IEA Bioenergy
Technology Collaboration Programme

Workshop summary and scoping report

Deployment perspective of green hydrogen from biomass and green hydrogen use in bio-based processes

IEA Bioenergy: Task 40: 06 2023

WP1 deliverable of IEA Bioenergy inter-Task project 'Synergies of green hydrogen and bio-based value chains'

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The expert workshop has been organised by IEA Bioenergy Task 40 in collaboration with IEA Bioenergy Tasks 32, 33, 34, 36, 37, 39, 42, 44, and 45.

Date: 29 March 2023 **Place**: BMEL Berlin, hybrid

Note: Presentations available as additional document.

BACKGROUND

As part of the IEA Bioenergy inter-task project (ITP) on “Synergies of green hydrogen and bio-based value chains deployment” an expert workshop with the focus on the deployment perspective of green hydrogen from biomass and green hydrogen use in bio-based processes. The objective is 1) to describe possible value chains combining hydrogen production (feedstocks, technologies, products) and deployment of hydrogen and bio-based processes (feedstock, technologies, products) for different bio-based end-products, and 2) based on this to discuss as well as agree on terminology, key process data and definitions on criteria, indicators and boundaries, and an assessment framework as project scoping activity.

The workshop has been organized by IEA Bioenergy Task 40 “Deployment of biobased value chains” in collaboration with 9 other IEA Bioenergy Tasks. This workshop belongs to work package 1 of this inter-task project which deals with the status quo of synergy value chains. The overall inter-task project is coordinated by IEA Bioenergy Task 44 “Flexible bioenergy and system integration”.

The workshop was an expert meeting where different stakeholders from among others industry, academia and linked IEA TCPs have been invited. It has been organized as a hybrid event in Berlin, Germany, with online participation and was hosted by the German Federal Ministry of Food and Agriculture. A total 29 of experts took part and 9 guest speakers presented their industrial and academic view.

The meeting had been divided into two sessions. One focusing on discussing actual concepts for producing green hydrogen from biomass and using green hydrogen in bio-based processes (industry session). And the other focusing on the assessment and role of these potential concepts in the energy system (science session).

In the industry session potential value chains combining hydrogen production and deployment of hydrogen and bio-based processes for different bio-based end-products, including technologies at different development stages. This was followed by a discussion on the status of their deployment perspective. Here different concepts have been presented and then further explored during a moderated open discussion. The IEA Hydrogen TCP and the IEA AMF TCP Task 64 gave their views on the presented concepts as well as a general assessment on the role of biomass-based hydrogen.

There was agreement that the demand for green hydrogen will increase in the future. Therefore, it is important to understand how biomass-based processes can complement water electrolysis-based hydrogen production. Biomass-based hydrogen is currently overlooked in the ‘hydrogen rainbow’. Hence, to identify the role and potential but also limitations of biomass-based hydrogen use is key. Here best practices can provide valuable insights to address the following main aspects 1) technology readiness level, 2) adaptation scale of the processes, 3) use for hydrogen and the best pathway to cover the demand of the type of use, and 4) potential of biomass supply to cover the hydrogen demand.

During the science session an assessment framework for evaluating the deployment of biomass-based hydrogen has been discussed. Indicators (i.e., Key Performance Indicators, KPIs) are one main component of the assessment framework. They can be grouped in technical, economic, system, and environmental KPIs. In the case of bioenergy technologies it can build on existing KPIs from various publications. Initial considerations for KPIs have been presented and further elaborated.

Based on the outcome of the discussions of the industry and sciences sessions promising concepts will be identified which will be then described and assessed in more detail throughout the inter-task project. This report content feeds into the actual case study considerations of WP2 ‘Case studies on hydrogen from biomass’ and WP3 Case Studies on hydrogen use in bio-based processes’ by providing:

- Case study selection for in-depth presentation and analysis
- Definition of boundaries, timeframe etc. (framing of the project)
- Indicators for technical, economic, environmental, system and “H2-link” criteria

AGENDA (CEST)

9:30	**Welcome & intro to the workshop** Welcome from the German Federal Ministry of Food and Agriculture, *Hannes Krüger* Presentation of the background and goal of the workshop, *Christiane Hennig, DBFZ, IEA Bioenergy TCP, Task 40* Presentation of the TCPs, IEA headquarters • *Luc Pelkmans, IEA Bioenergy TCP* • *Sandra Hermle, IEA AMF TCP* • *Marina Holgado, IEA Hydrogen TCP* • *Ilkka Hannula, IEA Paris*
	Industry Session
10:30	**Presentations of case studies on green hydrogen from biomass** Speakers from Industry and IEA Bioenergy TCP • Pathways for biobased hydrogen production, *Joakim Lundgren, LTU, IEA Bioenergy TCP, Task 33 (SE)* • Gasification of torrefied biomass, *Robert Berends, Torrgas (NL)* • Ethanol reforming, *Daniel Lopes, Hytron (BR)* • Methane pyrolysis, *Ulla Lassi, Oulu University (FI)* - Description of the technology/concept - From which/country region? - What is the TRL? Is the technology commercially available? - Any specifics of the concept: flexible bioenergy, link to CCS/CCU, etc.?
11:40	**Break**
11:45	**Presentations of case studies on green hydrogen use in bio-based processes** Speakers from IEA Bioenergy TCP • Pathways for green hydrogen use in bio-based processes, *Axel Funke, KIT, IEA Bioenergy TCP, Task 34 (DE)* • Synergies between biofuel production and hydrogen, *Nicolaus Dahmen, KIT, IEA Bioenergy TCP, Task 39 (DE)* - Description of the concepts - From which/country region? - What is the TRL? Is the concept commercially available? - Any specifics of the concept: flexible bioenergy, link to CCS/CCU, etc.?
12:15	**Moderated open discussion on case studies on green hydrogen from biomass and on green hydrogen use in bio-based processes** Commenting speeches from IEA Hydrogen TCP and IEA AMF • *Alberto Giaconia, IEA Hydrogen TCP* • *Zoe Stadler, IEA AMF TCP*
13:00	**Break**
	Science Session

14:00	**Presentation of an assessment framework for evaluating the deployment of 1) green hydrogen from biomass and 2) green hydrogen use in bio-based processes** *Christiane Hennig, DBFZ, IEA Bioenergy TCP, Task 40 (DE)* - Understanding of framing and criteria, and their role - Specifics of green hydrogen and bio-based value chains system assessment - Overview on assessment criteria
14:30	**Presentation of carbon footprint assessment for evaluating the deployment of 1) green hydrogen from biomass and 2) green hydrogen use in bio-based processes** *Martin Junginger, UU, IEA Bioenergy TCP, Task 45 (NL)* - Carbon footprint assessment
15:00	**Moderated open discussion on assessment framework** - Round table discussion for case study assessment - Definition and selection of boundaries, timeframe, set of criteria for evaluating the deployment of green hydrogen from biomass and green hydrogen use in bio-based processes
15:40	**Workshop summary and way forward**
15:45	**End of the workshop**

WELCOME & INTRO TO THE WORKSHOP

Christiane Hennig, DBFZ, IEA Bioenergy TCP, Task 40

Christiane Hennig (WP1 lead) welcomed all to the WS and introduced the agenda, and background and goal of the meeting. WP1 'Status quo of synergy value chains' is the framing Work Package of the Inter-Task project on 'Synergies of green hydrogen and bio-based value chains deployment'. Activities of WP1 consist of two phases. In phase 1, scope, indicators and criteria will be defined, assessment framework for case studies developed and an expert workshop organized. In phase 2, feedback loop especially with WP2 and WP3, but also with WP4 and WP5, will be coordinated and criteria and assessment framework revised. The outputs of WP1 include scoping report and collection of example synergy value chains with short value chain descriptions.

Hannes Krüger, the German Federal Ministry of Food and Agriculture, Division "energy, bioeconomy, renewable resources"

Hannes Krüger welcomed all to the workshop on behalf of the German Ministry of Food and Agriculture. He is working with biofuels and e-fuels among other things, so the topics of the WS is of high interest. Also work with national hydrogen strategy is on-going. Germany is preparing National Biomass Strategy, and from that point of view e.g., hydrogen from biomass is interesting.

Presentations by IEA Technology Collaboration Programmes and IEA headquarters

Luc Pelkmans, IEA Bioenergy TCP, Technical Coordinator

Luc Pelkmans gave an overview on the role of bioenergy in transition away from fossil energy and IEA Bioenergy TCP. IEA's roadmap 'Net Zero Emissions by 2050' shows that crucial steps towards net-zero needs to be taken in this decade. Regarding bioenergy, traditional biomass needs to be replaced by modern bioenergy. Bioenergy is a versatile energy source with different roles in different sectors. It can already now phase out fossil fuels within existing infrastructure (e.g., blending in transportation). Bioenergy is a storable and dispatchable energy source, which can complement intermittent renewables. Bioenergy can even provide carbon negative hydrogen from biomass. Furthermore, Luc introduced the goals, members, and current strategic action areas of IEA Bioenergy TCP. These include demonstrating the key role of bioenergy in decarbonizing the world, the complementary role with other renewables, and the potential to provide negative emissions, sustainable value chains, and stakeholder engagement.

Bioenergy Review 2023

Sandra Hermle, IEA AMF TCP, Swiss Delegate

Sandra Hermle talked about vision and mission of AMF. AMF has 14 member countries all over the globe. AMF's scope is in the entire spectrum of fuels from feedstock, through fuel processing and distribution, finally to end use in vehicles, and the work is based on cooperative R&D. AMF has collaborated e.g., with Hydrogen and Combustion TCPs. AMF has altogether 58 completed tasks and 6 tasks currently active. IEA AMF and IEA Bioenergy have worked together in AMF Task 58 / IEA Bioenergy Task 41 Project 10 'The role of renewable transport fuels in decarbonizing road transport' (more information). One of the main conclusions of the project was that countries that deploy a set of different measures such as reducing transport demand, improving vehicle efficiency, and adding renewable energy carriers such as biofuels, e-fuels, renewable electricity, and renewable hydrogen have the best chances to meet ambitious decarbonization goals. AMF is project partner to the Synergies ITP. Other Tasks relevant for Synergies ITP include Task 60 The Progress of Advanced Marine Fuels, Task 64 E-Fuels and End-Use Perspectives, Task 59 Lessons Learned from Alternative Fuel Experiences (more information). The Task 60 report is to be released soon.

Annual report 2021

Marina Holgado, IEA Hydrogen TCP, Technical Secretariat Coordinator

Marina Holgado introduced the Hydrogen TCP, which has 26 contracting parties and seven sponsor members. Hydrogen TCP was one of the first TCPs established under the IEA auspices in 1977. Since that more than 40 Tasks have been carried out and 250 experts involved. There have been altogether 15 Tasks concerning renewable hydrogen from different perspectives. Renewable hydrogen processes are different and there was seen need to bring these together. Thus, a new Task on Renewable Hydrogen Production is currently in definition. The workplan is divided in five Subtasks for different pathways. Especially Subtask 4 'Thermochemical conversion of C-feedstocks' is relevant for IEA Bioenergy. Further discussion on potential collaboration will be sought. Kick-off meeting of the Task is expected before June 2023. Besides, two other Tasks are "in definition"[1] on the topics of Certification and of Hydrogen LCA, societal and environmental impact which can be of interest for future collaboration between the Hydrogen TCP and IEAB. Marina suggested to have an exchange following the workshop.

Marina also informed that IEA is updating the Clean Energy Technology Guide (CETG). Over 40 technologies related to hydrogen have been identified. Hydrogen TCP has agreed to update the descriptions and suggests joint work with other TCPs. For this procedure Hydrogen TCP is now looking for the experts and has contacted IEA Bioenergy TCP. Hydrogen TCP plans to further utilize the work for technology briefs. Here, especially the TRL assessment is of relevance for IEAB.

Annual report 2022

Q&A session

Joakim noted that there will be large synergies with between Renewable Hydrogen Production Task and Inter-Task project.

Martin asked when the Task in definition for LCA will come active. Marina explained that Hydrogen TCP is involved in some projects focusing on transport applications. This is a preliminary proposal and will not be operational in 2023. When getting green light from the ExCo, Hydrogen TCP will approach other TCPs. The topic can be covered in another exchange afterwards.

It was agreed to follow-up with IEA Bioenergy's support the update of the Clean Energy Technology Guide.

The Role of Bioenergy and Hydrogen in the Net-Zero Emissions 2050 Scenario, Ilkka Hannula, Senior Energy Analyst, Renewable Energy Division, IEA

Ilkka Hannula pointed out that the peak of fossil fuels is coming this decade as today's policy settings are sufficiently strong. He talked about CO_2 emissions trends and scenarios until 2050. The power sector leads emissions reductions to 2030, but all sectors contribute to the net-zero emissions target. Remaining residual emissions will be balanced by atmospheric removals in 2050. Low emission fuels will be important. Both bioenergy and low-emission hydrogen play a key role in the NZE, both experiencing a significant growth. Cheap solar PV and wind will drive green hydrogen project development. A lot of additional renewable power capacity is needed for hydrogen production. Cost for low-emission hydrogen will fall especially in India, Chile, Australia, and some African countries. By 2050, 7.6 Gt of CO_2 is captured per year from a diverse range of sources, CO_2 from BECCS and DACCS representing a total of 2.4 Gt.

It was agreed to stay in touch on bio-based hydrogen options during the Synergies ITP and to reflect on the NZE 2050 scenarios.

INDUSTRY SESSION

Presentation of case studies on green hydrogen from biomass

Pathways for bio-based hydrogen production, Joakim Lundgren, LTU, IEA Bioenergy TCP, Task 33 (SE)

[1] Task in Definition means a project is in definition phase where all Hydrogen TCP members and external actors are invited to participate and contribute to draft the project. This stage is led by the Task organizer.

Joakim (WP2 lead) presented different pathways to produce green hydrogen from biomass. Fossil free hydrogen will play role especially in hard-to-abate sectors. Joakim pointed out that bio-based hydrogen has great potential as its production is non-weather dependent, it can simultaneously provide negative emissions, and there are process integration opportunities. Electrolysis is not the only pathway for renewable hydrogen production. Bio-based hydrogen has great potential to accelerate the realization of the hydrogen economy, but this is currently overlooked in the 'hydrogen rainbow'. One core output of WP2 is, thus, to present TRLs for different bio-based hydrogen pathways.

There are planned investments worth more than EUR 100 billion in hydrogen in heavy industry in North of Sweden. One of the largest ever industrial investment in Sweden, LKAB's investment, aims to shift from iron ore pellets to CO_2-free sponge iron. SSAB will invest in new electric arc furnace for fossil-free steel. There are many large industrial companies in the area of Norrbotten, and they will require more than 100 TWh per year of fossil-free power – energy demand will more than double from 2020 to 2030. If hydrogen will be produced by electrolysis, electricity demand will tremendously increase. Bio-based hydrogen would enable industrial symbiosis and process integration opportunities, e.g., through bio-carbon for steel industry, oxygen, and heat integration. Some resource efficient industrial clusters could be described in WP4.

Gasification of torrefied biomass, Robert Berends, Torrgas (NL)

Robert Berends presented Torrgas' innovative gasification technology. Some of the benefits of the technology include steady and easy operation, biomass resource flexibility (increases the feedstock availability for the given process), and that N_2 and tar free syngas are applicable for downstream catalytic conversion processes. Torrgas' two-stage gasification process of torrefied biomass enables steady operation through the use of homogenous feedstock, lowering logistic costs, and improving the biomass availability through use of variable feedstocks. Torrgas' calculations show that hydrogen production from verge grass leads to higher efficiency than SNG production. Economic analysis show economies of scale for 400 MW capacity compared to 100 MW. Hydrogen production with cost below 2 €/kg is possible with both capacities (taken CO_2 credit up to 125 €/ton in 2030). A LCA is carried out by Studio Gearup according to REDII methodology.

Torrgas has two projects under development to produce 6.5-13 kton of H_2 per year (per project) at 40 bar. Additionally, biochar will be produced and food grade CO_2 possibly for local offtake.

Ethanol reforming, Daniel Gabriel Lopes, Hytron (BR)

Hytron, founded in 2003, is a spin-off from Hydrogen Laboratory, Unicamp, and a globally distributed company. German NEA Group acquired Hytron in 2020 and thus integrated hydrogen generation in its portfolio. Their products include electrolysers and steam reforming. Ethanol is an interesting green hydrogen carrier as the entire value chain is already established, it is easy to transport and store, and hydrogen can be produced locally close to consumption. Ethanol reforming also enables constant hydrogen production. Ethanol reforming requires electricity for BoP, but much less than for producing hydrogen with an electrolyser.

Hytron has planned three phases for upscaling the reformer and hydrogen production. Phase 1 is based on collaboration and pilot project with Shell. In the project, 4.5 kg/h hydrogen is produced for use in buses. Phase 2 will lead to 10 times upscaling for the hydrogen use in industry. Phase 3 will lead to further 10 times upscaling and to hydrogen use for marine fuels and global markets. Timeline of the whole scaleup process is 08/2022-08/2025. Up to 5000 Nm^3/h reformer (450 kg/h hydrogen) will be ready in 2025 (with German company Neumann and Esser, NEA group). This is a scaleup from TRL 5 to TRL 7. The projects costs EUR 10 million. The process is to be used in hard-to-abate sectors as heavy industries.

Methane pyrolysis, Ulla Lassi, Oulu University (FI)

Ulla gave a presentation on methane pyrolysis (or rather *thermocatalytic decomposition of methane* as catalyst is used and nothing burned). There are interesting projects going on in Oulu and nearby regions: Woikoski in Kokkola (water electrolysis, hydrogen used in metal reduction), Flexens planning to invest in Kokkola in electrolysis, and Hycamite, a spin-off from Oulu University, in Oulu.

In addition to state-of-the-art for producing hydrogen with steam reforming of natural gas, there are also other options: water electrolysis and methane pyrolysis. Hycamite has brought the methane pyrolysis process from TRL 3 at the university to TLR 7 (pilot/semi-pilot scale >> pre-commercialization stage). There are several innovations behind the development: use of CO_2/CO free technology, catalyst, reactor set-up, and solid carbon for energy storage applications. The catalyst is innovative and cost-competitive, but the commercial name cannot be told.

Methane pyrolysis produces solid carbon as an interesting by-product, which can be used e.g., as carbon storage, and for batteries (to replace graphite) and supercapacitors. High purity carbon should be used instead of burning it. The high-value use of solid carbon raises the question of what is actually the main product of the process, hydrogen or carbon. Ulla has good connections to companies.

Q&A session

Martin Junginger knows well Studio Gearup. He asked if there is a public report of Torrgas' LCA (based on REDII methodology) available and if there has been conducted any publicly available LCA for methane reforming. Maybe collaboration around LCA could be possible. It would be also interesting to know how by-product carbon from methane reforming is considered in LCA. Maybe a LCA can be performed in the project. Ulla told that Hycamite has feasibility studies and LCAs, but she is not aware which company has conducted them. Oulu University's data can be used, but availability of Hycamite's studies needs to be checked with them. An EU project together with LTU (Joakim involved) just started where techno-economic data is available. Ulla and Joakim will discuss possible synergies with the ITP. Robert told that Studio Gearup's LCA for Torrgas is available and can be shared, collaboration is possible.

Franziska Müller-Langer asked whether it is more important to have clean hydrogen with high H_2 rate as an end-product from a thermochemical process or rather to process hydrogen with syngas for many applications. This is an interesting question. According to Robert, in principle, it is better to directly convert biomass to fuels (e.g., methanol synthesis, FT) than to use hydrogen for e-fuels. Hydrogen from biogenic sources is better when you can directly use it or use in chemical processes. If there are any other applications, that can use syngas directly, that is good (taking also the carbon).

Luc Pelkmans asked Robert about their business plan, which counts on CO_2 credits. Normally, the credit is gotten when the CO_2 is stored, and then one should also count the storage and transport costs (e.g., 100 USD/t CO_2). Did you take storage into account? Robert explained that the CO_2 credit is the saving for using a biogenic CO_2 source compared to a fossil source. The saving can be sold as ETS if it is produced from biogenic source (compared to fossil). GHG saving compared to fossils and selling the biogenic CO_2 from gasification are two different things. Hence, during the discussion it was noted that Luc and Robert might refer to different things >> This aspect should be clarified further and highlighted. Christiane also noted that this should be considered in KPI discussion.

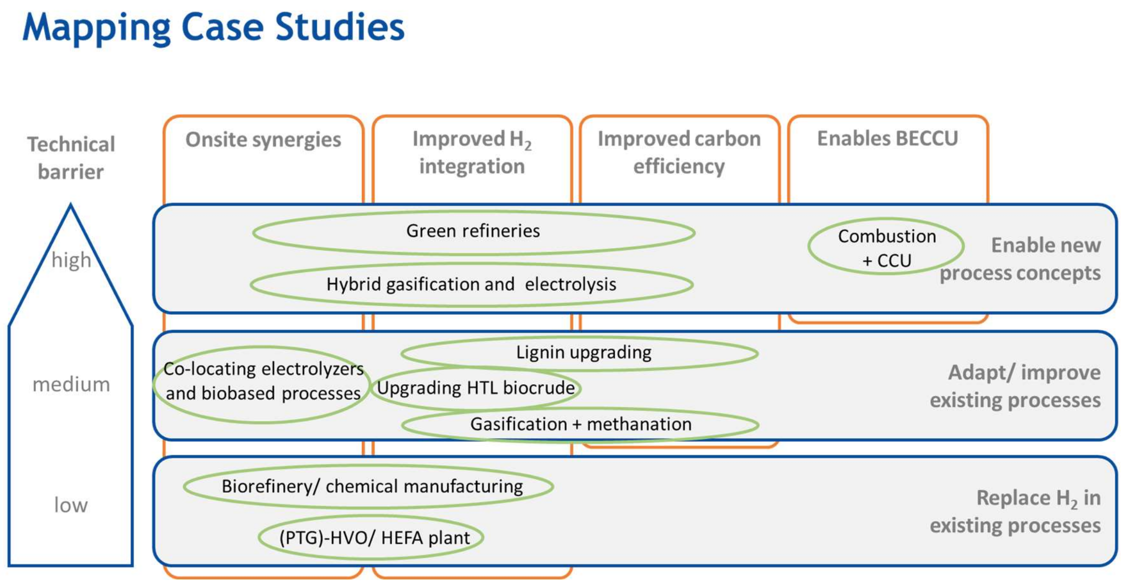
Presentation of case studies on green hydrogen use in bio-based processes

Pathways for green hydrogen use in bio-based processes, Axel Funke, KIT, IEA Bioenergy TCP, Task 34 (DE)

Axel Funke (WP3 lead) gave an overview of possible pathways and benefits for using green hydrogen in bio-based processes instead of presenting certain case studies as there are many of those. Around 10 potential case studies have been identified.

Benefits/synergies of applying hydrogen in bio-based processes include synergies through process integration of electrolysis/biofuels, integration of green hydrogen in existing infrastructure, increase of carbon efficiency of bio-based value chains, and enabling BECCU liquids/gases. Along to this list, the expected technical barriers increase.

One important aspect to be aware of is that if we want to have BECCU it is "impossible" without hydrogen.



Synergies between biofuel production and hydrogen, Nicolaus Dahmen, KIT, IEA Bioenergy TCP, Task 39 (DE)

Nicolaus Dahmen presented a general view on lessons from previous projects concerning synergies. Expectations in the case of biomass gasification-based fuels include even doubling the hydrocarbon yield and that oxygen by-produced is sufficient for autothermal gasification. Different process pathways and even process variants can benefit to variable extent from hydrogen supply. Economics may be determined by the carbon conversion vs. costs trade-off and/or other optimization criteria – synergies and trade-offs between additional effort of adding hydrogen to the process vs. increased carbon efficiency should be studied through sensitivity analysis. Carbon dioxide is available at different partial pressure and purity. Costs need to be looked into very carefully. If we have to recover CO_2 from the process, then the effort might be high.

Options for hydrogen integration include gasification-based processes, pyrolysis/HTL-based processes, and microbial processes. Examples show that not all processes are efficient. Options for CO_2 activation include three various options (all at or below TRL 6). Biotech processes should be included in the case studies. Also, a case study on microbial processes is recommended.

As conclusions, power enhanced BtL processes are promising, in optimum case increased effort of hydrogen supply is compensated by increased yield, and CO_2 capture is, but RWGS is not state-of-the-art today. Scenarios are technical and market development for hydrogen needs to be included.

Marina asked about the future of industrial scale gasification processes as they are not there yet. Nicolaus and Axel see the technology available in the future. Successful development can be done and several companies are working on that, also on co-electrolysis.

Moderated open discussion on case studies on green hydrogen from biomass and on green hydrogen use in bio-based processes

Commenting speech, Alberto Giaconia, IEA Hydrogen TCP

Alberto is responsible for Task in definition, 'Renewable Hydrogen Production' at IEA Hydrogen TCP. Demand for green hydrogen will increase in the future. It is important to understand how bio-based processes can complement water electrolysis-based hydrogen production and what is the potential. One of the main objectives of the new Task is to compare different pathways. Green hydrogen can feed the biomass-based value chains. When we can rely only on renewable sources in hydrogen production, but constant hydrogen load is needed, would biomass be the resource for this? The interesting questions are what is the potential of biomass-based hydrogen, is it enough to cover the gap from intermittent hydrogen production, what is the potential of biomass supply to cover relevant portion of hydrogen demand, is there enough biomass for different applications? What is the TRL status? What are the best practices? Alberto has made a case study for Italy. Renewable hydrogen

Task will look at best practices all over the world as best practices are needed. Task will also identify scientific and technological gaps to reach TRL 8 and 9. Experts from the WS are welcome to join these exercises.

To summarize, there are three main issues to be explored with bio-based hydrogen: 1) TRL, 2) adaptation scale of the processes, and 3) potential of biomass supply to cover the hydrogen demand.

Alberto is personally working on biogas steam reforming, which is expected to be a well-working process. Interesting question is how biomethane reforming will differ from fossil steam reforming. There is still work to do with small-scale plants (scale down to ratio 1:100 compared to fossil steam reforming).

In many cases biomass conversion leads to syngas, which demand in industry (e.g., steel production) increases. It is good to have an alternative approach to electrolysis to satisfy specific industrial demands.

Joakim noted that we must remember the limitations – biomass cannot replace everything.

Luc highlighted the economic story and potential. **What is the economic value of hydrogen compared to biomethane and e-fuels (and biomethane vs. e-fuels).** The price will further drive the technical development. Where hydrogen has most value?

Alberto noted that direct air capture is still quite expensive, but biomass can also provide CO_2 and interact with hydrogen. Luc commented that cheap carbon source is needed to push the conversion efficiency. First low-hanging fruits for CCU are needed to boost the production. Economics are important as well as boosting the processes and the carbon efficiency.

Commenting speech, Zoe Stadler, IEA AMF TCP, leading Task 64

Zoe's background is in PtX. Hydrogen and e-fuels will both play a role in the future and need to be considered. A core question is what is the use for hydrogen? Thereby the whole chain needs to be considered. And what is the best pathway to cover the demand of the type of use. Economics will be different in different pathways and applications. One question is where hydrogen will be used when both renewable power and bioenergy are limited resources. Not all industries are similarly capable to pay for the fuels. E-fuels, hydrogen and syngas have remarkable costs. Biofuels are cheaper than e-fuels but limited. Production cost of e-fuels for aviation is 10 times higher than for fossil fuels.

Hydrogen is important not only for economics but also for LCA. Often the reasoning for e-fuels is that it will support grid stability (i.e., uptake excess VRE), which is though hard from the costs point of view. Bio-based hydrogen is overlooked in the 'hydrogen rainbow' – it does not increase the stability of the power grid, but also does not put extra pressure on it. Availability of biogenic CO_2 from bio-based processes, and in addition from WtE, is also an important point. Biogas upgrading is also significant with about 40% CO_2. Avoiding double counting of renewable power should be kept in mind.

Open discussion

The following aspect were discussed, among others:

- Regional/local solutions vs. global solutions. Global trading of hydrogen increases the cost through transport. There is no single global solution. The local framework defines the application. **Regional differences should be looked at and it should be reflected why some concepts work in some region and not in another region** (e.g., hydrogen from ethanol in Brazil vs. Europe) **under certain circumstances**.
- How does regionality fit into the assessment framework? How do we reflect on this as this IEAB ITP has a global scope? Through case studies with a broad coverage of countries and respective technologies. Likely qualitative descriptions of benefits are needed in addition to / instead of a single KPI / KPIs.
- Regional coverage needs to be ensured.
- What affects the costs? We should look at the policies and GHG mitigation costs (note by-products, e.g., by-product solid carbon in methane pyrolysis example) (KPI >> CO_2 reduction cost?). There is a 2022 study from DBFZ and the German Energy Agency (dena) on Hydrogen

from biomass for the BMEL (available only in German language: https://www.dbfz.de/pressemediathek/publikationsreihen-des-dbfz/dbfz-reports/dbfz-report-nr-46). In the German National hydrogen strategy focus is on green hydrogen based on water electrolysis.
- Carbon content of the biomass is an important point. For e-fuels the problem is where to get the carbon.
- Biological pathways are important to have as a case.
- The position of ETIP and RHC on biomass based hydrogen has been mentioned: https://www.etipbioenergy.eu/images/RHC_ETIPB_Renewable_Hydrogen_position_paper.pdf

SCIENCE SESSION

Presentation of an assessment framework for evaluating the deployment of green hydrogen from biomass and green hydrogen use in bio-based processes

Christiane Hennig, DBFZ, IEA Bioenergy TCP, Task 40 (DE)

The purpose of Synergies ITP WP1 is to support the selection of case studies, define reference system, timeframe, and boundaries, and provide a set of indicators for case studies. All these activities go hand in hand. Workshop in Vienna on 19/10/2022 served as a kick-off discussion and its results were presented by Christiane. Most of our experience is based on bioenergy technologies and on certain regions, now we have to expand. Both in WP2 and WP3 we have now some 10-12 potential cases identified, and we have to select the ones we want to further analyze and present in more detail. WP2 and WP3 have already filled in a case study collection template.

Christiane presented the discussion and outcomes so far. Case studies will focus on actual projects/companies (not modelling). Contacts are/will be established through IEA Bioenergy Task members. There is need for two timeframes (2030 and 2050) in addition to presenting the status quo as of today. Reference system is a challenge due to market evolution. There is need for two different reference systems for the years 2030 and 2050 (which comparable technology will be prominent in 2030 and 2050, respectively, e.g., renewable hydrogen reference system based on wind and solar or biomethane). IAMs can support this definition.

Indicators (i.e., Key Performance Indicators, KPIs) can be grouped in technical, economic, system, and environmental (in WP5) KPIs. In the case of bioenergy technologies, we can build on existing KPIs from various publications. Hydrogen link has to be better involved in KPIs. Regarding data availability, economic KPIs will be a challenge for emerging technologies. For commercial technologies companies can presumably provide costs, also own calculations are possible if enough data is available. WP2 and WP3 have different requirements for case study assessment and KPIs. Some of the KPIs might need a qualitative description. Initial considerations for KPIs are presented in the following figure.

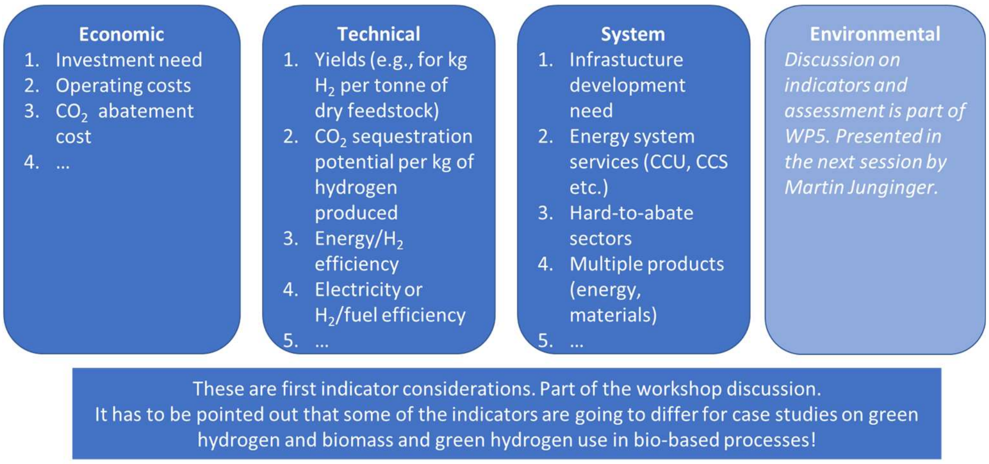


Figure 1 Example for grouping Key Performance Indicators (KPI)

One solution to summarize all cases would be to use a traffic light system, for which examples and expertise from other projects is already available (German example (2019) presented, ESYS DBFZ). Some of the Synergies ITP project members have been involved in this previous work, so there is expertise available. The available assessment frameworks for bioenergy technologies should be further developed to the ITP needs, e.g., by adding the H_2 link, timeframe, etc.

A proposal for methodological approach is to: 1. Define indicators, 2. Define technologies/case studies, 3. Create traffic light scheme, 4. Define reference system, 5. Make assessment, and 6. Provide overview on all technologies/case studies.

Traffic light system and reference systems were discussed, with the following key points:

- Traffic light approach in principle got support.
- The purpose of and need for reference system was discussed. 'Reference system' is not necessarily the best describing term but needed if we want to give color for the technology in the traffic light system. The other option is to compare the technologies with each other, but we agreed before to avoid comparing case studies/technologies.
- We have to keep in mind that a certain reference system fits better to some technologies than the others. Also, the previous conclusion that the case studies are local / location-dependent should be kept in mind. Choosing a certain technical pathway for reference would rather lead to a global view.
- WP2 and WP3 traffic light systems could be separated in two different tables as they are different by nature and all KPIs do not necessarily fit to both cases.
- It was suggested not to compare to traditional fossil system, rather to an electrofuel or biofuel system. A further suggestion was to not include fossil fuels at all, rather hydrogen or biomethane. One way could be a renewable system or system with specific amount of renewables. Maybe fossils are still needed for one of the reference systems.
- Traffic light system has the danger of leading to misinterpreting the results i.e., what does the color actually mean. It is important to clearly describe the approach of the traffic light system and how to use it. It tells how the concepts would behave in certain conditions. One way is to complement the traffic light system with qualitative description of which role certain case study can play and where the concept fits and where not.
- It would be interesting to see under which circumstances and combinations the technologies response to a certain indicator with a certain color ("scenario") and how changes in circumstances affect the traffic light system.
- Also, online tools could be a nice option to present where are trade-offs and challenges with each of the concepts/case studies.
- Should we do a literature check for the case study data (as case studies are examples)? Real data would be good, but a check and comparison can be added to show the relation. Literature data is more relevant for low TRL cases, which do not have so much data available.
- Another suggestion is to describe general cases and show ranges from literature in addition to the case study assessments. Hence, it can be reflected that one is aware of the ranges, but the core focus of the Synergies ITP is on the individual case study assessment.
- How does co-processing fit to the assessment framework?
- Besides the ESYS DBFZ work a bit similar work with traffic light system was done before for renewable fuels for transport sector by DBFZ (Monitoring renewable energies in transport, 2023, p. 254 f.).
- An iterative process between assessment framework and case study selection is needed.

Presentation of carbon footprint assessment for evaluating the deployment of green hydrogen from biomass and green hydrogen use in bio-based processes

Martin Junginger, UU, IEA Bioenergy TCP, Task 45 (NL)

Martin Junginger explained the objectives of WP5, i.e., exploring the potential of hydrogen in wind- and PV-dominated energy system with respect to the anticipated role of biofuels and e-fuels by reviewing existing 1.5/2 degree energy system modeling and IAM scenarios and the role of hydrogen in those, assessing the reduction of the carbon footprint of PtX products through biogenic CO_2, and providing an outline of promising value chains under different framework conditions and timeframes.

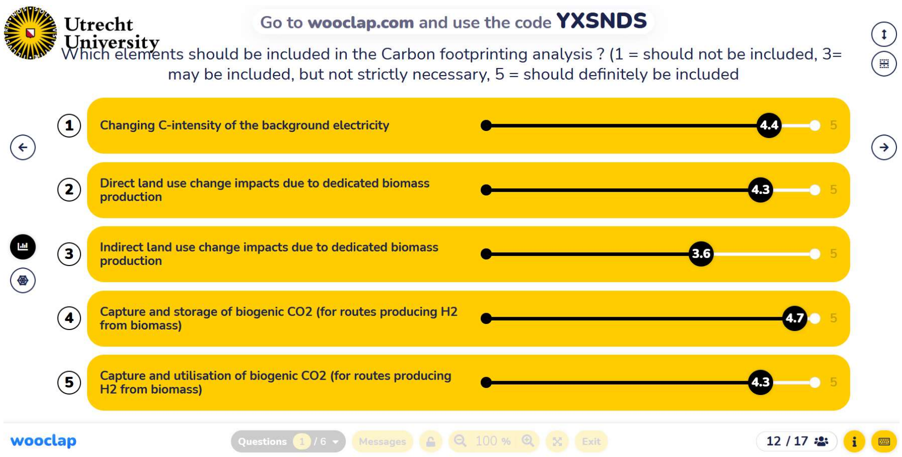
Martin introduced the two types of LCA: static and prospective. The idea is to start with a simple LCA analysis in the project, and then change to prospective LCA. Prospective LCA would be relevant as we look at the future. It considers different time and geographical backgrounds, which is important in the case of climate impacts. Location/region-specific and temporally dynamic background data could provide insights into specific benefits of individual value chains. The target is to link IAM model to LCA; example of producing PtX hydrogen: [Linking Life Cycle and Integrated Assessment Modeling to Evaluate Technologies in an Evolving System Context: A Power-to-Hydrogen Case Study for the United States]. The example study shows how strong impact changing background systems / scenarios can have on the absolute environmental impact of new technologies and on the relative impacts compared to the incumbent technologies.

Moderated open discussion on assessment impacts

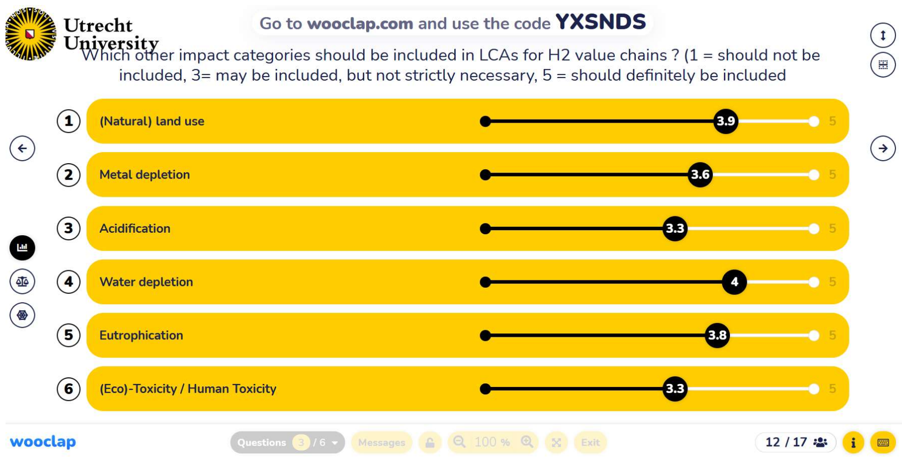
Martin launched Wooclap questions to gather ideas and discuss boundaries and KPIs for LCA of case studies.

The questions and discussion points included the following:

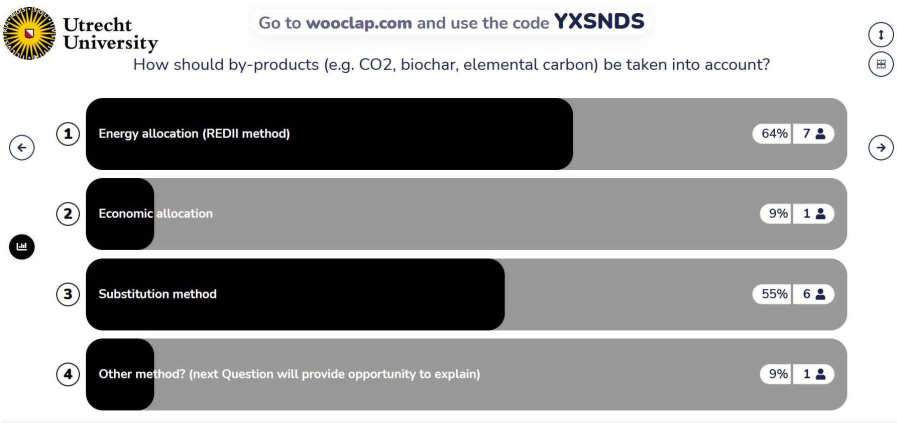
- Which elements should be included in the Carbon footprint analysis? Which other aspects should be considered for C-footprinting / Climate impacts of H_2 supply chains?



  - Leakage of methane, reflections on climate impact of hydrogen, ILUC, considerations if H_2 production is the most appropriate use of the feedstock from climate mitigation perspective, qualitative discussion on effect on carbon payback time, different references (sector, location), effects of by-products from the H2 production
  - The possible challenge of getting data for the case studies should be kept in mind.
  - Describe what kind of land is considered in land use in LCA.
- Which other impact categories should be included in LCAs for H_2 value chains?



  - Critical materials, employment, human health, SDGs, possible impact on biodiversity loss, efficiency of production chain for H_2 use, regionalization
- How should by-products (e.g., CO_2, biochar, elemental carbon) be taken into account?



- Most votes for Energy allocation (REDII) (64%) and Substitution method (55%). Both could be used in the assessment. Other options were Economic allocation (9%) and Other method (9%).
- Other methods: Exergy allocation.
- One problem is that there are many regulations (EU). However, when we go towards 2050 we do not know which kind of environmental legislation will be in the future.

Please contact Martin if you are interested in joining WP5.

WORKSHOP SUMMARY AND WAY FORWARD

Christiane Hennig, DBFZ, Task 40

After digesting all the information, we will start working with the first case study selection of WP2 and WP3 discussed and agreed on today, and then develop a case study template. In terms of the assessment framework the next step is completing the key performance indicators overview and to integrate this into case study template. Furthermore, scientific exchange if and how to make best use of a traffic light system for evaluating the different concepts will be vital.

As part of WP5, methodological guidance and the development of Life Cycle Assessment (LCA) methodology addressing both the impacts of either biomass-based hydrogen production and adding renewable hydrogen to biobased vaue chains.

LINKS

https://www.etipbioenergy.eu/images/RHC_ETIP-B_Renewable_Hydrogen_position_paper.pdf

https://energiesysteme-zukunft.de/fileadmin/user_upload/Publikationen/PDFs/ESYS_Position_Paper_Biomass.pdf

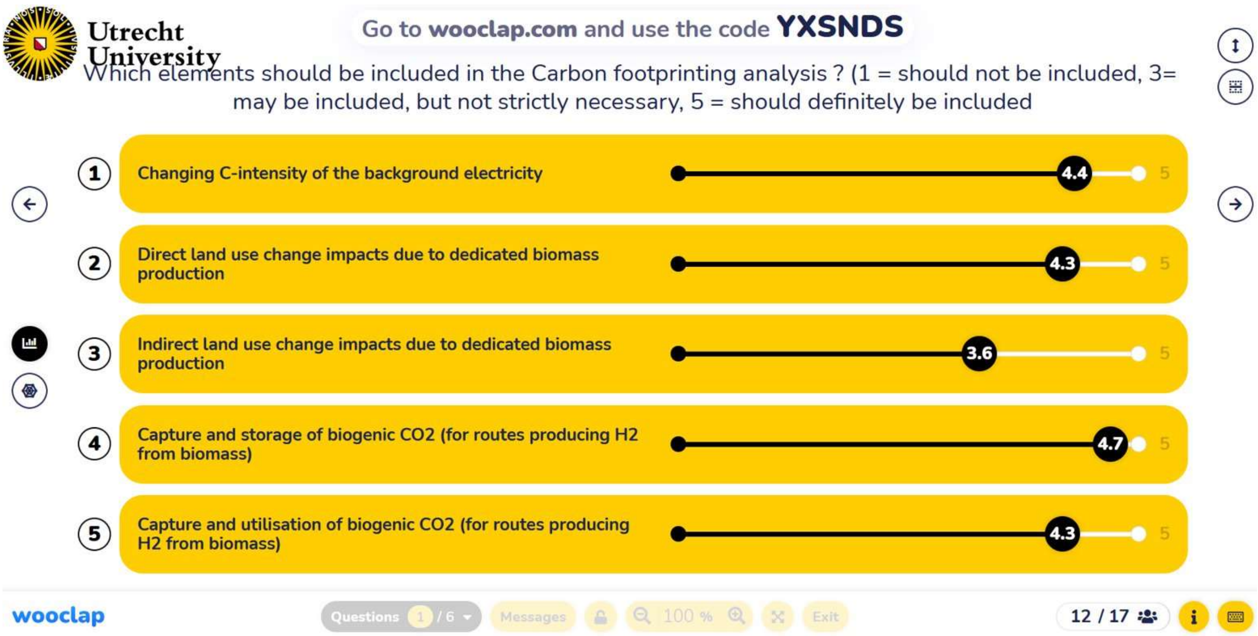
https://www.dbfz.de/fileadmin/user_upload/Referenzen/DBFZ_Reports/DBFZ_Report_44_EN.pdf

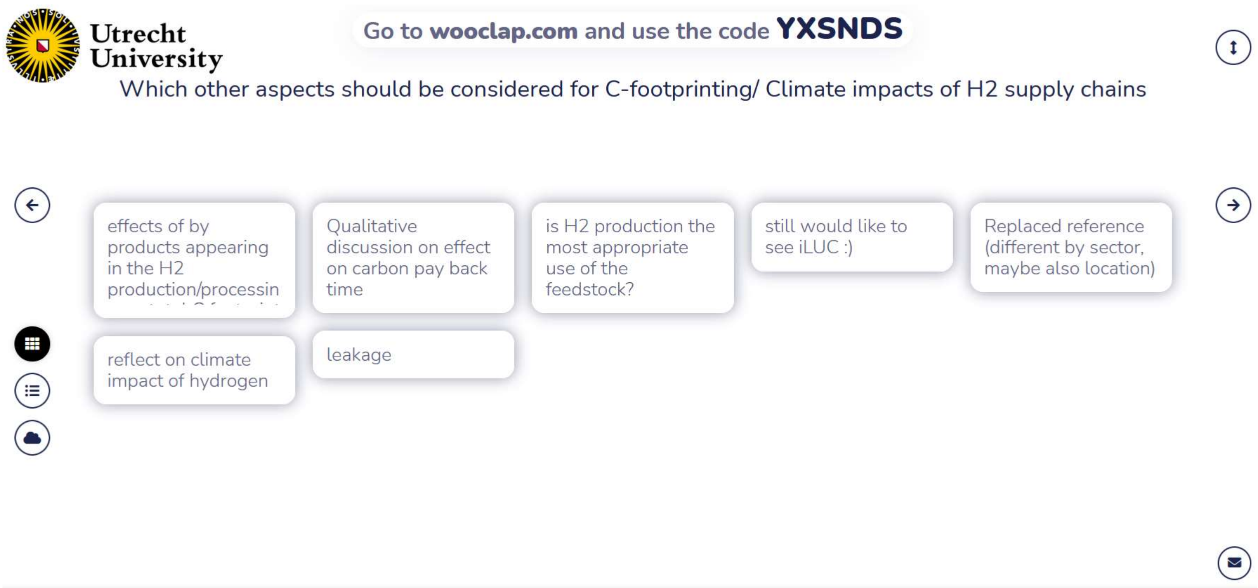
https://www.researchgate.net/publication/367963266_Linking_Life_Cycle_and_Integrated_Assessment_Modeling_to_Evaluate_Technologies_in_an_Evolving_System_Context_A_Power-to-Hydrogen_Case_Study_for_the_United_States

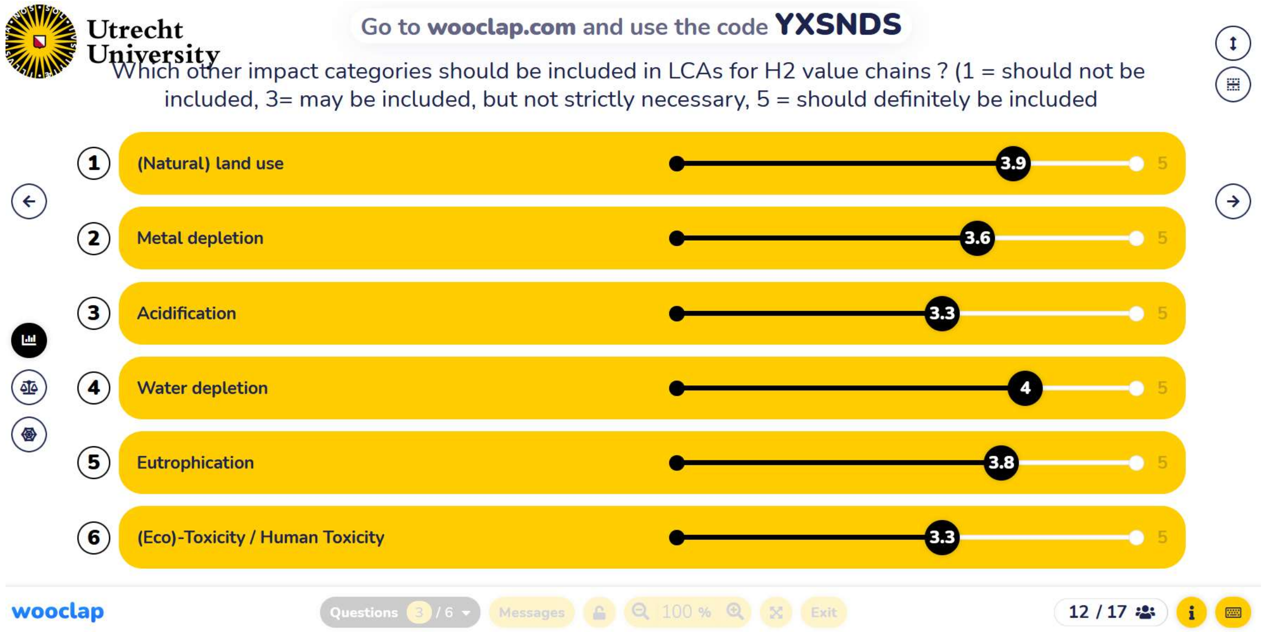
LIST OF PARTICIPANTS

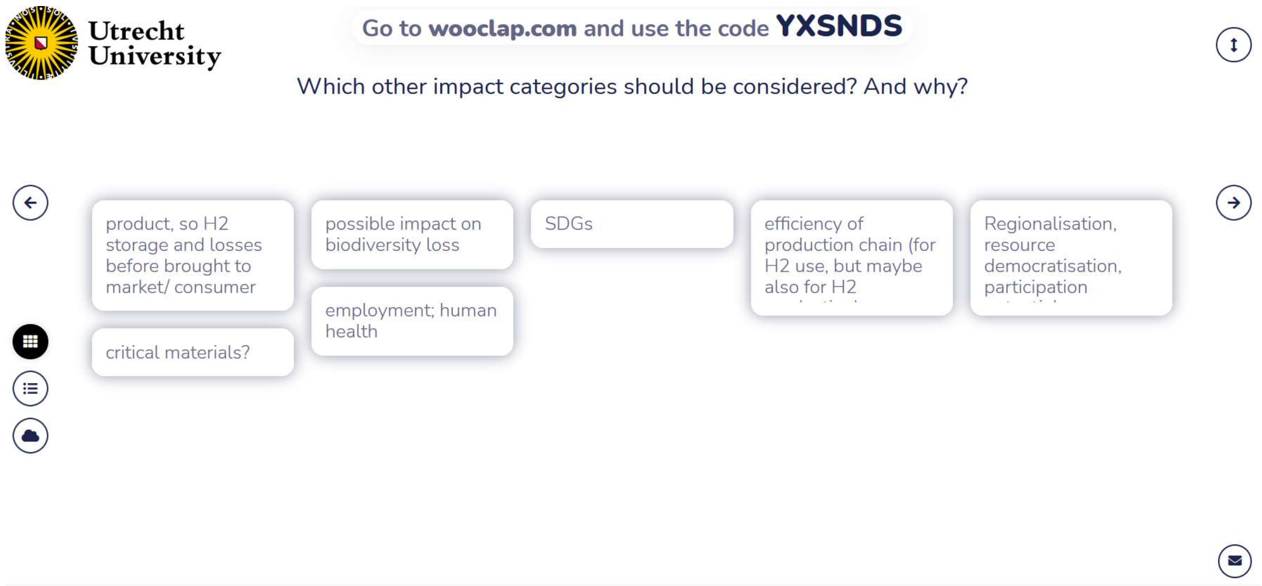
First name	Surname	TCP/company/ institution	Task	Morning	Afternoon	Physical participation
Berends	Robert	Torrgas		X		
Buffi	Marco	IEA Bioenergy	39	X	X	
Dahmen	Nicolaus	IEA Bioenergy	39	X	X	
Daioglou	Vassilis	IEA Bioenergy	45		X	
Eymans	Erwin	Torrgas		X		
Fritsche	Uwe	IEA Bioenergy	40/45	X		
Funke	Axel	IEA Bioenergy	34	X	X	
Giaconia	Alberto	IEA Hydrogen		X	X	
Giuliano	Aristide	IEA Bioenergy	42	X		
Hannula	Ilkka	IEA Paris		X		
Hennig	Christiane	IEA Bioenergy	40/44	X	X	X
Hermle	Sandra	IEA AMF		X		
Holgado	Marina	IEA Hydrogen		X		
Huck	Lena	IEA AMF		X	X	
Junginger	Martin	IEA Bioenergy	45	X	X	X
Kerckow	Birger	IEA Bioenergy / AMF		X	X	
Krüger	Hannes	BMEL		X		X
Lange	Nora	IEA Bioenergy	40/44	X	X	X
Lassi	Ulla	Oulu University		X		
Lopes	Daniel	Hytron/NEA Group		X		
Lundgren	Joakim	IEA Bioenergy	33	X	X	X
Mäki	Elina	IEA Bioenergy	44	X	X	X
Müller-Langer	Franziska	IEA Bioenergy	39	X	X	X
Pelkmans	Luc	IEA Bioenergy		X	X	
Pettersson	Karin	IEA Bioenergy	40	X	X	
Schipfer	Fabian	IEA Bioenergy	40/44	X	X	
Stadler	Zoe	IEA AMF	64	X	X	X
Tynjälä	Tero	LUT University		X		
Wild	Michael	IEA Bioenergy	40	X	X	

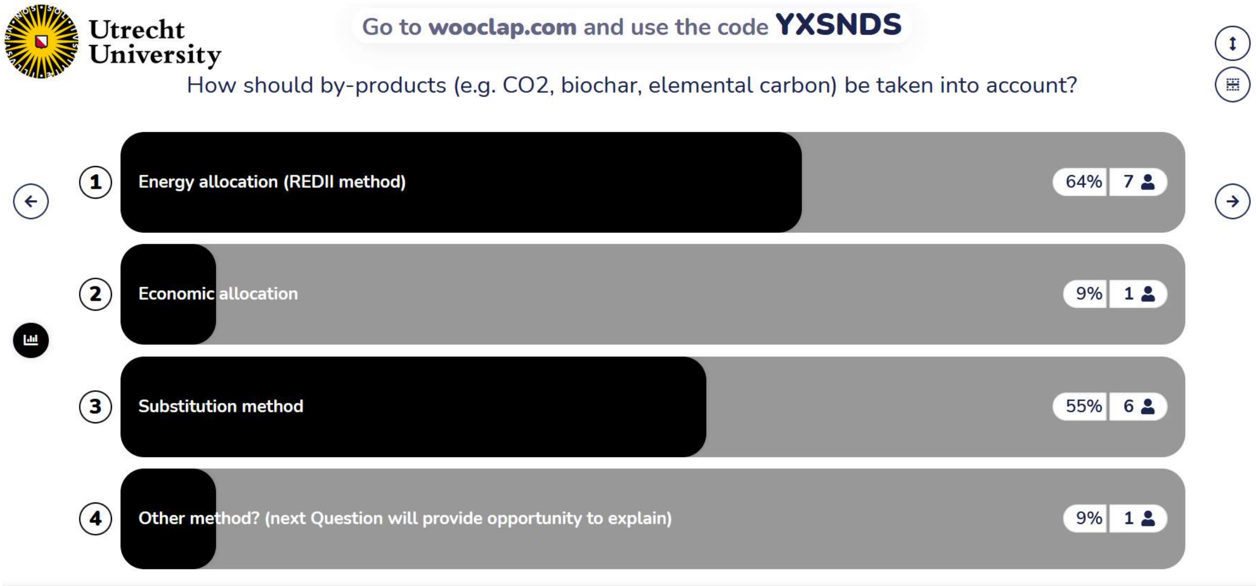
WOOCLAP RESULTS

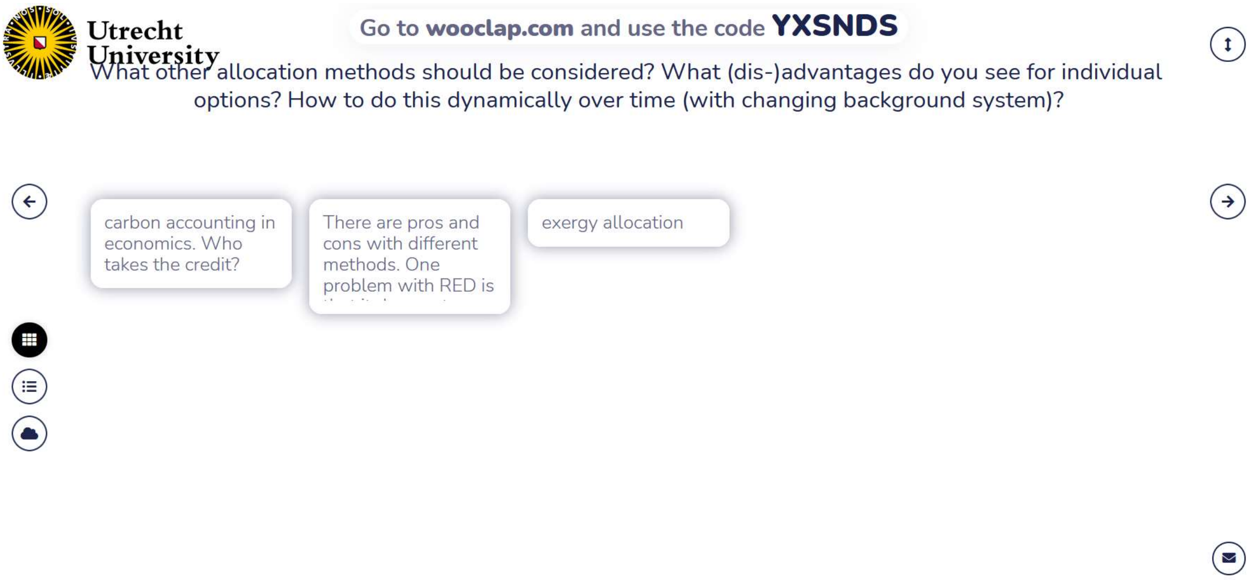





Utrecht University
Go to wooclap.com and use the code YXSNDS
Which other impact categories should be included in LCAs for H2 value chains ? (1 = should not be included, 3= may be included, but not strictly necessary, 5 = should definitely be included
1 (Natural) land use 3.9 5
2 Metal depletion 3.6 5
3 Acidification 3.3 5
4 Water depletion 4 5
5 Eutrophication 3.8 5
6 (Eco)-Toxicity / Human Toxicity 3.3 5
wooclap
Questions 3 / 6
Messages
100 %
Exit
12 / 17


Utrecht University
Go to wooclap.com and use the code YXSNDS
Which other impact categories should be considered? And why?
product, so H2 storage and losses before brought to market/ consumer
critical materials?
possible impact on biodiversity loss
employment; human health
SDGs
efficiency of production chain (for H2 use, but maybe also for H2
Regionalisation, resource democratisation, participation


Utrecht University
Go to wooclap.com and use the code YXSNDS
How should by-products (e.g. CO2, biochar, elemental carbon) be taken into account?
1 Energy allocation (REDII method) 64% 7
2 Economic allocation 9% 1
3 Substitution method 55% 6
4 Other method? (next Question will provide opportunity to explain) 9% 1


Utrecht University
Go to wooclap.com and use the code YXSNDS
What other allocation methods should be considered? What (dis-)advantages do you see for individual options? How to do this dynamically over time (with changing background system)?
carbon accounting in economics. Who takes the credit?
There are pros and cons with different methods. One problem with RED is
exergy allocation