MODULE 3

HYDROGEN LOGISTICS AND SUSTAINABILITY AND ECOLOGY

How does hydrogen logistics affect the environment and how can its negative effects be minimized?

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GREENHOUSE GAS EMISSIONS ASSOCIATED WITH HYDROGEN LOGISTICS

Analysis of greenhouse gas emissions in different stages of hydrogen logistics

Comparison of CO2 emissions emissions for “green”, “blue” and “grey” hydrogen

The global impact of emissions from logistics processes on climate change.

GREENHOUSE GAS EMISSIONS ASSOCIATED WITH HYDROGEN LOGISTICS

Calculations of CO2 emissions for different methods of transporting hydrogen over a given distance.

Case study: analysis of greenhouse gas emissions associated with associated with hydrogen transportation in a selected logistics scenario.

Develop a logistics strategy that reduces greenhouse gas emissions for the selected hydrogen distribution model.

HYDROGEN AS A KEY ELEMENT IN THE ENERGY TRANSITION

Hydrogen is considered a fuel of the future - it is one of the of the solutions to **decarbonizing the economy.**

The EU plans to produce **10 million tons** of green hydrogen annually by 2030 and import another **10 million tons.**

Currently, **96%** of hydrogen is produced from fossil fuels (mainly natural gas), which emits about **900 million** tons of CO_2 per year.

TYPES OF HYDROGEN AND THEIR IMPACT ON THE ENVIRONMENT

Type of hydrogen	Energy source	CO_2 emissions.	Production costs	Technology status
Gray hydrogen	Natural gas (SMR)	High (9-11 kg CO_2 per 1 kg H_2).	Low (€1.5-2.5/kg).	Mature, dominant
Blue hydrogen	Natural gas + CCS	Average (with CCS about 2 kg CO_2 per 1 kg H_2).	Medium (€2.5-4/kg)	In the deployment phase
Green hydrogen	Renewable energy (electrolysis)	No emissions	High (€4-7/kg)	Investment growth

HYDROGEN SUPPLY CHAIN - STAGES AND KEY CHALLENGES

Production

- RES water electrolysis (green hydrogen) vs. methane reforming (gray hydrogen).
- High cost of green hydrogen production.

Storage

- Possibilities: compressed hydrogen, liquid hydrogen, chemical form (such as ammonia).
- Energy losses - compression requires about 20% of hydrogen's energy, and condensation requires up to 30%.

Transport

- Gas pipelines, road transport, sea transport, pipelines - each form has its technological and economic limitations.

Distribution and use

- Applications in industry, energy, transportation and building heating.

MAIN SOURCES OF EMISSIONS IN HYDROGEN LOGISTICS

Transport

High energy consumption in condensing and compression of hydrogen.

Production

Methane reforming (SMR) results in high CO_2 emissions.

Storage

Energy losses and low storage efficiency

CO_2 EMISSIONS IN DIFFERENT METHODS OF HYDROGEN PRODUCTION

Hydrogen production can be carried out by various methods that vary in terms of CO_2 emissions, **energy efficiency and production costs.**

Key technologies include gray, blue and green hydrogen, but new concepts such as turquoise and white hydrogen are also on the horizon.

GRAY HYDROGEN - A DOMINANT BUT CARBON-INTENSIVE PRODUCTION METHOD

Technology description:

- Produced by the Steam Methane **Reforming (SMR) process.**
- Natural gas reacts with steam to produce hydrogen and carbon dioxide.
- It currently accounts for more than **96% of the world's hydrogen production.**

Challenges:

❌ High carbon intensity - no CO_2 capture and storage.
❌ Dependence on fossil fuels - mainly natural gas.
❌ Low energy efficiency - high heat loss.

GRAY HYDROGEN - A DOMINANT BUT CARBON-INTENSIVE PRODUCTION METHOD

9-11 kg CO_2 per 1 kg H_2 (average 10 kg CO_2).

Emissions

It accounts for **2% of global CO_2 emissions.**

That's more than the emissions of the entire aviation industry!

Chemical industry (production of ammonia, fertilizers).

Refining crude oil

Examples of application

BLUE HYDROGEN - A STEP TOWARDS REDUCING CO_2 EMISSIONS

Technology description:

- Similar to gray hydrogen, but using Carbon Capture and Storage (CCS) technology - **CO_2 capture and storage.**
- CCS reduces emissions by **50-90%**, depending on the technology.

Challenges:

❌ CCS increases production costs by **30-50%.**
❌ Lack of developed infrastructure to transport and store CO_2.
❌ Need for large amounts of energy for CO_2 separation.Challenges.

BLUE HYDROGEN - A STEP TOWARDS REDUCING CO_2 EMISSIONS.

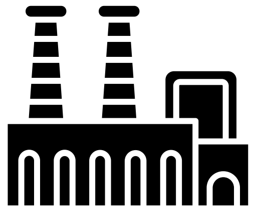
No CO_2 emissions - if energy comes from 100% RES.

Emissions

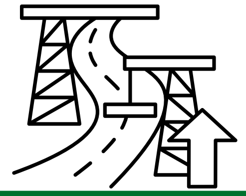
In fact, emissions can come from the process of building photovoltaic, wind or electrolyzer plants (the so-called carbon footprint of the technology).

That's more than the emissions of the entire aviation industry!

H2 Green Steel (Sweden) - producing steel using green hydrogen.



HySynergy (Denmark) - a project to integrate electrolyzers with transportation infrastructure.



Examples of application

OTHER METHODS OF HYDROGEN PRODUCTION -
FUTURE TECHNOLOGIES

Turquoise hydrogen (methane pyrolysis)

- Producing hydrogen from natural gas without emitting CO_2 - **solid carbon is produced instead.**
- **Emissions:** Close to zero (if energy comes from RES).
- **Challenges:** Still under development, limited scale of production.

Example Turquoise Hydrogen:

Monolith Materials (USA) - development of turquoise hydrogen pilot projects.

White hydrogen (natural sources of hydrogen)

- Naturally occurring hydrogen in the Earth's crust.
- **Emissions:** No CO_2 emissions if extraction is green.
- **Challenges:** Low scale of occurrence, lack of extraction technology.

Example White hydrogen:

Discoveries of natural hydrogen in Mali, the U.S. and Australia - research on exploitation possibilities.

COMPARISON OF EMISSIONS AND EFFICIENCY OF DIFFERENT HYDROGEN PRODUCTION METHODS

Type of hydrogen	Production method	CO_2 emissions (kg per 1 kg H_2).	Production cost (€ / kg)	Energy efficiency
Gray	Methane reforming (SMR)	9-11 kg CO_2	1,5-2,5 €	65-75%
Blue	SMR + CCS	2-4 kg CO_2	2,5-4 €	55-65%
GreeN	Electrolysis (RES)	0 kg CO_2	4-7 €	60-70%
Turquoise	Pyroliza metanu	Close to zero	3-5 €	75-85%
White	Natural sources of hydrogen	0 kg CO_2	Unknown	Unknown

CHALLENGES IN HYDROGEN TRANSPORTATION - GAS PIPELINE

CHALLENGES:

- ChallengesHydrogen causes hydrogen embrittlement - weakens pipelines, requiring special materials.
- High conversion costs - upgrading gas pipeline networks requires an investment of €5-15 million per km.
- Limited availability of dedicated pipelines - currently most infrastructure is adapted to natural gas.

BENEFITS:

- Ability to integrate with existing gas infrastructure.
- Potentially the cheapest form of long-distance hydrogen transportation.

EXAMPLE:

- The European Union plans to create a European Hydrogen Network by 2030, including 28,000 km of gas pipelines (70% are converted gas pipelines).

CHALLENGES IN HYDROGEN TRANSPORTATION - CRYOGENIC TANKERS

CHALLENGES:

- High energy consumption - liquefying hydrogen requires cooling to -253°C, which consumes up to 30-40% of hydrogen energy.
- Boil-off losses - liquid hydrogen undergoes slow evaporation, resulting in losses of 1-2% per day.
- Specialized cryogenic tanks - high price and limited number of manufacturers.

BENEFITS:

- Flexible transportation to locations without pipeline infrastructure.
- Relatively well-developed technology.

EXAMPLE:

- Air Liquide transports liquid hydrogen by cryogenic tankers to refueling stations in Europe.

CHALLENGES IN HYDROGEN TRANSPORTATION - LOHC

CHALLENGES:

- The process of hydrogen release (dehydrogenation) requires additional energy, which reduces efficiency.
- LOHC is in the testing phase - no widespread commercialization.
- Material issues - need to use appropriate chemicals for hydrogen storage (e.g., toluene, dibenzyltoluene).

BENEFITS:

- Can be transported at room temperature and normal pressure.
- Can use existing fuel infrastructure.

EXAMPLE:

- LOHC technology being developed by Hydrogenious LOHC Technologies - first pilot installations in Germany.

OPTIMIZING HYDROGEN TRANSPORTATION ROUTES USING AI AND BIG DATA

Technology application:

- **Artificial intelligence (AI)** analyzes hydrogen transportation data in real time and proposes the most efficient delivery routes, minimizing travel time and energy consumption.
- **Big Data** makes it possible to analyze large data sets related to weather conditions, traffic volume and the efficiency of different modes of transportation.
- **IoT (Internet of Things) -** smart sensors monitor pressure, temperature and energy consumption during hydrogen transportation, enabling optimal delivery management.

OPTIMIZING HYDROGEN TRANSPORTATION ROUTES USING AI AND BIG DATA

Challenges:

- Need for advanced digital infrastructure that integrates logistics systems across countries.
- High cost of AI and IoT deployment - investments in data analytics systems require large amounts of money.

Examples of implementations:

- **H2Haul project** - uses AI to optimize hydrogen truck transport routes in Europe.
- **Siemens Digital Logistics** - develops platforms to monitor hydrogen logistics in real time.

USE OF RENEWABLE ENERGY SOURCES IN HYDROGEN COOLING AND COMPRESSION SYSTEMS

Technology solutions

- **Solar-powered cooling systems** - reduces the consumption of fossil-fuel electricity in the hydrogen liquefaction process (-253°C).
- **Use of wind turbines to power hydrogen compressors** - reduces CO_2 emissions in the process of compressing hydrogen gas to 700 bar.
- **Intelligent energy management systems** - automatic regulation of cooling and compression processes based on the availability of renewable energy.

USE OF RENEWABLE ENERGY SOURCES IN HYDROGEN COOLING AND COMPRESSION SYSTEMS

Challenges:

- Lack of adequate RES-integrated hydrogen infrastructure in many regions of the world.
- Variability of renewable energy production - need for energy storage systems.

Examples of implementations:

- **H2 Green Steel (Sweden)** - a hydrogen steel plant using only renewable energy to produce and transport hydrogen.
- **HySynergy (Denmark)** - a project integrating RES electrolyzers with hydrogen transportation infrastructure.

MODERN CCS (CARBON CAPTURE AND STORAGE) METHODS IN HYDROGEN PRODUCTION

CO_2 capture technologies for hydrogen production:

- **Pre-combustion capture** - capturing CO_2 before fossil fuels are burned in the methane reforming (SMR) process.
- **Post-combustion capture** - technology used in refineries and power plants to reduce CO_2 emissions from fuel combustion.
- **CO_2 mineralization technologies** - conversion of CO_2 into solids (e.g., carbonates) for long-term storage.

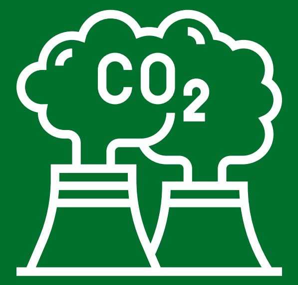
MODERN CCS (CARBON CAPTURE AND STORAGE) METHODS IN HYDROGEN PRODUCTION

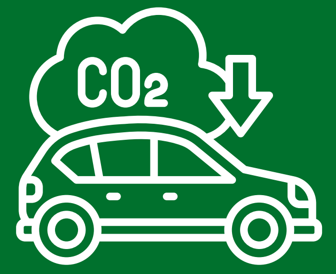
Challenges:

- **High capital costs** - CCS implementation increases the price of hydrogen produced from fossil fuels by 30-50%.
- **Limited availability of CO_2 storage infrastructure** - need to expand underground CO_2 storage.

Examples of implementations:

- **Northern Lights Project (Norway)** - transport and storage of CO_2 in undersea geological formations.
- **Shell Blue Hydrogen (Netherlands)** - application of CCS in the production of blue hydrogen.





HYDROGEN STORAGE - EFFICIENCY AND ENERGY LOSS

Hydrogen storage is one of the key technological challenges of its large-scale application. The efficiency of this process depends on the storage method, energy consumption and losses due to storage technology.

STORAGE OF HYDROGEN IN COMPRESSED FORM

Technology description:

- Hydrogen is compressed to **200-700 bar** and stored in high-pressure tanks.
- This is currently one of the most widely used methods for storing hydrogen, such as in hydrogen vehicles.
- It requires special carbon fiber and metal composite tanks that can withstand high pressure.

STORAGE OF HYDROGEN IN COMPRESSED FORM

Benefits:

- Technology well developed and commercially available.
- Rapid refueling of hydrogen in vehicles (e.g. trucks, buses, cars).
- Does not require cooling to extremely low temperatures.

Challenges:

- Energy losses: Compressing hydrogen consumes 15-20% of its energy.
- Safety: High pressure carries the risk of leaks and explosions.
- Large storage volume: Compressed hydrogen takes up much more space than liquid hydrogen.

STORAGE OF HYDROGEN IN COMPRESSED FORM

Application examples:

- **Hydrogen vehicles** - Toyota Mirai cars, Hyundai Nexo, Nikola trucks.
- **Industrial storage of hydrogen** in high-pressure cylinders.

THANK YOU FOR YOUR ATTENTION

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