

ELEMENTS OF HYDROGEN SYSTEMS AND STORAGES

Dr. Zhengmao Li
Assistant Professor

A''

Aalto-yliopisto
Aalto-universitetet
Aalto University



Introduction



A/P. Li Zhengmao

<https://people.aalto.fi/zhengmao.li>

Education Background

2009-2016 **Shandong University** B.Eng. & M.Eng.
School of Electrical Engineering
2016-2020 **Nanyang Technological University** Ph.D.
School of Electrical and Electronic Engineering
2020-2023 **Stevens Institute of Technology & ETH Zurich** Postdoc
Department of Electrical & Computer Engineering
2023-Now, Dr. Li joined **Aalto University** as an Assistant Professor.

Research Interest

Optimal Planning and Operation of Multi-energy systems (MES):

1. Planning and operation of MES, i.e., **microgrids, ships, seaports, buildings**, etc., with power, heat, water, and hydrogen networks.
2. Tackling diverse uncertainties from **renewable** energies, outdoor temperature, hydrogen prices, etc.
3. Online **data-driven** operation of MES with machine learning or reinforcement learning methods.
4. **Market mechanism** design with electric vehicles and **P2P trading**.
5. **Resilience** enhancement with the support from transportation and reconfiguration.

Google scholar



Li Zhengmao

Aalto University, Finland, Assistant Professor
在 aalto.fi 的电子邮件经过验证 - 首页

multi-energy system smart grid ship and building uncertainty handling

ResearchGate



Zhengmao Li Edit

Doctor of Engineering · Professor (Assistant) at Aalto University
Espoo, Finland | Website

99 Currently an Assistant Professor at Aalto University, Finland

MESPO (Multi-Energy System Planning & Operation) Research Team

<https://research.aalto.fi/en/organisations/multi-energy-system-planning-and-operation>

New Team Formed on Hydrogen



Supervisor



Li Zhengmao, Assistant Professor

Research Areas: multi-energy systems (ships, microgrids, buildings, etc.), green hydrogen, heat and cooling, electricity, low carbon, machine learning, optimization

Citation: 2029; 6 High cited papers; TOP 2% researcher, Best reviewer

Students (all with hydrogen)

PhD students:

Fei Zhineng (Green ships and shipboards)
Jia Xueyong (Data-driven Green energy systems)
Saeid Amanpour (Green seaport with port cranes)

Co-supervised students and RA(masters):

Li Zhongtian (Green airport with wind power)
Li Wanhao (Green rural microgrids)
Zhu Xinghan (Forecasting for green energy systems)
Xu Yang (Green energy trading and market)

Course Designed on Hydrogen System

ELEMENTS OF HYDROGEN SYSTEMS AND STORAGES

Dr. Zhengmao Li
Assistant Professor



Course Name

Element of Hydrogen Systems and Storages

Responsible Teacher

Dr. Zhengmao. Li

Course Schedule

Spring, 2024

Course General Content

- Basic units in the hydrogen system
- Electrolyzer (power to hydrogen)
- Hydrogen in traditional energy system
- Hydrogen Economy
- Low carbon with hydrogen
- Hydrogen System Future

Invited Guest Lecture

Optimization of Microgrids @ NTU Singapore



A Special Issue Hosted on Hydrogen



electronics

IMPACT
FACTOR
2.9

an Open Access Journal by MDPI

Special Issue "[Hydrogen and Fuel Cells:
Innovations and Challenges](#)"

Guest Editor



Prof. Dr. Zhengmao Li
Department of Electrical Engineering and
Automation, Aalto University, FI-00076
Aalto, Finland

Email: zhengmao.li@aalto.fi

<https://people.aalto.fi/zhengmao.li>

Journal lists for editor positions

- IET Renewable Power Generation
- IET Energy Conversion and Economics
- Frontiers in Energy Research
- Energies
- IET Smart Grid
- Electronics

Master thesis!

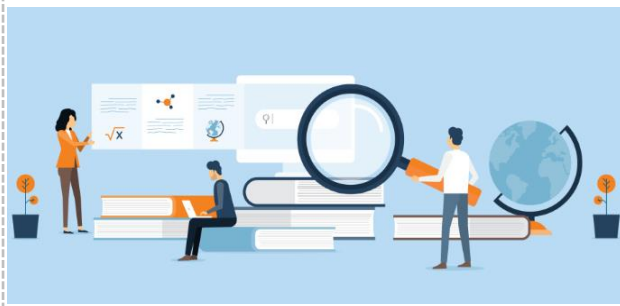
MESPO (Multi-energy System Planning & Operation) Research Team

<https://research.aalto.fi/en/organisations/multi-energy-system-planning-and-operation>

Research Outcomes on Hydrogen

Activities Attended on Hydrogen

Academic Exchanging on Hydrogen



Journal paper

1. R. Zhang, Y. Chen, **Z. Li***, et al, "Two-stage Robust Optimal Dispatch of Electricity-Gas-Heat Integrated System Considering Heterogeneous Uncertainty" IEEE Trans Sustain. Energy (submitted), 2023.

Conference paper

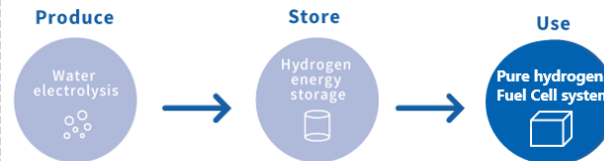
1. **Z. Li**, Z. Shi, G. Ruan, et al, "Resilience-oriented Operation of Power Distribution Networks with Line Hardening and Comprehensive Reconfiguration Measures", USA.
2. Z. Fei, **Z. Li**, "Coordinated Operation of A Green Multi-Energy Ship Microgrid with Hydrogen and Seawater Desalination" IEEE International Conference on Communications, Control, & Computing Technologies for Smart Grids, 2024 (Accepted).

Workshops

1. Modelling H₂ & Decarbonisation with PLEXOS
2. Nordic Roadmap Workshop
3. Aalto H₂ networking workshop
4. Hydrogen Breakfast Series introductory event
5. IEEE SmartGrid Communication 2024

Seminars

1. Prospects for the hydrogen economy and regional hydrogen cooperation in the CEE and the Baltic Sea



Invited talk with International Guests

Guest: R. Leng.

Topic: Two-stage stochastic programming for coordinated operation of distributed energy resources in unbalanced active distribution networks with diverse correlated uncertainties

Guest: Y. Shang.

Topic: Towards scalable and privacy-preserving distributed vehicle-to-grid services

Guest: Y. Yang.

Topic: Resilience analysis for interdependent power and water systems

Guest: M. Bai.

Topic: Forecast of PV generation with weather Information

MESPO (Multi-energy System Planning & Operation) Research Team

<https://research.aalto.fi/en/organisations/multi-energy-system-planning-and-operation>



Hydrogen-related Conference Attended

Funding Application & Collaboration

More Hydrogen Information Sharing



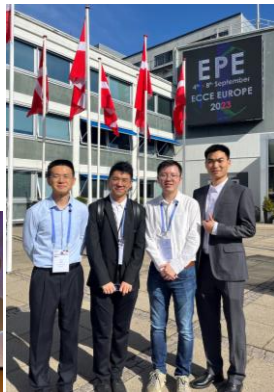
IEEE SG comm UK



ISGT EU France



ECCE EPE, Denmark



Hydrogen Based Funding to be Applied

- 1: AKA Mobility calls
w. Prof. Zhu Jizhong (IEEE Fellow) at SCUT
Title: Optimal Coordinated Operation of Multi-energy Microgrids with Green Hydrogen Technology
- 2: Early Career Funding
- 3: Business of Finland
Title: Green Ship Energy Management with Hydrogen

Potential Hydrogen Collaborations

- 1: Nanyang Technological University
w. Prof. Xu Yan
- 1: Aalborg University
w. Prof. Josep M. Guerrero (IEEE Fellow)
- 2: Konecranes, Finland
Under Zero4 project
- 3: The Hongkong Polytechnic University
w. Prof. Yan Jinyue (Chief editor of Applied Energy)



The video from MESPO Group (w. subtitle):



Low Carbon Hydrogen Economy in Denmark

<https://mp.weixin.qq.com/s/lilH2X7jpmRC84IplVKhyA>

What is Hydrogen System ?

- Hydrogen is a kind of **energy**.
- A hydrogen system is a form of **energy system** like the power system, thermal system, water system.
- It typically consists of hydrogen **generation**, **transmission**, **storage** and **consumption**.
- There are mainly three types of hydrogen: black, **blue** and **green**.

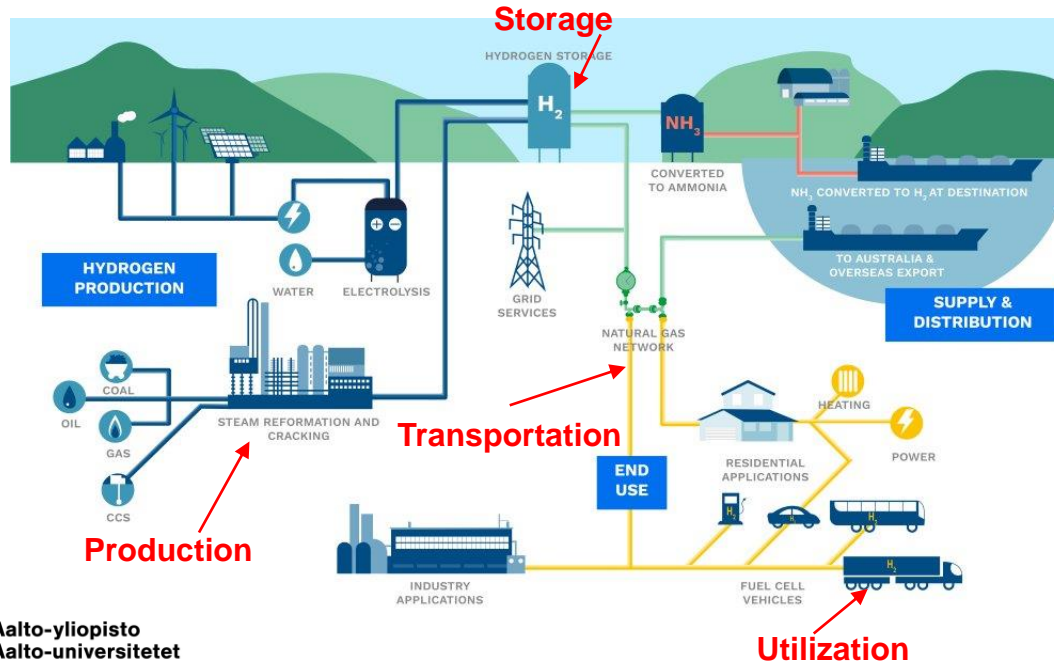


Fig.1 A general structure of hydrogen system

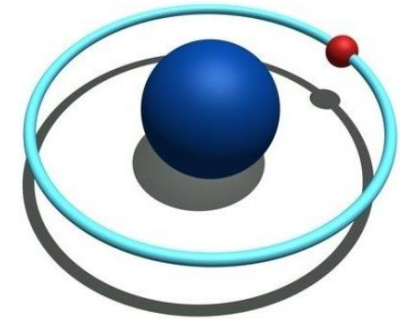


Fig.2 Element

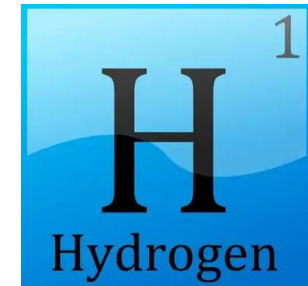


Fig.3 1st periodic table of elements

What is Hydrogen Storage ?

- ❖ Energy storage can store **excess** energy (generation is **larger** than the demand), then it will compensate for the energy **deficiency** (generation is **lower** than the demand).
 - ❖ Hydrogen storage is form of energy storage in which the energy carrier is **hydrogen**.
 - ❖ The **input** is hydrogen (charge), the **storing media** is hydrogen (storage), and the **output** is hydrogen(discharge)
- *** The primary function is **balancing** the generation & consumption.

The hydrogen value chain

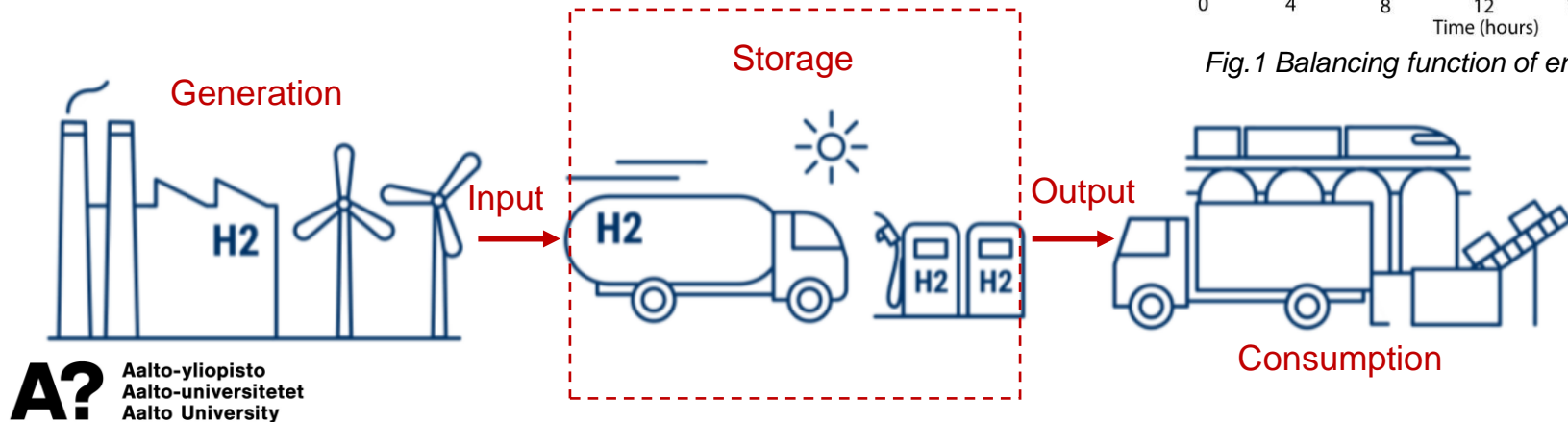


Fig.2 The hydrogen value chain with the storage system

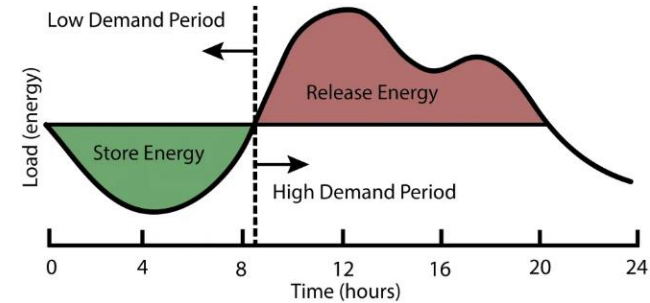


Fig.1 Balancing function of energy storage

Why Hydrogen?

1: High density (efficient):

- as the first element of the periodic table, hydrogen has **high** energy density.
- compared with other forms of energy, there will be **reduced** tank space.
- the conversion of hydrogen into mechanical or electrical energy is **efficient**.

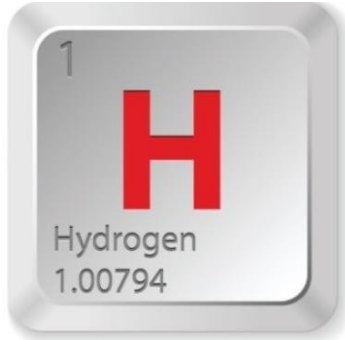


Fig.1 First element
(lightest & smallest)



Fig.2 High density

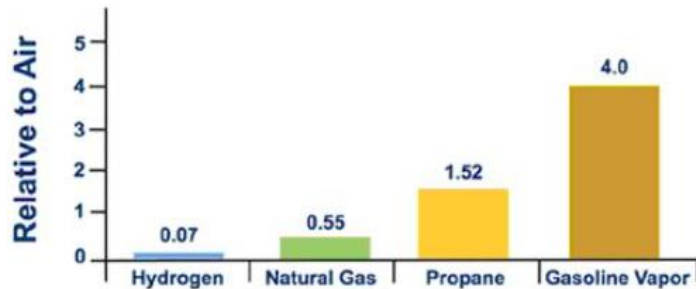


Fig.3 Light weight

Fuel	Energy density (MJ/kg)
Hydrogen	119.7
Natural Gas	45.8
Petrol	44.8
Diesel	42.5

Source (Yip et al. 2019).

Fig.4 High efficiency

Why Hydrogen?

2 Clean (environmentally friendly):

- ❖ Hydrogen is a **clean** energy carrier: only byproduct is **water**, does not produce greenhouse gases or contribute to air pollution, reduce carbon emissions and combat climate change.
- ❖ The generation media for **green hydrogen** is only **water**
- ❖ The electricity to generate **green hydrogen** is **renewable energy sources**.

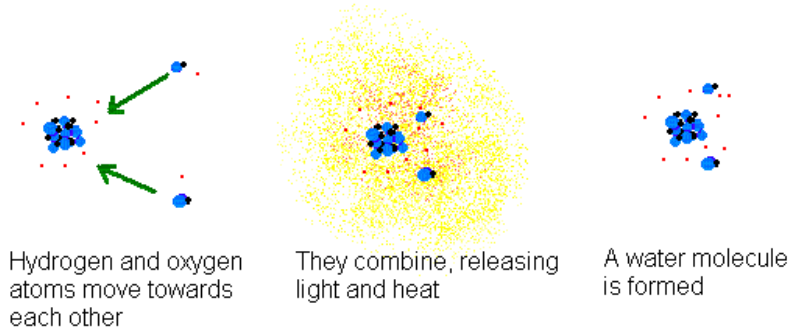


Fig.1 Hydrogen consumption

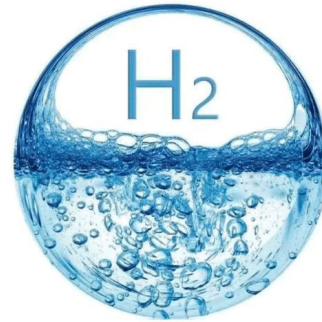


Fig.3 Hydrogen and water

*** Green Hydrogen!**

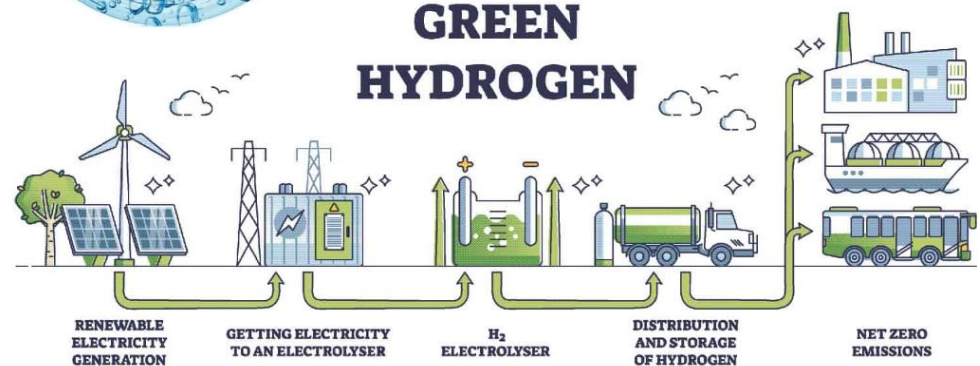


Fig.2 Green hydrogen

Why Hydrogen?

3 Low self-decay rate when stored:

- ❖ hydrogen can be stored in tanks with high pressure and low self-decay (degradation) rate.
- ❖ suitable for long term storage such as seasonal storage.

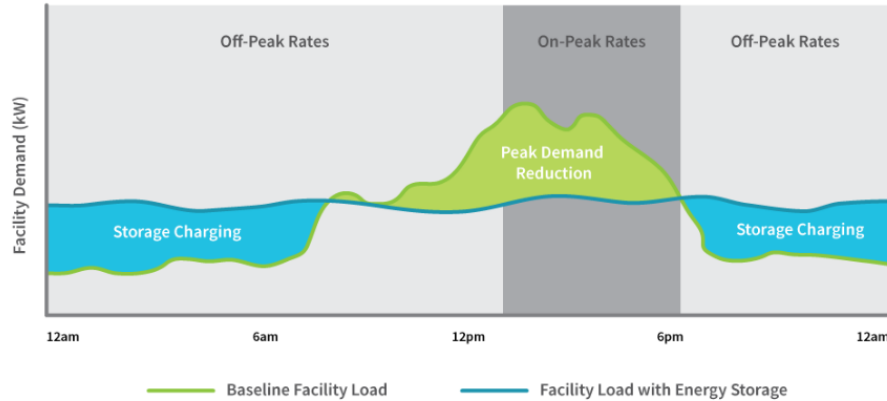


Fig. 1 Short term (daily) storage



Seasonal storage is a form of storage typically accommodating yearly cycles in demand and generation. It stores energy during one seasonal condition (summer or winter) and discharges the stored energy in the other seasonal condition.

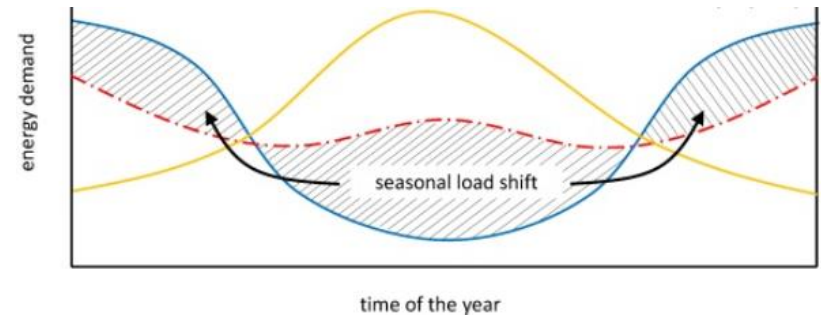


Fig. 1 Long term (seasonal) storage

Current condition of hydrogen?

Hydrogen has been gaining worldwide attention as a **clean** and **sustainable** resource, several countries were actively investing in hydrogen technologies and infrastructure.

- **Europe:** The European Union has identified hydrogen as a critical part of its **clean energy transition**. The European Commission unveiled its Hydrogen Strategy in July 2020, with plans to scale up hydrogen production, transport, and use across various sectors. The EU aims to install at least 6 GW of renewable **hydrogen electrolyzers** by 2024 and up to 40 GW by 2030.
- **Asia:** Japan launched its Basic Hydrogen Strategy in 2017 and aims to establish a "**hydrogen society**" by 2050. South Korea targets the production of 6.2 million **fuel cell vehicles** and the establishment of 1,200 refueling stations by 2040. China has set hydrogen as a priority in its energy strategy. China is investing heavily in research, and deployment of hydrogen technologies, including **fuel cell vehicles** and **hydrogen-powered trains**.
- **North America:** In the U.S., states have established hydrogen strategies and pilot projects. The U.S. Department of Energy has also launched the **H2@Scale initiative** to advance affordable hydrogen production, storage, distribution, and utilization. Canada has committed to developing a **hydrogen economy** and launched the Hydrogen Strategy for Canada in December 2020.
- **Australia:** Australia has vast renewable energy resources, and it has been actively exploring hydrogen as a means of exporting clean energy. The Australian government released a **National Hydrogen Strategy** in 2019, with a vision to develop a globally competitive hydrogen industry.

Hydrogen in Europe

Current production capacity.

- 12 Mt/year, mostly based on natural gas.
- 0.2% based on water electrolysis (capacity:200-500MW)

2030 Clean hydrogen target.

- 10Mt/year own production (plus 10Mt/year imports).
- Deploy 40 GW of electrolyzers capacity in 2030
(in practice about 140GW needed to produce 10 Mt/year)

2050 scenarios

- Electrolyser capacity 500-1000GW.



Hydrogen
Europe

Hydrogen in Finland

Current production capacity.

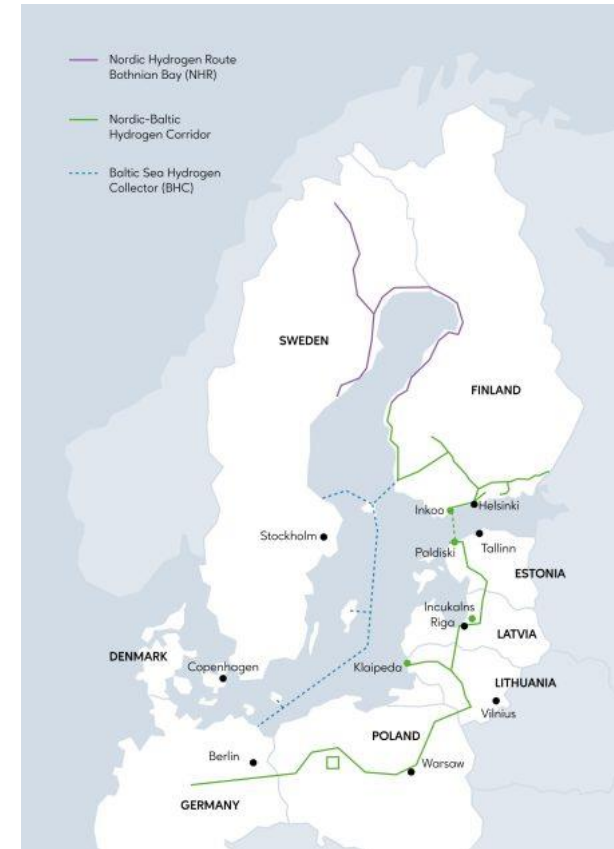
- 0,5 Mt/year.
- 99% based on natural gas

2030 Clean hydrogen target.

- At least 10% of EU's production
- Production of 1 Mt consumes 50TWh of electricity (assumes efficiency of 80%)

Finland has several strengths in the hydrogen economy

- Wind, infrastructure, water, biomass, industry, use for heat.



Current applications of hydrogen?

❖ Fuel Cells:

- Hydrogen fuel cells to generate **electricity** by combining **hydrogen** and **oxygen**, with **water** being the only byproduct.
- Fuel cells are being used in **transportation**, including cars, buses, and trains, as well as in stationary applications like backup power systems.

❖ Transportation:

- Hydrogen is an alternative fuel for transportation (**high density**). Especially for supporting other areas lack of energy (**resilience**)

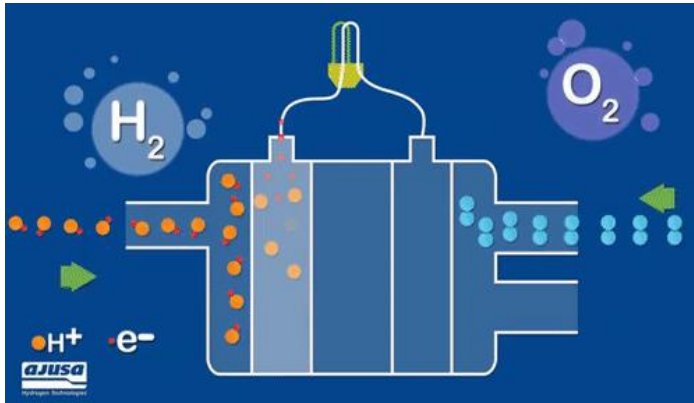


Fig.1 Fuel Cells



Fig.2 Hydrogen Transportation

Current applications of hydrogen?

❖ Energy Storage:

- Hydrogen can be used as an **energy storage medium**.
- Excess electricity generated from renewable sources, such as wind and solar, can be used to produce hydrogen through electrolysis.
- The stored hydrogen can then be used in fuel cells or converted **back to electricity** when needed.

❖ Industrial Processes:

- Hydrogen is a **feedstock** in industrial processes:
- production of **ammonia** for fertilizers, methanol for **chemicals** and **fuels**, and the **refining of petroleum** products, reduce emissions in industries such as **steel and cement manufacturing**.



Fig.1 Hydrogen energy storage

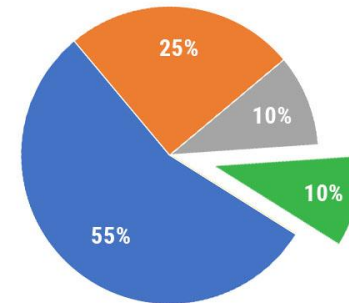


Petroleum Refining
25%



Ammonia Production
55%

GLOBAL HYDROGEN CONSUMPTION
BY INDUSTRY



Data from Hydrogen Europe (hydrogeneurope.eu/hydrogen-applications)
Illustration © WHA International, Inc. (wha-international.com)



Methanol Production
10%



Other
10%

Fig.2 Hydrogen for industrial process

Current application of hydrogen?

❖ Power Generation:

- Hydrogen is a **fuel** for power generation in gas turbines or combined cycle power plants.
- This can help reduce carbon emissions, especially when produced from renewable sources (**green**).

❖ Heat and Cooking:

- Hydrogen can be used for **heating applications** in residential and commercial buildings.
- It can also be used for **cooking**, like natural gas, by utilizing hydrogen-powered stoves and appliances.

❖ Hydrogen Infrastructure:

- hydrogen **refueling** stations, pipelines for transportation, and storage facilities, to support widespread adoption of hydrogen technologies.



Fig.1 Heat and cooking



Fig.2 Hydrogen driven cars



Fig.3 Hydrogen Rocket



Fig.4 Hydrogen Plant

Career Prospect of hydrogen major?

The career development prospects for hydrogen major are quite **promising**, given **the growing global interest** in clean energy and the **potential of hydrogen** as a key component of the transition to a **sustainable** energy future.

➤ **Research and Development (researchers):**

- Professionals with expertise in hydrogen can contribute to the ongoing research and development efforts.
- Research **scientists**, **engineers**, and **technicians** are in demand to develop innovative solutions.

➤ **Renewable Energy and Power Generation (specialists):**

- As the demand for renewable energy increases, there will be a need for **specialists** who can design, operate, and maintain hydrogen production facilities.

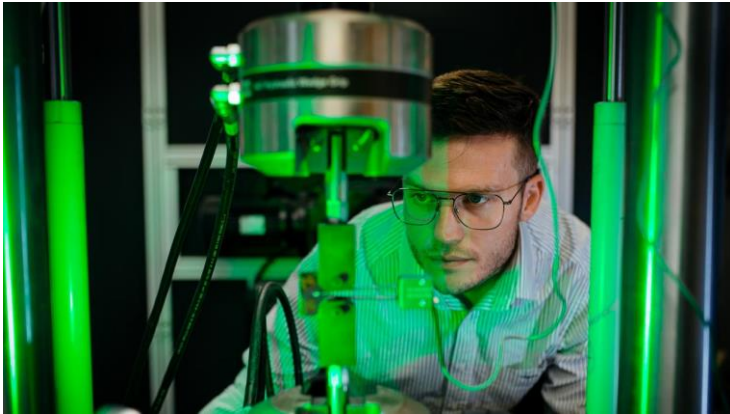


Fig.1 Researchers on green hydrogen



Fig.1 Specialists for renewables with green hydrogen

Career Prospect of hydrogen major?

➤ Energy Storage and Grid Integration (specialists):

- Careers in energy storage involve **designing and developing hydrogen storage systems**.
- This field requires skills in **engineering, project management, and system design**.

➤ Hydrogen Infrastructure (specialists):

- Careers in hydrogen infrastructure involve **planning, designing, and implementing** hydrogen refueling stations, pipelines, storage facilities, and transportation systems.
- This includes roles in **engineering, construction, project management, and policy development**.

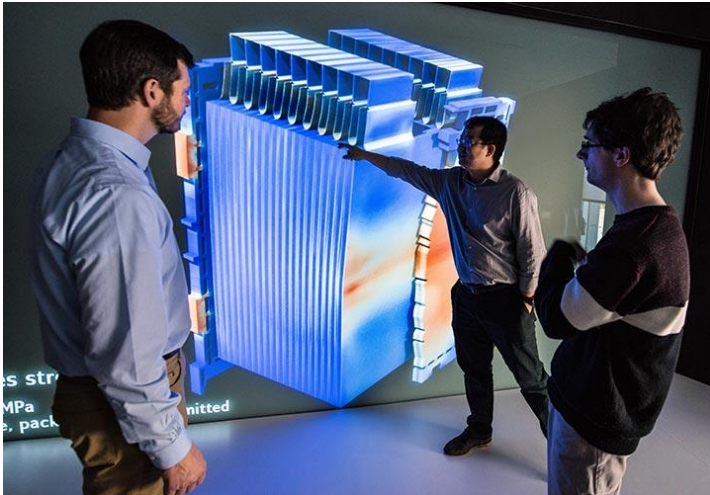


Fig.1 Hydrogen system designer



Fig.2 Hydrogen infrastructure operator

Career Prospect of hydrogen major?

➤ Policy and Advocacy (Officers):

- Governments are increasingly recognizing the importance of hydrogen as part of their decarbonization strategies.
- **Professionals** in policy and **advocacy roles** can work on shaping hydrogen-related policies, regulations, and incentives. They can also contribute to **market analysis**, **technology assessments**, and the **promotion** of hydrogen as a viable energy solution.

➤ Consulting and Advisory Services (consultants):

- As the hydrogen industry evolves, there will be a need for **consultants** and **advisors** who can provide expertise and guidance to businesses, governments, and organizations.
- These professionals can assist with **technology evaluation**, **market analysis**, **feasibility studies**, **project development**, and **investment strategies** related to hydrogen.



Fig.1 Government officer or advocate for green energy



Fig.2 Consultants or advisors

Career Prospect of hydrogen major?



It's worth noting that the hydrogen industry is still in its **early stages!**
Aalto is leading in the development of hydrogen system and hydrogen economy!
The career landscape is **rapidly evolving** with a **huge and bright** job market!



**BUSINESS
FINLAND**



A? Aalto-yliopisto
Aalto-universitetet
Aalto University

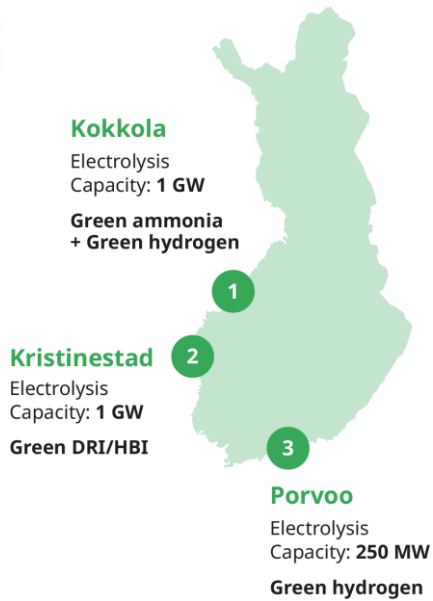


Fig.1 Novel Finnish hydrogen projects

Hyfindr

Growing the Hydrogen Economy

Executive Guide

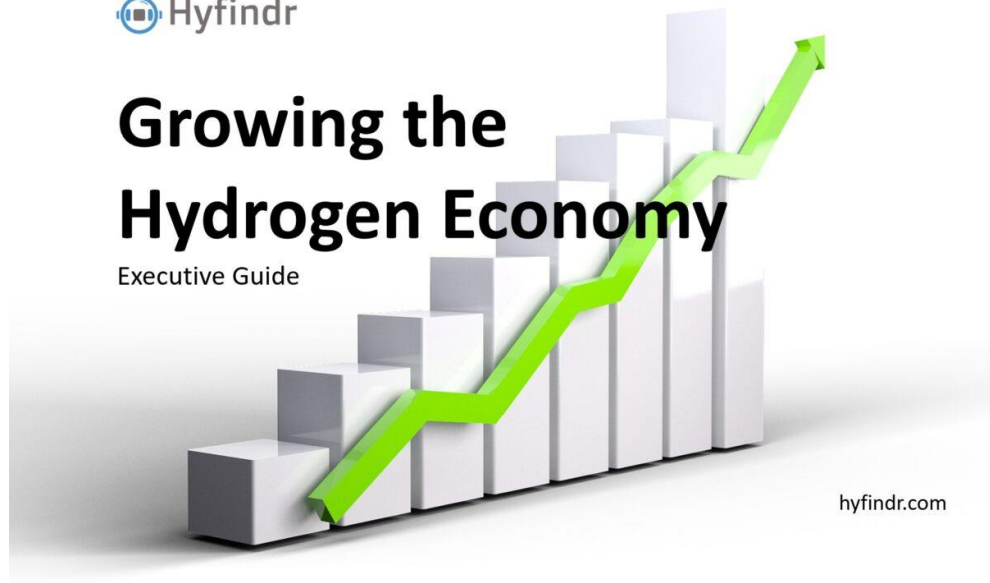


Fig.2 Worldwide growing hydrogen economy

Course Content

1

Electrolysers

2

Tubework & H₂ transportation

3

H₂ storages

4

Compressors

5

H₂ tubework physics & dynamic phenomena

6

Material questions

7

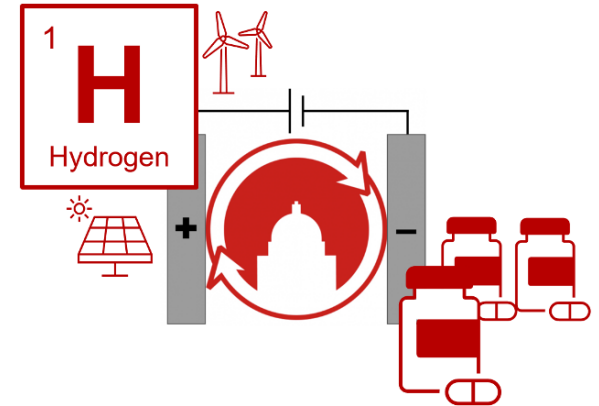
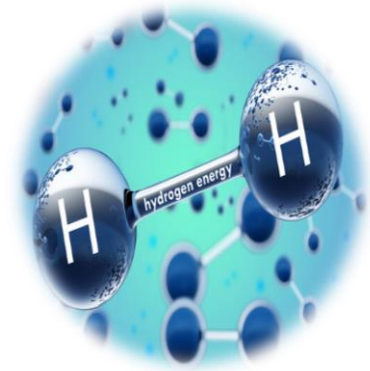
Safety questions

8

H₂ use cases & their influence on H₂ tubework

9

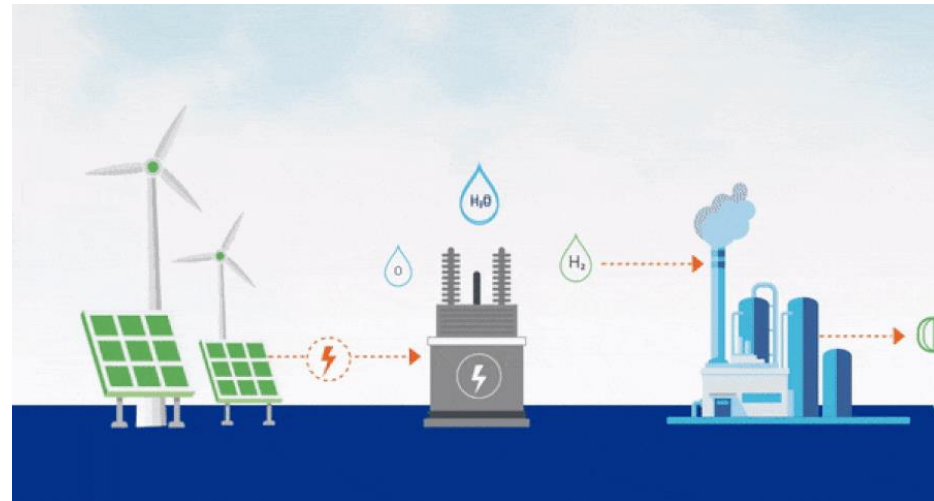
Integration of the power system and hydrogen system.



Learning Outcomes

After completing this course, our graduates could get the following abilities (but not limited to)

1. **classify** and **evaluate** the technologies in the hydrogen value chain.
2. **model** and **conduct analyses** on the functionality and societal impacts of hydrogen technologies.
3. **analyze** and **evaluate** the role of hydrogen components at different stages
4. **apply** the principles of capturing, storing, and usage of hydrogen.
5. **analyze** and **develop** the components and feasible technical solutions
6. **identify**, **create**, and **push forward** new business opportunities.
7. **manage** uncertainties when dealing with future challenges.
8. **know** how to **analyze** the dynamic and steady-state behavior.



Course Assessment (Tentative)

A. Continuous Assessment---Exercises

- Assignments
- Literature review
- Small Projects
- Basic Performance (Bonus)



B. Practical Projects---Projects

- Individual Project
- Group projects



easy

C. Final Test---Tests

- Exam test

