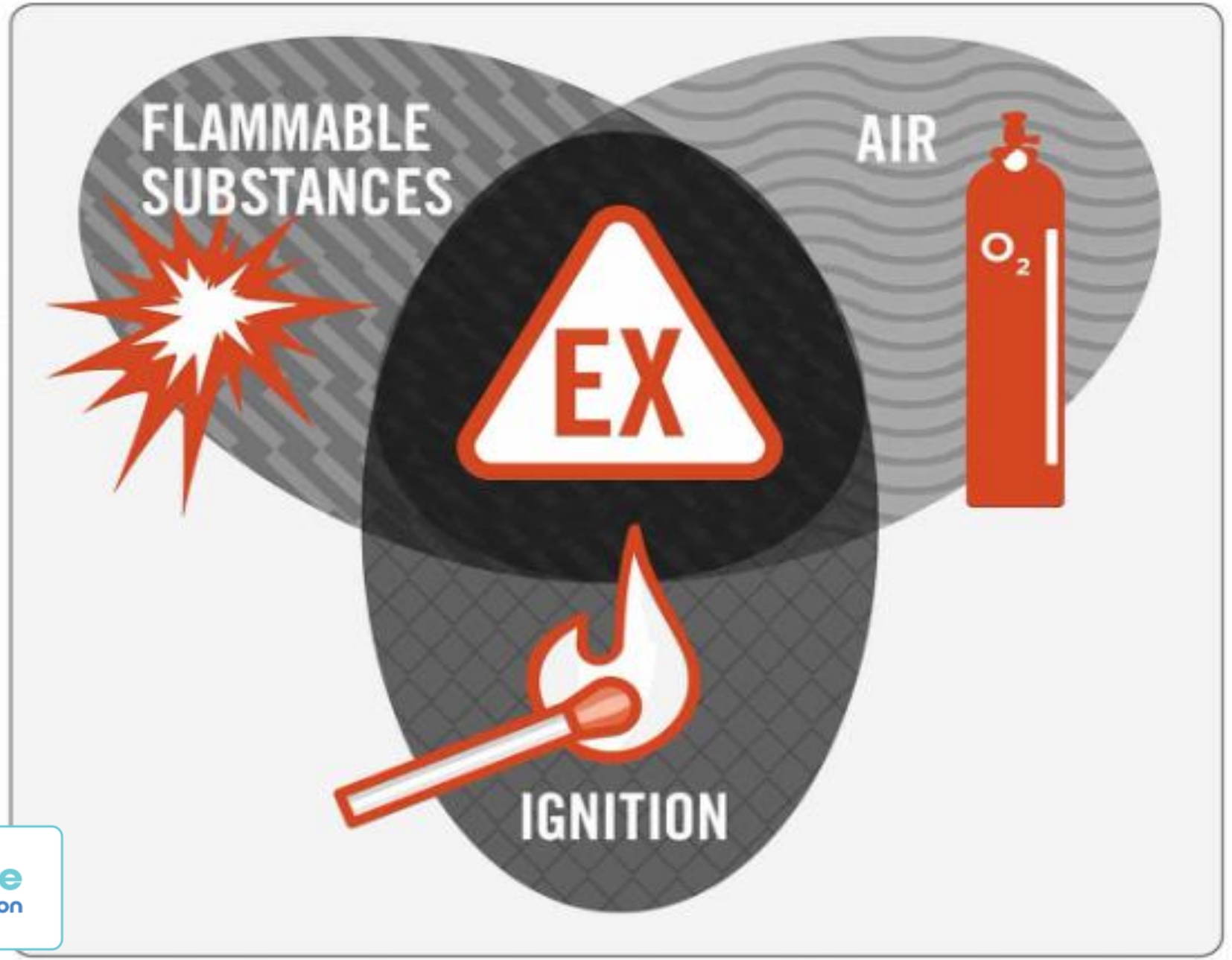
Wha



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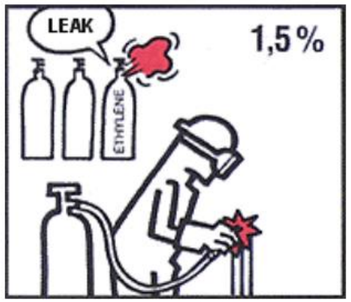
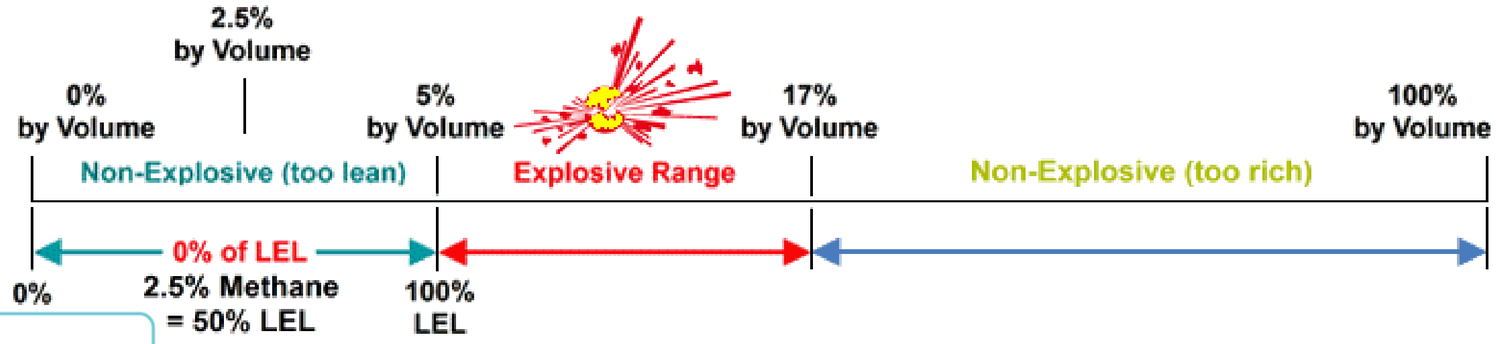
What is EX atmosphere?



Nedre eksplosionsgrænse: (**LEL**) lower explosiv limit.

Øvre eksplosionsgrænse: (**UEL**) upper explosiv limit.



Acetylen	2.5	100

Laws and regulations

- Directive of the European Parliament and of the Council: 2014/34/EU
- BEK no. 590 of 26/06/2003 Executive Order on the Classification of Hazardous Areas
- BEK no. 811 of 03/06/2022 Executive Order on Products for Use in a Potentially Explosive Atmosphere
- BEK no. 478 of 10/06/2003 Executive Order on Work in Connection with Explosive Atmospheres
- BEK no. 1444 of 15/12/2010 Executive Order on Technical Regulations for Gases
- DS/EN 60079-14:2014: Explosive atmospheres - Construction, selection and construction of electrical installations
- DS/EN 60079-17:2014: Explosive atmospheres - inspection and maintenance of electrical installations
- The Danish Safety Technology Authority: from 1 Dec. 2018, responsibility for the control of products covered by the 2014/34/EU directive
- The Danish Working Environment Authority: Guidelines C.0.9 on work in connection with explosive atmospheres
- The Danish Emergency Management Agency: Guidance on the classification of hazardous areas

T-shore Education

Assignment

+

+

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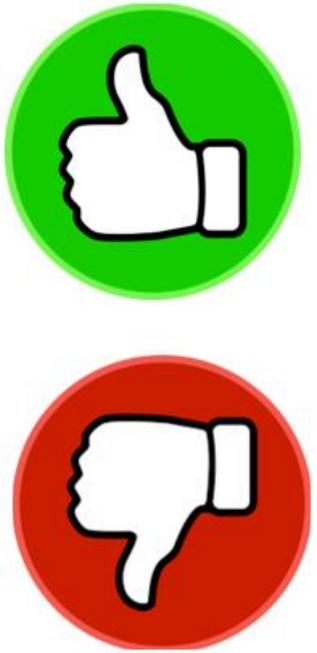


T-shore Education

støv?

Skal ATEX-mærkningen være synlig? +

Skal alt (kabler, dåser, forskruninger) være lyseblåt ved egensikre installationer? +

Må jeg bruge samlemuffer i klassificeret område? +

Er det tilladt at anvende stikforbindelser i egensikre kredse? +

Hvordan skal udligningsforbindelser kontrolmåles i EX-område? +

In areas with explosive gas atmospheres (zone 1 and zone 0), the connection of power conductors must not be made with connectors. However, connectors may be used if the assembly is carried out in a certified pressure-proof enclosure (i.e. marked Ex d).
All other power conductors must be assembled in certified terminal boxes, which will typically be in increased safety (i.e. marked Ex e) and with light blue terminals.
For power conductors in areas with dust (zone 21 and zone 20), connectors may be used if the enclosure is certified as dust protected (i.e. marked Ex tb for zone 21 or Ex ta for zone 20).
Since you are not allowed to change certified CE marked products, it must therefore be stated in the manual that connectors may be used. As a rule, the equipment will be prepared with terminals).

ATEX: Clothing

When working in an ATEX environment, clothing certified to EN 1149-3/5 must be worn to ensure that the clothing does not create static sparks, which can cause an explosion.

ATEX
APV

EN 1149-3

EN 11612

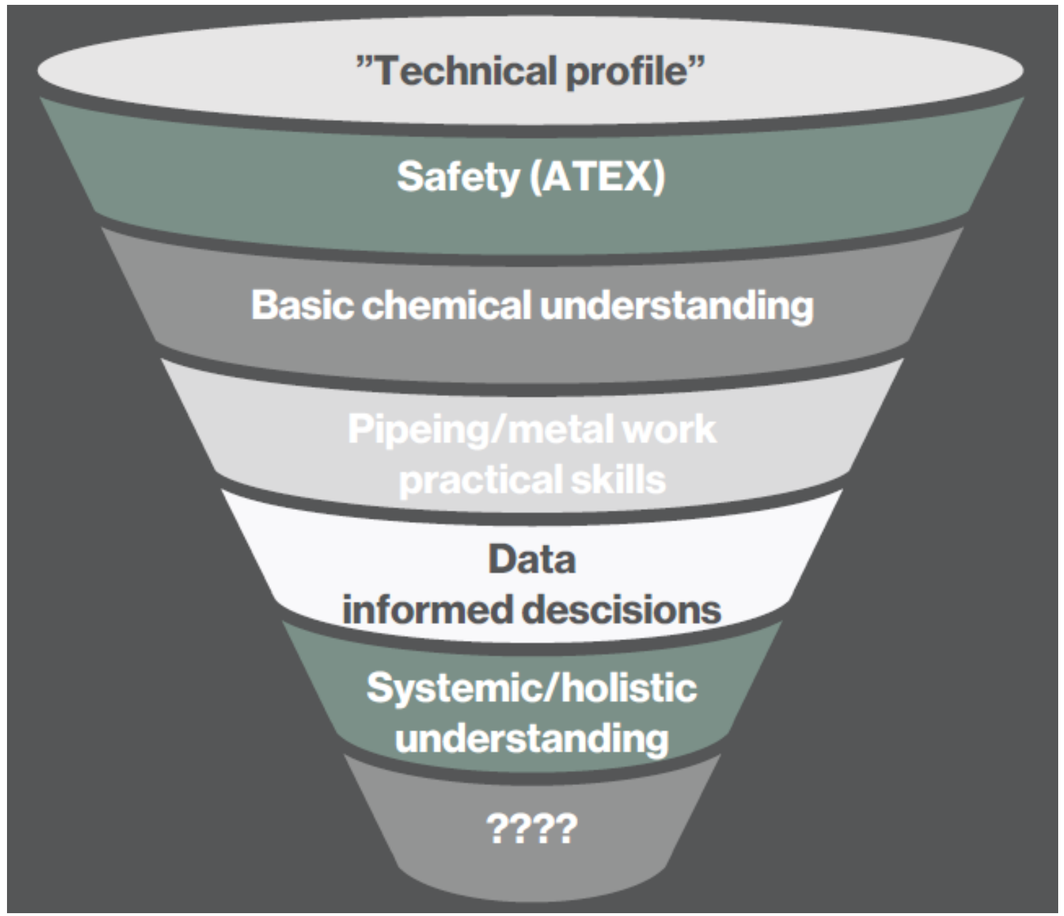
EN ISO 20471

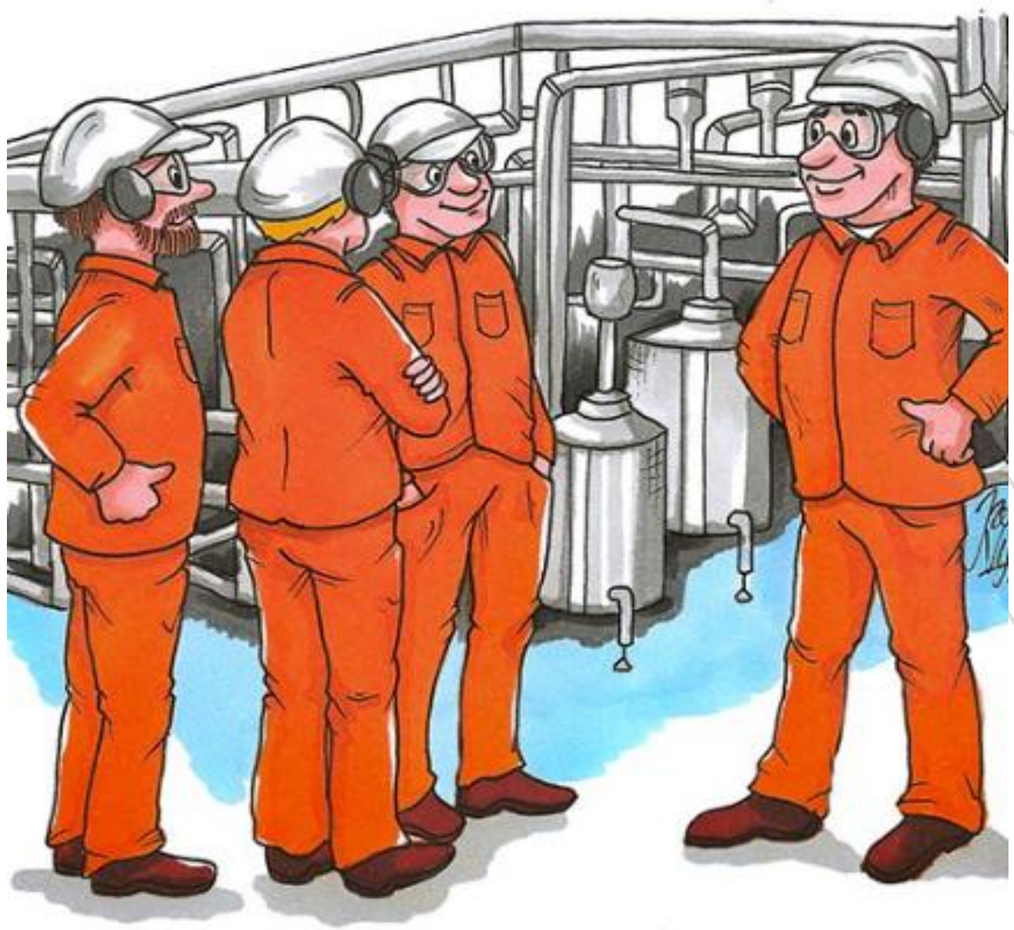
EN61482-1-2

ISO 15797

PtX employees' skills and training.

"Help wanted to put together the best profile"





Scenario - Visit to Power-to-x facility

- Participants will learn to perform a proactive visual inspection of the different elements of a Power-to-x facility. A visit to a Power-to-x facility could be planned. If not possible, the module could be supplemented by a virtuel tour to a plant: **Maade PtX** – where the same learning sceanario will be performed (as in real life).

- In the following slides, are information about HyBalance facility in Hobro, close to Hydrogen Valley.

T-shore Education

HyBalance

From wind turbine power to green hydrogen

The HyBalance project has received funding from the Fuel Cells and Hydrogen 2 Joint Undertaking under grant agreement No 671384. The Joint Undertaking receives support from the European Union's Horizon 2020 research and innovation program and France, Germany, Denmark and Belgium. www.fch.europa.eu.
The HyBalance project has furthermore received funding from the Danish ForskEL program, which is administered by Energinet.dk. www.forskel.dk

Groundbreaking ceremony for advanced hydrogen plant at Hobro

- The hydrogen factory will convert wind energy to green hydrogen as part of the HyBalance project
- The minister said: "Hydrogen is one of the technologies we will be investing in in the future. I am very pleased that Denmark is at the forefront with this plant. We are going to show that we can do something here. It's not just talk and big desk plans - it's something that comes out in the real world"

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What is HyBalance?

- HyBalance is a project that will demonstrate how hydrogen can be included in the energy system of the future
- Conversion of wind turbine power via electrolysis of water to hydrogen
- This allows wind turbine power to be stored when there is plenty of it
- At the same time, the conversion can help to balance the electricity grid, which is essential to ensure stable voltage in the grid
- Green hydrogen can be used in the transport sector and in industrial production.

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The partners in the HyBalance project

- Air Liquide, Copenhagen Hydrogen Network (CHN), Hydrogenics, Neas Energy, Hydrogen Valley, Ludwig-Bölkow-Systemtechnik

- The project is budgeted at DKK 125 million. It is supported by the ForskEL programme, managed by Energinet.dk, and the EU's Fuel Cells and Hydrogen 2 Joint Undertaking.

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Background: The EU's objectives and challenges

- The EU is committed to a long-term climate policy that prioritises a stable and independent energy supply - based on non-fossil energy sources
- The share of renewable energy will increase. Therefore, it is crucial to be able to store renewable energy and use it in sectors that have hitherto been dependent on fossil fuels – including transport
- Hydrogen is considered one of the keys to solving that challenge.

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Why has Denmark been selected for HyBalance?

- Denmark is one of the countries in the EU with the most ambitious energy policy
- In 2012, a parliamentary majority entered into the energy agreement, which states that
- 50% of Denmark's electricity consumption must be covered through wind power by 2020
- The use of fossil fuels in heating and electricity must end by 2035
- Denmark must be independent of fossil fuels by 2050
- Denmark has a lot of wind energy
- Denmark has know-how in hydrogen and fuel cell technologies
- Denmark is the first and only country in the world to have a nationwide network of hydrogen filling stations
- Hydrogen cars are exempt from taxes until 2019

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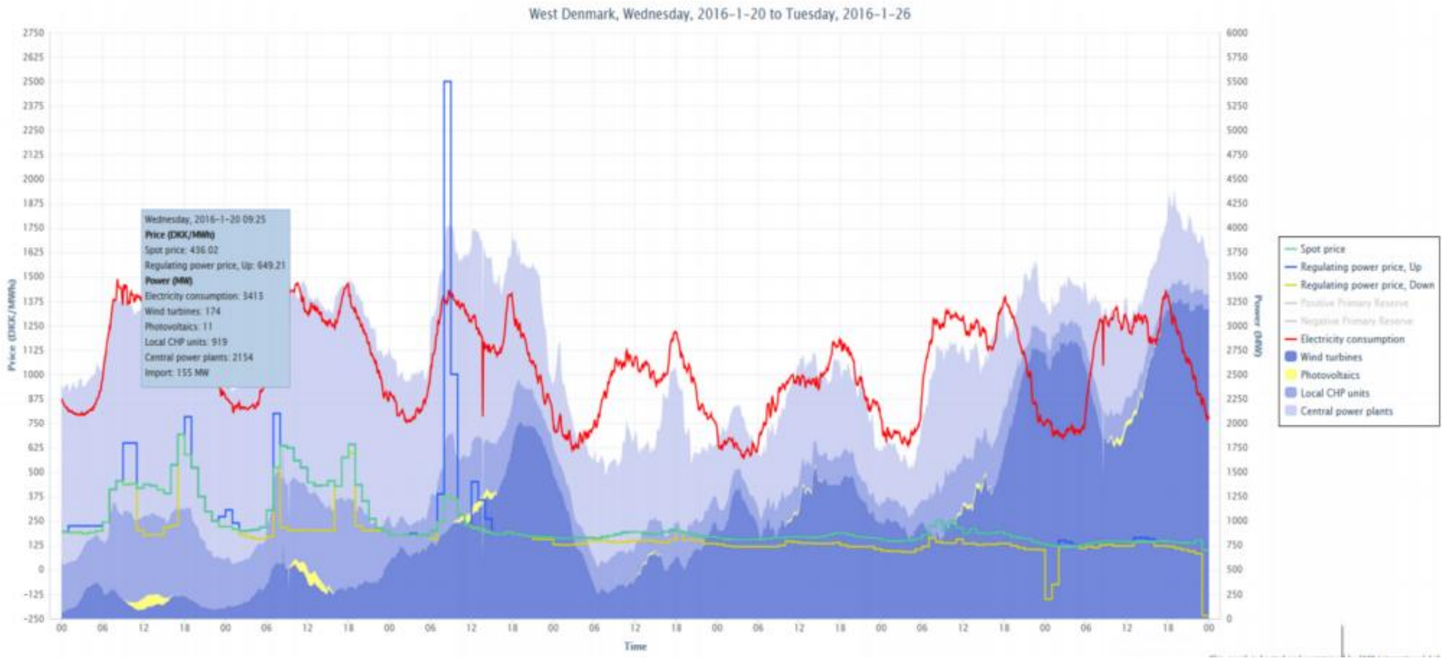
Wind turbine power will be an important source of energy

- The supply from renewable energy sources is becoming more important, and the share of green electricity from wind turbines in particular is increasing



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The necessity of balance in the electricity grid

- Wind energy is fluctuating – the electricity grid requires a stable supply
- In some periods, we can produce more electricity from wind turbines than the grid can absorb
- We can export surplus electricity production – or bring wind turbines to a standstill
- Or we can store surplus wind energy by converting it into hydrogen
- HyBalance will develop business models for when it is worthwhile to convert electricity to hydrogen

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Storage and storage of renewable energy

- By storing wind turbine energy as hydrogen, we can make optimal use of the wind turbine energy
- And we get a product – green hydrogen – that can be used in industry and in the transport sector.

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Hydrogen in the transport sector

- Hydrogen cars are on the rise
- Most major car manufacturers have hydrogen cars on their program
- Hydrogen cars only emit water, are quick to refuel and have a large driving radius compared to electric cars
- Denmark has 10 hydrogen filling stations – and plans for more filling stations

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The HyBalance process

GRID BALANCE

WATER ELECTROLYSIS

STORAGE

CLEAN MOBILITY, LOGISTICS AND INDUSTRY

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PEM Electrolysis

- PEM (Proton Exchange Membrane) electrolysis is characterised by high efficiency (hydrogen per kWh of electricity)
- The technology is flexible (short start-up time and no problems with frequent starts/stops)
- This makes PEM very suitable for balancing fluctuating energy sources
- HyBalance to validate how dynamic PEM electrolysis is

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HyBalance timetable

- In 2016, construction of the hydrogen plant begins
- From the end of 2017, the plant is expected to be able to deliver hydrogen

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Potential: Supply to the transport sector

- The plant will be able to produce 230 Nm^3/h hydrogen
- It will be able to keep 1000 hydrogen cars on the roads
- Also production for hydrogen buses and hydrogen forklifts
- There is a need for more hydrogen cars to be rolled out
- There is a need for more filling stations that can service hydrogen cars and meet the need

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Potential: Supplementing energy to the natural gas grid

- Denmark has a well-established natural gas network
- CO2 (from biogas) and hydrogen can be fused under high pressure - and can thereby form artificial methane
- The methane can be fed directly into the natural gas grid

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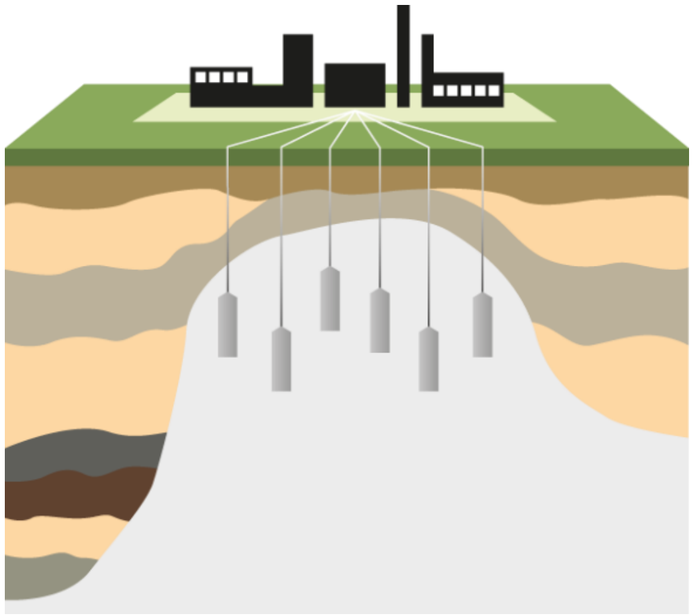
Potential: Storage of larger amounts of hydrogen

- In North Jutland, close to Hobro, there are salt caverns that can eventually be used to store hydrogen and biogas on a larger scale



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Summary: HyBalance promotes green transition

- HyBalance converts wind turbine power to hydrogen
- The hydrogen is sold to industry and the transport sector
- HyBalance uncovers business models for when it is worthwhile to convert wind turbine power to hydrogen
- HyBalance validates PEM technology
- HyBalance uncovers how hydrogen can contribute to making Denmark free of fossil energy sources

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Read more on www.hybalance.eu

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Thank you!

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