sbh4 consulting

Decarbonisation, hydrogen and CCTUS training courses and public speaking events

Virtual and on-site training, seminars and events for the energy transition

Stephen B. Harrison, January 2024

Introduction to Stephen B. Harrison, Managing Director and founder of sbh4

Stephen B. Harrison is the founder and managing director at sbh4 GmbH in Germany. His work focuses on decarbonisation and greenhouse gas emissions reduction. Hydrogen and CCUS are fundamental pillars of his consulting practice.

Stephen has intimate knowledge of the full hydrogen value chain from commercial, technical, operational and safety perspectives. In 2022 Stephen supported the World Bank and IFC on hydrogen strategy development and electrolysis projects for Namibia and an enterprise in Pakistan. He has also served as the international hydrogen and CCUS expert for multiple ADB projects in Pakistan, Palau and Viet Nam. In 2021 Stephen specified more than 2GW of electrolysers for projects in Asia.

In 2023, Stephen was a technical assessor for the EU Innovation Fund, third round. This allocated more than €3 billion to multiple large-scale projects. His role focused on evaluation of electrolysis-based projects for e-fuels production and CCS projects. Stephen is now also supporting the EIB to provide Project Development Assistance to one of the successful Innovation fund applicants.

Stephen's background is in industrial and specialty gases, including 27 years at BOC Gases, The BOC Group and Linde Gas. For 14 years, he was a global business leader in these FTSE100 and DAX30 companies and spearheaded geographic expansion in China and other Asian countries. For 10 years at Linde, he managed two electrolyser product ranges with responsibilities ranging from supplier negotiations and technology selection to maintenance and after-sales service of installed equipment.

Stephen has extensive buy-side and sell-side M&A due diligence and investment advisory experience in the clean-tech sector. Private Equity firms, investment fund managers and hydrogen start-ups are regular clients. He also works closely with operating companies to support the development and execution of their industrial decarbonisation strategies.

As a member of the H2 View and **gas**world editorial advisory boards, Stephen advises the direction for the leading hydrogen-focused international publications. Through World Hydrogen Leaders he has led Masterclasses covering many hydrogen and hydrogen derivatives themes in virtual and live sessions.

Stephen was session chair for the e-fuels and hydrogen propulsion track at the Bremen Hydrogen Technology Exhibition in September 2023. He was also conference chair for day-2 of the CO2 utilisation Summit in Hamburg in 2023. Stephen also served on the Technical Committee for the Green Hydrogen Summit in Oman in December 2022 and the Advisory Board of the International Power Summit in Munich in September 2022.

Expertise across the full hydrogen value chain

Hydrogen production

- Electrolysis for green hydrogen
- Steam methane reforming
- Methane pyrolysis for turquoise hydrogen
- Gasification for hydrogen and syngas
- Hydrogen liquefaction to enable distribution
- Conversion of hydrogen to ammonia
- Air separation: oxygen for gasification and nitrogen for ammonia
- CCS: carbon capture and storage for blue hydrogen

Hydrogen distribution

- Hydrogen pipelines
- Hydrogen pipeline compression
- Hydrogen gas tube trailer filling
- Liquid hydrogen tanker distribution
- Liquid hydrogen shipping
- Liquid ammonia shipping
- LOHC hydrogen shipping

Hydrogen storage

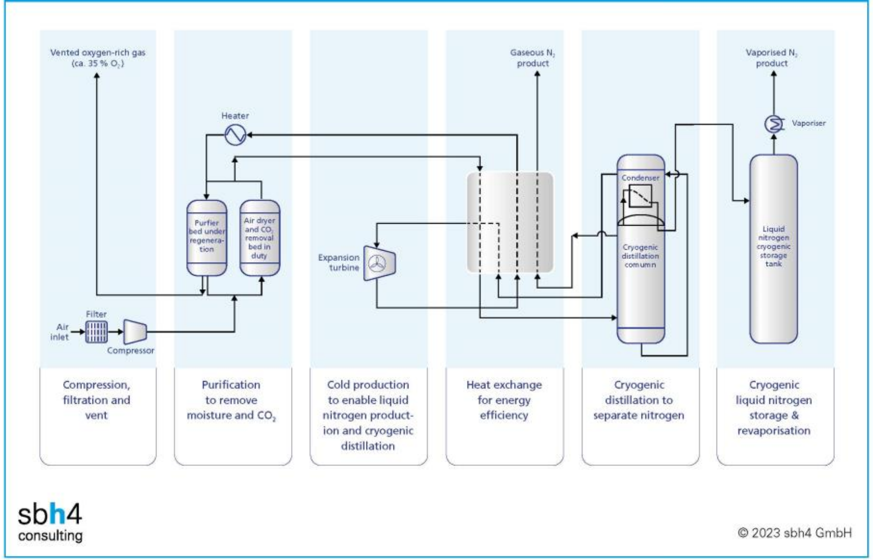
- Underground hydrogen storage
- Compressed hydrogen
- Liquid hydrogen
- Liquid ammonia terminals
- LOHC hydrogen terminals

Hydrogen utilisation in new and established applications

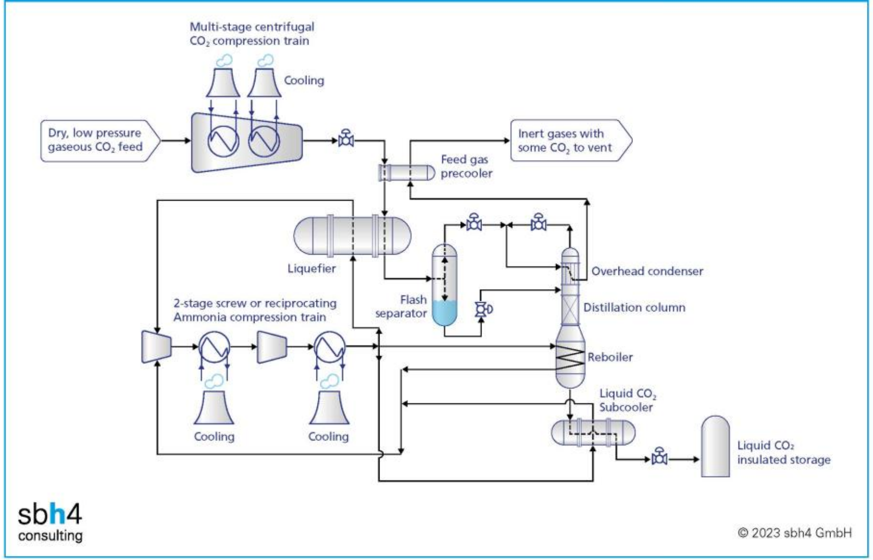
- Hydrogenation of edible oils to fats
- Biofuels hydrogenation
- Synthetic aviation fuels
- Hydrogen for backup power generation on fuel cells
- Hydrogen fired gas turbines for power generation
- Hydrogen conversion to ammonia
- Hydrogen for direct reduction of iron
- Hydrogen blending into gas pipelines
- Hydrogen for float glass making
- Fossil fuel desulphurisation and hydrotreating
- Hydrogen refuelling stations
- Hydrogen mobility
- Hydrogen fired burners
- Hydrogen conversion to methanol
- Methanation
- Annealing metals

Expertise in nitrogen and CO2 feedstock production for clean ammonia and e-methanol

Cryogenic Nitrogen Generator to Produce Geseous and Liquid Nitrogen

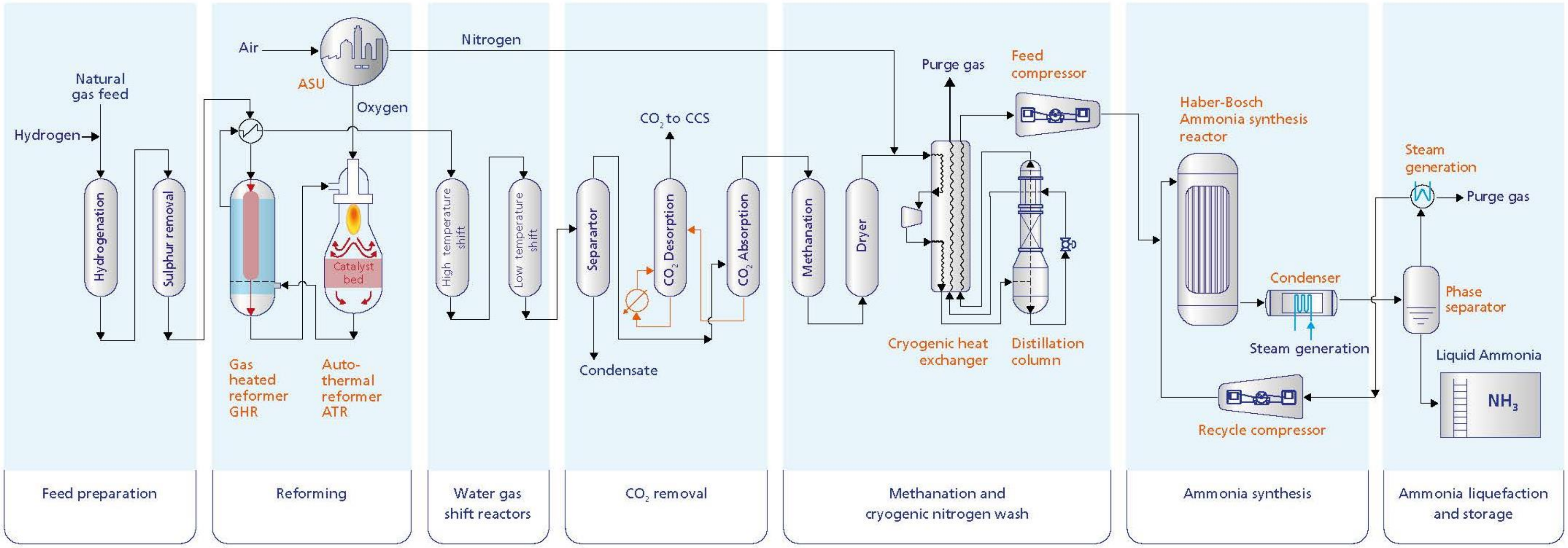


CO_2 Liquefier with Ammonia Refrigeration Cycle



Ammonia and methanol synthesis expertise

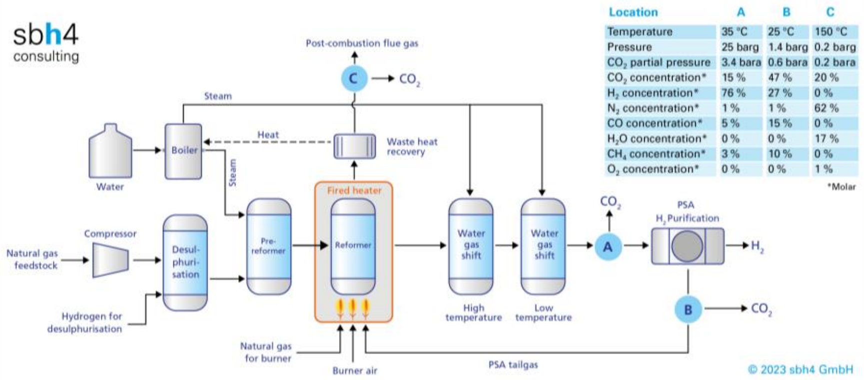
sbh4 consulting



Expertise across the full CO2 capture, transportation, storage and utilisation value chain

sbh4 consulting

Potential Locations for CO_2 Capture from Steam Methane Reforming

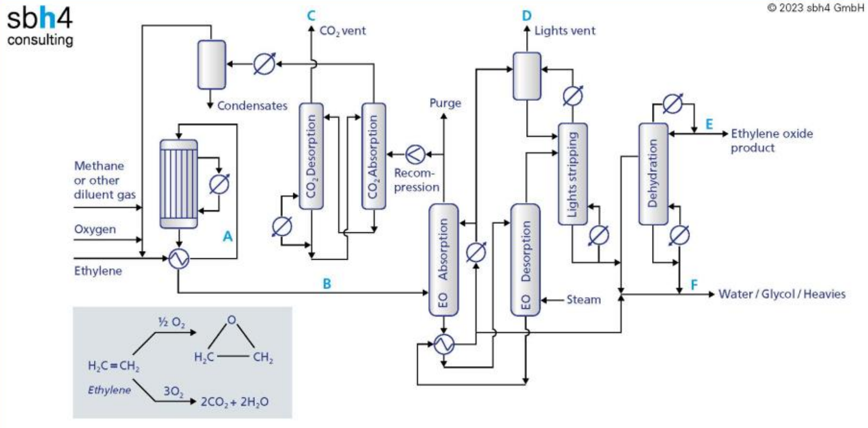


Location	A	B	C
Temperature	35 °C	25 °C	150 °C
Pressure	25 barg	1.4 barg	0.2 barg
CO_2 partial pressure	3.4 bara	0.6 bara	0.2 bara
CO_2 concentration*	15 %	47 %	20 %
H_2 concentration*	76 %	27 %	0 %
N_2 concentration*	1 %	1 %	62 %
CO concentration*	5 %	15 %	0 %
H_2O concentration*	0 %	0 %	17 %
CH_4 concentration*	3 %	10 %	0 %
O_2 concentration*	0 %	0 %	1 %

*Molar

	Location A	Location B	Location C
Process stage	Pre-PSA	Post-PSA	Post-combustion
Advantages	High pressure, high CO_2 concentration, highest CO_2 partial pressure, lowest unit cost of CO_2 capture from Amine Solvent or VSA processes	Low flowrate (H_2 removed), highest CO_2 concentration	More than 90 % capture rate possible (captures process CO_2 and burner CO_2 emissions), low pressure location can be suitable for emerging CO_2 capture technologies such as TSA and mineralisation
Disadvantages	Max 70 % CO_2 capture rate possible (burner CO_2 emissions not captured), high flowrate (H_2 included)	Max 70 % CO_2 capture rate possible (burner CO_2 emissions not captured), low pressure	Low pressure, lowest CO_2 concentration, high flowrate due to combustion air, highest unit cost of CO_2 capture from Amine Solvent or VSA processes

Oxygen-fed Ethylene Oxide Production with Integrated CO_2 Capture



	A: Reactor feed	B: Reactor outlet	C: CO_2 vent	D: Lights vent	E: EO Product	F: Water
Ethylene	34.6 %	25.4 %	0.4 %	64.6 %		
Ethylene oxide (EO)		2.1 %			99.7 %	5.8 %
Oxygen	23.4 %	3.9 %		0.8 %		
Methane	34.6 %	57.2 %	0.4 %	11.0 %		
Water	4.2 %	3.7 %	1.7 %		0.2 %	94.2 %
Carbon Dioxide (CO_2)	3.2 %	7.7 %	97.5 %	23.6 %	0.1 %	

Training and seminar speaker: delivery formats

Virtual sessions via Zoom or Teams

Virtual training can be provided using Zoom or Teams. Benefits of this format include:

- Increased convenience and flexibility
- Increased virtual collaboration
- Accessibility for a diverse international team
- Affordability

On-site format

- **On-site training** can be also provided. Benefits of this include format:
- More interaction with the trainer
- Active collaboration.
- **Customised courses** can be discussed, for example: half of one course combined with half of another course within a 3-hour slot, or a full day combining two 3-hour courses.

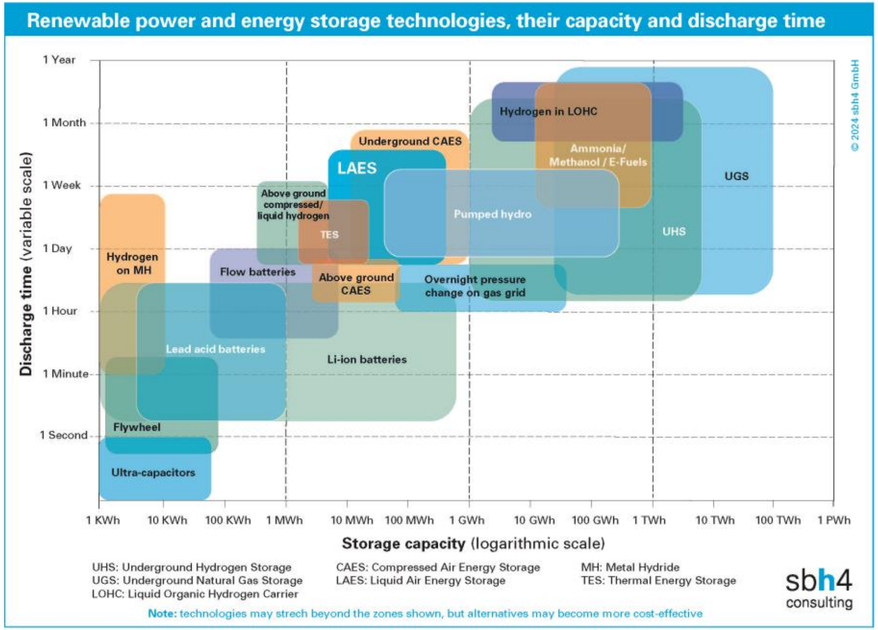
Seminar speaker for your customer events

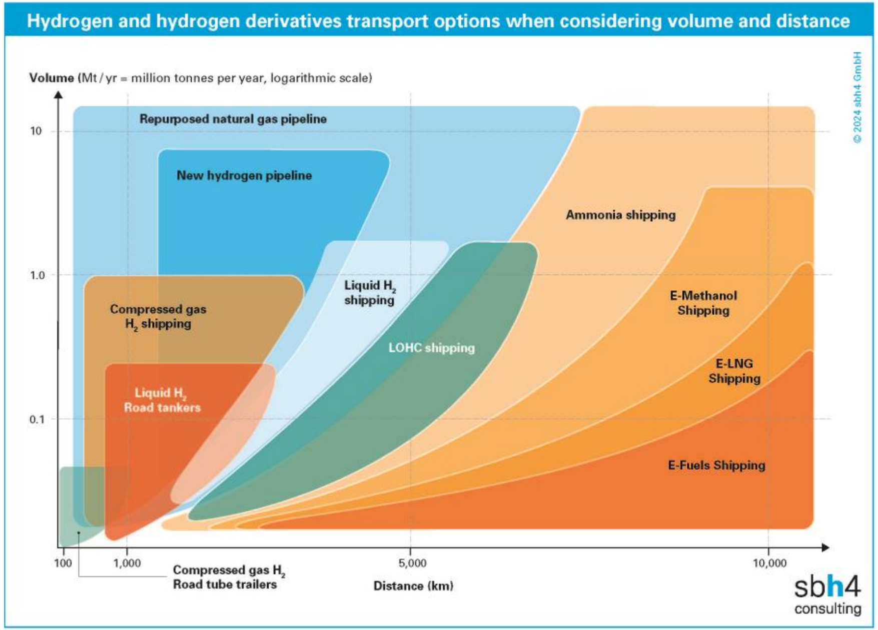
sbh4 consulting

- Aside from being an expert in the hydrogen and CCUS fields, Stephen has a vast experience delivering in-person seminars and online webinars on the growth potential, technologies and challenges within the world of hydrogen and broader decarbonisation topics.
- With his 33 years of experience in this industry, his skills in public speaking, many years operating at C-level, and fluency in both English and German, Stephen is an exceptional speaker for those interested in the hydrogen economy, decarbonisation and the energy transition.

Training approach and example training material

Solutions oriented, technology agnositc approach to allow genuinely objective assessment of strategic options

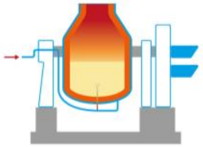


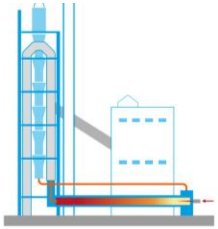


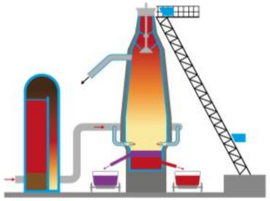
Decarbonisation cases and technologies from a broad range of CO2-intensive industrial and transportation sectors

Notes:
- CO_2 emissions are also associated with the energy and power requirements for this industry sector
- These can potentially be decarbonised with renewable power and electrical heating or microwaves
- CCS to capture CO_2 from the process and / or the associated energy production is possible


Steam Methane Reformer


Aluminium smelting


Calciner tower & clinker kiln


Blast furnace

	Oil refining	Aluminium smelting	Cement making	Iron making
Application that releases CO_2	Hydrogen production from methane reforming for fuels desulphurisation	Reduction of alumina to aluminium using graphite electrodes	Reduction of limestone to calcium oxide	Reduction of iron ore to iron using coke
Chemical reaction pro-ducing CO_2	$CH_4 + H_2O \rightarrow CO + 3H_2$ $CO + H_2O \rightarrow CO_2 + H_2$	$2Al_2O_3 + 3C \rightarrow 4Al + 3CO_2$	$CaCO_3 \rightarrow CaO + CO_2$	$2Fe_2O_3 + 3C \rightarrow 4Fe + 3CO_2$ $Fe_2O_3 + 3CO \rightarrow 2Fe + 3CO_2$
Decarbonisation approach for CO_2 generated by the process	Use turquoise hydrogen or green hydrogen to avoid the reforming reaction; or feed the reformer with biomethane instead of natural gas	Use carbon from turquoise hydrogen production instead of carbon from fossil fuels to make the electrodes	Replace a portion of the lime-stone with alternative materials such as calcined clay to make clinker for cement	Use hydrogen instead of coke; or substitute coke with carbon from turquoise hydrogen production
Reactions for the decar-bonised process	As above using renewable methane	As above using renewable graphite electrodes	Above reaction can only partially be avoided	As above using renewable carbon, or use hydrogen: $Fe_2O_3 + 3H_2 \rightarrow 2Fe + 3H_2O$
Other industries with similar applications	Ammonia, Urea, Methanol, Gas-to-liquids	Gold and silver refining, electric arc furnace to melt scrap steel	– Lime making, as above – Refractory materials, $MgCO_3 \rightarrow MgO + CO_2$ – Glass making Na_2CO_3, $CaCO_3$, $MgCO_3$	None

Concise presentation of comparative data to put options into context and support evaluation of strategic options

sbh4 consulting

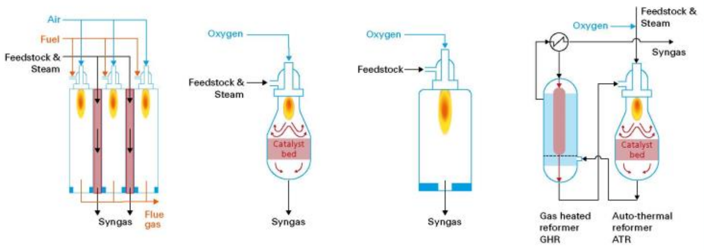
	Hydrogen Gas	Liquid Hydrogen	Liquid Ammonia (Green Ammonia)	Liquid Methanol (eMethanol)	Dimethylether (eDME)	Liquefied Natural Gas (eLNG)	Synthetic Aviation Kerosene (eSAF)
Ideal universal reaction	Compressed H_2	Liquefied H_2	$3H_2 + N_2 \rightarrow 2NH_3$	$3H_2 + CO_2 \rightarrow CH_3OH + H_2O$	$6H_2 + 2CO_2 \rightarrow CH_3OCH_3 + 3H_2O$	$4H_2 + CO_2 \rightarrow CH_4 + 2H_2O$	$10CO_2 + 31H_2 \rightarrow C_{10}H_{22} + 20H_2O$
Hydrogen yield	100 %	100 %	100 %	4/6 = 67 %	6/12 = 50 %	4/8 = 50 %	22/62 = 35.5 %
Volumetric energy density, LHV (MJ/L)	2.43 - 6.8	8.52	12.7	15.7	18.7 Liquefied gas at 20°C	22.2	35
Gravimetric energy density, LHV (MJ/kg)	120	120	18.6	19.9	28.4 Liquefied gas at 20°C	48.6	42.2
Infrastructure readiness for large scale deployment in mid-term	Low	Low	High	High	High	High	High
Transportation and storage temperature	Ambient	-253 °C	-33.3 °C	Liquid at ambient temperature	Liquefied gas at 4.2 bar 20°C	-162 °C	Ambient
Transportation and storage phase and pressure	Compressed gas at 250 to 700 bar	Liquid at amos-pheric pressure	Liquid at amos-pheric pressure	Liquid at amospheric pressure	Liquefied gas at 4.2 bar 20°C	Liquid at amospheric pressure	Liquid at amospheric pressure
Density	0.017 kg/L	0.071 kg/L	0.68 kg/L	0.79 kg/L	0.66 kg/L Liquefied gas at 20°C	0.46 kg/L	0.83 kg/L
Toxicity	Non toxic	Non toxic	TWA 25 ppm	TWA 200 ppm	TWA 1,000 ppm	TWA 1,000 ppm	TWA 30 ppm
Flammability (% in air)	4 - 74 %	4 - 74 %	14.8 - 33.5 %	6.0 - 36.5 %	3.4 - 18 %	4 - 15 %	0.7 - 4.8 %

Comparative cases to support technology evaluation and selection

SMR, ATR, POX and GHR processes for syngas production

Notes:

- In the SMR the air/fuel combustion reaction takes place in a separate part of the process to the reforming reaction
- SMR may alternatively be side-fired or upwards-fired
- Shaded area denotes catalyst bed
- GHR may be combined with POX instead of ATR

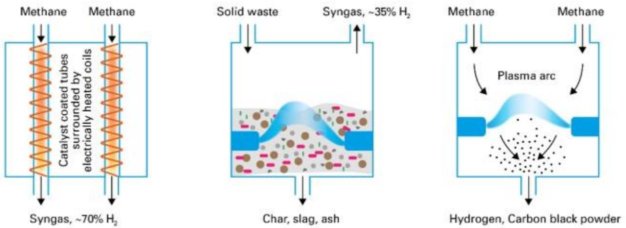


Process	Steam Methane Reforming – SMR	Auto Thermal Reforming – ATR (Oxidative Steam Reforming)	Partial Oxidation – POX (Gasification)	Gas Heated Reactor (GHR)
Carbon feedstock	Natural gas, refinery gas or naphtha	Natural gas or light gaseous hydrocarbons	Gaseous, liquid or solid hydrocarbons	Natural gas or light gaseous hydrocarbons
Oxygen feedstock	Air for fuel combustion to heat the process (not used for hydrogen generation in the SMR reactor tubes)	Oxygen from ASU fed with controlled stoichiometry to limit CO_2 generation	Oxygen from ASU fed with controlled stoichiometry to limit CO_2 generation	Oxygen from ASU fed with controlled stoichiometry to limit CO_2 generation
Steam feedstock	Yes	Yes, often from combined SMR	No	Yes
Catalyst required	Yes, Nickel	Yes, Nickel, Cobalt and others	Not for thermal POX	Yes, Nickel, Cobalt and others
Target chemical reactions	$CH4 + H_2O \rightarrow CO + 3H_2$	$CH_4 + H_2O \rightarrow CO + 3H_2$ $2CH_4 + O_2 \rightarrow 2CO + 4H_2$	$2CH_4 + O_2 \rightarrow 2CO + 4H_2$	$CH_4 + H_2O \rightarrow CO + 3H_2$ $2CH_4 + O_2 \rightarrow 2CO + 4H_2$
Additional side reactions	$CO + H_2O \rightarrow CO_2 + H_2$	$CH_4 + O_2 \rightarrow CO_2 + 2H_2$	$CH_4 + O_2 \rightarrow CO_2 + 2H_2$	$CH_4 + O_2 \rightarrow CO_2 + 2H_2$
Energy required/released	Endothermic, requires heat input	Balance of endothermic and exothermic	Exothermic, releases heat for steam	Balance of endothermic and exothermic
Hydrogen content in syngas	~70%	~65%	~60%	~65%
Syngas pressure	15 to 40 bar	30 to 50 bar	40 to 80 bar	30 to 50 bar
Syngas temperature	850 °C	1000 °C	1400 °C	1000 °C

Electrically powered syngas and hydrogen production from hydrocarbons

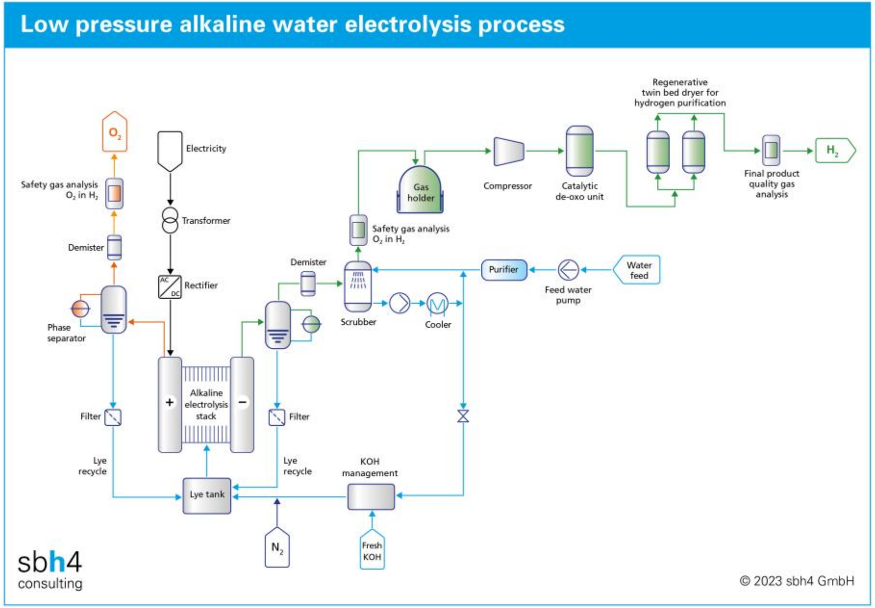
Notes:

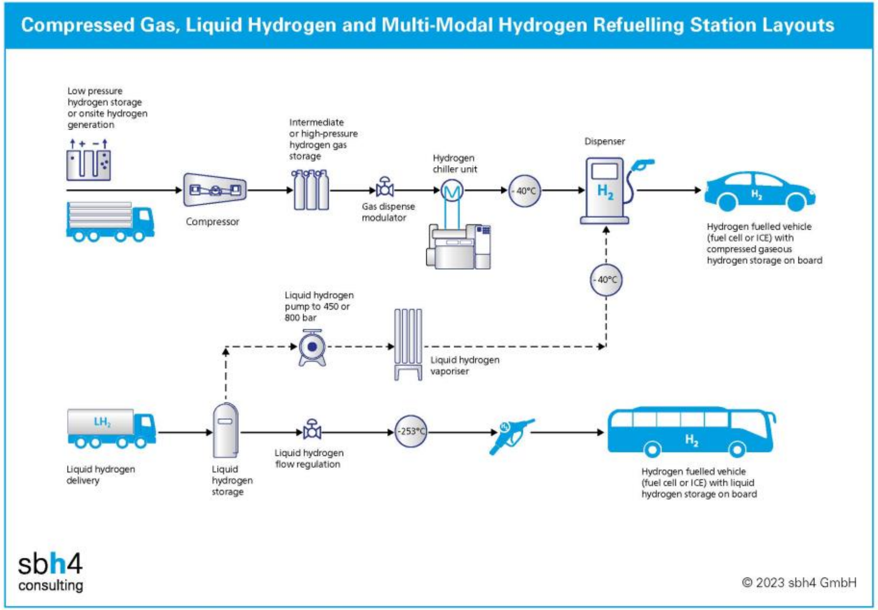
- Combustion-heated SMR is an alternative to electrical heating
- Thermal or catalytic methane pyrolysis are alternatives to plasma
- Steam may be added to the waste gasifier to increase hydrogen yield, if waste is very dry
- For the plasma gasification reaction stoichiometry shown, methane is used as an example hydrocarbon
- Electrolysis is an alternative electrically powered pathway to produce hydrogen from water (AEC, PEM, SOE) or syngas from steam and carbon dioxide (SOE)



Process	Electrical Steam Methane Reforming (eSMR)	Plasma Gasification of Solid Hydrocarbons, eg waste	Plasma Pyrolysis of Methane (Methane Cracking, Methane Splitting)
Carbon feedstock	Natural gas, refinery gas or naphtha	Municipal solid waste, dried waste water treatment sludge, biomass, waste paper, tyres, etc	Methane from natural gas
Target chemical reactions	$CH_4 + H_2O \rightarrow CO + 3H_2$	$Hydrocarbon + O_2 \rightarrow 2CO + 4H_2$ $Hydrocarbon + H_2O \rightarrow CO + 3H_2$	$CH_4 \rightarrow C + 2H_2$
Additional side reactions	$CO + H_2O \rightarrow CO_2 + H_2$	$Hydrocarbon + 2O_2 \rightarrow CO_2 + 2H_2O$	$2CH_4 \rightarrow C_2H_2 + 3H_2$
Carbon produced as	CO and CO_2	CO, CO_2, char, slag and ash	Carbon black powder
Product gas pressure	15 to 40 bar	Close to atmospheric pressure	Close to atmospheric pressure
Product gas temperature	~850 °C	~1000 °C	1500 to 2000 °C

Complex processes simplified to discrete unit operations for more detailed examination





Relevant real-life images to enrich the content with tangible examples and cases

sbh4 consulting

sbh4 consulting

Training course themes

- Each of the courses presented here is approximately 2 to 3-hours duration and suitable for a half-day training session.
- Two courses can be combined for a more diverse full-day session, examples of potential course combinations are given.
- Each course is designed to give an impactful overview suitable for investors, executives, senior managers, and policy makers.
- The courses are ideal for experienced professionals looking to leverage their functional expertise into the hydrogen economy.

1. Buy-side Due Diligence for the Energy Transition 1: Background and definitions

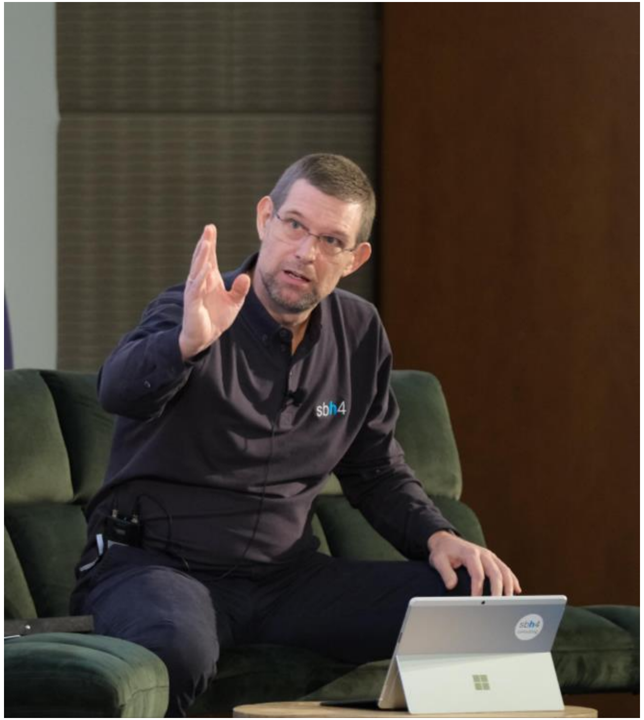
Combines well with Buy-side Due Diligence for the Energy Transition 2

This course is designed to make your investment origination and screening process more efficient. It will help you to prepare your project for the rigorous round of due diligence that awaits it. Case studies from electrofuels and SAF projects will be used to characterise transactions, projects and technologies relevant to the energy transition.

As a startup, you will maximise the impact of your capital raise process. The course will help buyers and sellers see the case from an alternative perspective. It will also give non-technical advisors an appreciation of what to look for in the technical and strategic aspects of a deal.

Agenda

- Types of due diligence and their role in project finance and investment
- What should an ideal project or technology look like?
- Risk tolerance and expected financial returns
- Debt for large, low-risk capital versus equity participation
- Decarbonisation mandates and portfolio balancing for ESG and impact investing
- TRL, CRL and MRL – maturity and risk of the technology components
- The whole may be greater than the sum of the parts: process risk and scale up risk
- Project risk and project maturity
- Risk mitigation through technical, operational and product mix levers
- Matching investment opportunities to investor and lender profiles



2. Buy-side Due Diligence for the Energy Transition 2: Putting Theory Into Practice

Combines well with Buy-side Due Diligence for the Energy Transition 1

sbh4 consulting

This course is designed to make your investment origination and screening process more efficient. It will help you to prepare your project for the rigorous round of due diligence that awaits it. Case studies from electrofuels and SAF projects will be used to characterise transactions, projects and technologies relevant to the energy transition.

As a startup, you will maximise the impact of your capital raise processes. The course will help buyers and sellers see the case from an alternative perspective. It will also give non-technical advisors an appreciation of what to look for in the technical and strategic aspects of a deal.

Agenda

- The fundamentals of sell-side and buy-side project finance due diligence
- Tempting pitfalls that the “sell-side” may fall into
- Fatal mistakes that the “buy-side” may inadvertently make
- SAF-related project case studies and examples
- The essentials of sell-side and buy-side technology investment due diligence
- Tempting pitfalls that the “sell-side” may fall into
- Fatal mistakes that the “buy-side” may inadvertently make
- SAF-related technology case studies and examples

3. An introduction to Hydrogen
Combines well with any other course

The hydrogen economy is with us and is here to stay. Decarbonisation and the energy transition are "here and now" topics. The momentum and urgency are visible through project announcements, investments, and regulatory influences.

This short course will put hydrogen and hydrogen derivatives into context. You will have the chance to ask questions or raise concerns that you might have about the emerging hydrogen economy in a friendly environment.

Agenda

- Green electrons are good, but not enough – why we need hydrogen
- The hydrogen value chain – production, storage, distribution, and utilisation
- Making hydrogen – green, grey, blue and a rainbow of colours
- Decarbonising hydrogen production: the transition from grey to green
- Decarbonising transport and industry with hydrogen and hydrogen derivatives
- Can hydrogen ever replace fossil fuels?
- Hydrogen as hydrogen, or hydrogen derivatives
- Hydrogen trade – linking producers and consumers
- Losses all the way – is it really worth it?

4. Mature Electrolysis Technologies for Green Hydrogen & Green Ammonia Projects

Combines well with Emerging and Challenger Electrolysis technologies, or Ultrapure Water and Lye for Electrolysis

sbh4 consulting

Green hydrogen is becoming synonymous with electrolysis of water with renewable power. And, accordingly, the scale and breadth of electrolyser technologies is in an exponential phase of growth. Salt-water electrolysis may be the answer for offshore hydrogen generation on floating wind turbines and arid coastal regions with ideal wind and solar conditions. There are numerous additional examples of application niches and innovative electrolyser solutions.

This course will provide tangible examples of technologies for green hydrogen generation from electrolysis pathways. Many of the electrolysis technologies covered in this course have the potential to become mainstream green hydrogen production routes in future decades and will challenge established equipment and well-known electrolyser industry names. If you are investing in the hydrogen economy or considering technologies to implement for your projects, thinking through the best fit solution and likely winners and losers will be fundamental to your analysis. This course will provide some insights support that process.

Agenda

- Wind, solar and hydro renewable power pull for different electrolyser technologies
- The impact of electrolyser capex & utilisation on green hydrogen project economics
- Alkaline and PEM technologies, the established solutions
- SEOC and AEM technologies, rising to challenge
- Containerised, standardised products vs engineer to order solutions
- Disruptive technologies that could steal the lion's share of the market in coming decades
- Supply chain de-bottlenecking and achieving GW scale production capacity

5. Emerging and Challenger Electrolysis Technologies
Combines well with Mature Electrolysis Technologies for Green Hydrogen & Green Ammonia Projects or Ultrapure Water and Lye for Electrolysis

sbh4 consulting

Green hydrogen is becoming synonymous with electrolysis of water with renewable power. And, accordingly, the breadth of electrolyser technologies and technology innovators is in an exponential phase of growth. There are numerous additional examples of application niches and innovative PEM and alkaline electrolyser solutions. Salt-water electrolysis may be the answer for offshore hydrogen generation on floating wind turbines and arid coastal regions with ideal wind and solar conditions. AEM and Solid Oxide electrolysis are also emerging as potential winners.

This course will provide tangible examples of emerging and challenger technologies for green hydrogen generation from electrolysis. Many of the electrolysis technologies covered in this course have the potential to become mainstream green hydrogen production routes in future decades and will challenge established equipment and well-known electrolyser industry names. If you are investing in the hydrogen economy or considering technologies to implement for your projects, thinking through the best fit solution and likely winners and losers will be fundamental to your analysis. This course will provide some insights support that process.

Agenda

- The state of the art – introduction to electrolyser technologies
- R&D needs for alkaline and PEM technologies
- PEM and alkaline technology innovators
- AEM technologies and technology providers
- SOEC for hydrogen and Co-SOEC or CO2 electrolysis for syngas in industrial applications
- Disruptive and challenger electrolyser technologies

6. Ultrapure Water and Lye for Electrolysis

Combines well with Mature Electrolysis Technologies for Green Hydrogen & Green Ammonia Projects

sbh4 consulting

Green hydrogen is produced through the electrolysis of water. The purity of the water is critical to ensure longevity of the electrolyser. Often, the best location for renewable power generation is in arid locations where pure water is scarce. However, desalination of the sea water is a viable route to ensure plentiful water supply for electrolysis without stressing local freshwater systems.

The other 'hidden' utilities for electrolysis are the Lye, or electrolyte solution and nitrogen which is essential for safe operation of the electrolyser. Local production and access to these utilities is essential. This course will look at the technologies and processes required to produce, purify, store, and use these essential utilities and feedstocks. Safety considerations when handling these materials will also be presented.

Agenda

- Electrolysis technologies overview
- The problems with impurities
- Water purity, desalination, and purification
- Lye sourcing, storage, and electrolyte maintenance
- Nitrogen for daily operations and shut-down purging
- Nitrogen production or sourcing
- Safety implications of these utilities and feedstocks

7. Biomass to Green Hydrogen
Combines well with Waste to Hydrogen

Green hydrogen is becoming synonymous with electrolysis of water with renewable power. But the definition also covers other renewable pathways to hydrogen such as thermolysis of biomass or reforming of biomethane.

This course will provide tangible examples of technologies for green hydrogen generation from non-electrolysis pathways. Some of the processes are used at scale today; others are plans or pipedreams for the future. Many of the technologies covered in this course have the potential to become mainstream low-carbon hydrogen production routes in future decades.

If you are investing in the hydrogen economy or considering technologies to implement for your projects, thinking through the likely winners and losers will be fundamental to your analysis. This course will provide some insights support that process.

Agenda

- Biomass-rich municipal solid waste as a feedstock
- Woody biomass and agricultural wastes as feedstock
- Thermolysis technologies for biomass to hydrogen and other coproducts
- Wastewater / animal waste to biomethane to hydrogen with reforming
- Carbon-negative pathways

8. Waste to hydrogen
Combines well with Biomass to Green Hydrogen

Hydrogen enables 'sector-coupling'. Simply put, we can 'couple' the unrelated sectors of garbage collection and operation of a zero-emission bus fleet though the use of hydrogen to join the links in this value chain.

This course will provide tangible examples of chemcycling and waste to hydrogen pathways. Many of the technologies covered in this course are in use today and some will emerge to become mainstream clean energy generation routes in future decades.

If you are investing in the hydrogen economy or considering technologies to implement for your projects, thinking through the likely winners and losers will be fundamental to your analysis. This course will provide some insights support that process.

Agenda

- Chemcycling and its role in the waste management hierarchy
- Thermolysis of municipal solid waste and industrial wastes
- Review of commercialised technologies and others in development
- Hydrogen and other coproducts of thermolysis processes
- Waste incineration for power to hydrogen with electrolysis

9. Technologies for Turquoise Hydrogen
Combines well with Blue Hydrogen Production or Pathways to Low Carbon Hydrogen

Hydrogen production will scale up by several orders of magnitude in the coming decades and the range of low-carbon production technologies will diversify. Grey hydrogen today means small modular reactors (SMRs). Blue hydrogen for tomorrow will integrate those with carbon capture and storage (CCS) and see autothermal reforming (ATRs) become popular. Green and pink hydrogen produced on electrolysers from renewable and nuclear power will play a growing role. All of those are on the radar for the 2020s.

In addition, turquoise hydrogen will also become a mainstream low greenhouse gas emission hydrogen production technology. Turquoise hydrogen is made from methane using pyrolysis (also known as splitting, or cracking). When the process is fed with renewable electricity and biogas it has the potential to be carbon negative.

This course will introduce the main technologies for producing turquoise hydrogen and identify the companies leading their development and commercialisation. The course will also explore current and emerging high scale applications for the solid carbon and graphite that are produced through these processes.

Agenda

- Defining methane pyrolysis and turquoise hydrogen
- Plasma, catalytic and thermal technologies for methane pyrolysis
- Carbon allotropes and applications for the solid carbon co-products
- Carbon negative and carbon neutral pathways

10. Technologies for HRS

Combines well with Hydrogen & Derivatives as Heavy Transportation Fuels

sbh4 consulting

Hydrogen mobility is one of the best-known aspects of the hydrogen economy. However, the low volumetric energy density of hydrogen can make storage of hydrogen challenging. Therefore, high pressure gas or liquid hydrogen are required. Hydrogen refuelling stations (HRS) compress and store gaseous hydrogen or store and pump liquid hydrogen. The technologies behind the refuelling stations are complex diverse.

This course will provide examples of hydrogen refuelling station configurations and the equipment that is required to make them work. On-board hydrogen storage on fuel-cell electric vehicles will also be covered.

If you are involved in hydrogen mobility or hydrogen fuelling infrastructure development, this course will provide some insights into the technologies that are enabling this value chain.

Agenda

- The status of HRS infrastructure development and hydrogen mobility
- Hydrogen storage on board the fuel cell electric vehicles (FCEV)
- Gas and liquid supply modes to the refuelling station
- Technologies for hydrogen compression and pumping at the HRS
- High pressure gaseous hydrogen storage at the HRS
- Hythane and compressed natural gas (CNG) - hydrogen and natural gas

11. Hydrogen and Derivatives as Heavy Transportation Fuels Combines well with Technologies for HRS

sbh4 consulting

Green hydrogen can be converted to green ammonia, e-methanol, or synthetic e-fuels to enable long distance transportation. Aviation, railways, long distance trucking, shipping, and mining operations all require high powered engines and extended operating times. Selecting the most appropriate fuel for the use case is dependent on multiple factors beyond the cost of the fuel. Asset availability, fuel availability, refuelling times and range are all key to the overall business model.

If you are investing in the production, storage, distribution, or use of e-fuels then an appreciation of the alternatives is required. Understanding the market drivers and most likely use cases is essential. Furthermore, consideration of the transition requirements from fossil fuels and future operating cost implications will be beneficial. This course will provide insights support all these processes.

Agenda

- Transport sector decarbonisation
- Properties of an ideal clean heavy-duty transportation fuel
- Clean fuels for aviation
- Clean maritime fuels
- Clean fuels for mining vehicles
- Clean fuels for trains, trucks, and buses
- Hydrogen refuelling stations
- Safety precautions

12. SAF: Hydrogen and Derivatives as Aviation Fuels
Combines well with Technologies for Power to Liquids or Hydrogen and Derivatives as Heavy Transportation Fuels

sbh4 consulting

Hydrogen can be used directly as a fuel for flight. Hydrogen can also be converted to synthetic aviatio
enable long distance transportation on existing aircraft. Aviation requires high powered engines and e
times. There are multiple pathways to SAF and eSAF. Selecting the most appropriate fuel for the use c
on multiple factors beyond the cost of the fuel. Asset availability, repurchase costs, conversion costs a
overall business model in addition to fuel cost, availability, refuelling times, and range.

If you are investing in the production, storage, distribution, or use of SAF, eSAF or hydrogen for aviati
appreciation of the alternatives is required. Understanding the market drivers and most likely use cas
Similarly for aviation sector operators, understanding the range of fuels available is essential. Further
consideration of the transition requirements from fossil fuels and future operating cost implications w
This course will provide insights support all these aspects.

Agenda

- Transport sector decarbonisation
- Properties of an ideal clean aviation fuel
- Hydrogen as a fuel for aviation
- eSAF and the role of hydrogen in its production
- SAF and the role of hydrogen in its production through various pathways
- Case studies from hydrogen aviation pioneers

13. CCTUS (Carbon capture, transportation, utilisation & storage)

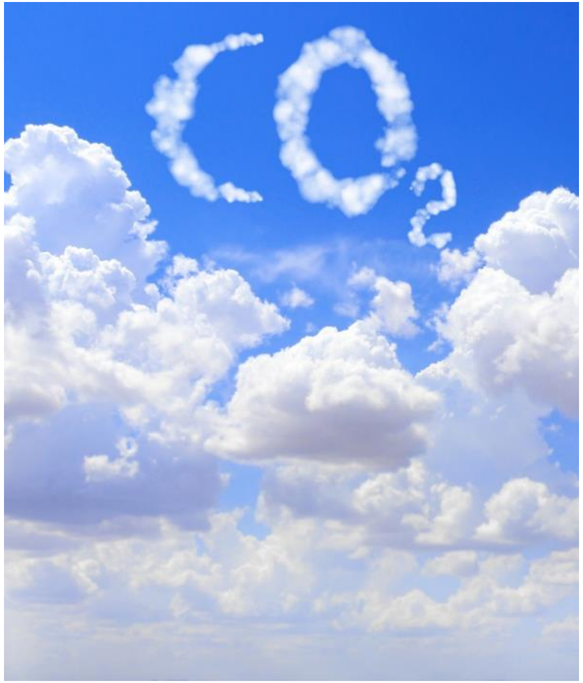
Combines well with Blue Energy Islands & Blue Ammonia or Low-carbon Hydrogen

sbh4 consulting

CCTUS is one of the most powerful tools for decarbonisation of existing assets. Furthermore, many chemical, biological and mineral processing applications liberate CO2 from within the process, so decarbonisation using hydrogen or electrification is not possible: CCTUS can help to solve the issues. However, underground CO2 storage is also a controversial topic - are there viable alternatives?

This course will provide tangible examples of technologies for carbon capture from flue gases and the ambient air. Pipeline transmission, liquefaction, terminals, and shipping infrastructure will also be covered. Drivers of the carbon capture and storage (CCTUS) business cases such as CO_2 emissions taxation and climate pledges will also be covered.

If you are investing in CCTUS, considering technologies for your projects, and thinking through the best fit solutions will be fundamental to your analysis. This course will provide insights support that process.



Agenda

- Mature and emerging CO_2 capture technologies for flue gas emissions
- Flue gas CO_2 pressure and concentration – the implications for carbon capture
- Direct air capture of CO_2
- Supercritical CO_2 compression and transmission in pipelines
- CO_2 liquefaction and liquid CO_2 shipping on purpose-built tankers
- Permanent underground CO_2 storage
- Mineralisation of CO_2

14. Pathways to Low-carbon Hydrogen

Combines well with Blue Energy Islands & Blue Ammonia or CCTUS

sbh4 consulting

Hydrogen production will scale up by several orders of magnitude in the coming decades. Electrolysers are currently operating at 10 to 20MW and already we have plans for GW schemes. Similar scaleup leaps are proposed for thermal hydrogen production processes.

This course will explain the current and proposed low-carbon Giga-scale hydrogen production technologies such as ATR, POX, pyrolysis, and utility scale electrolysis. The best-fit criteria to apply each of these technologies will be discussed.

Spotting the right technologies early can mean the difference between a good and an excellent project. If you are investing in the hydrogen economy or considering technologies to implement, thinking through the pros and cons of various options will be fundamental to your decision making. This course will provide some insights support that process.

Agenda

- Methane splitting (pyrolysis / cracking) – turquoise hydrogen
- Autothermal reforming (ATR) and partial oxidation (POX) for natural gas conversion to hydrogen
- Coal, vacres and petcoke gasification
- Combining thermolysis pathways with carbon capture and storage (CCS) to produce low-carbon hydrogen
- Utility scale electrolysis from renewable power

15. Blue Hydrogen, Ammonia & Methanol

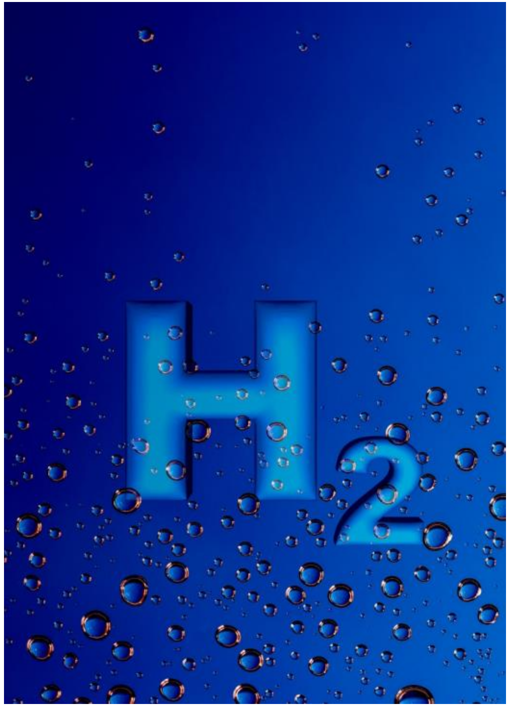
Combines well with Giga-scale Low-carbon Hydrogen or CCTUS

sbh4 consulting

Hydrogen and ammonia production will scale up by several orders of magnitude in the coming decades. Blue hydrogen and ammonia will be produced using carbon capture and storage (CCS) retrofits to existing steam methane reformers. And to generate the additional capacity, new on-purpose blue hydrogen and ammonia plants will be built as integrated energy islands.

This course will explain how thermochemical hydrogen production technologies such as steam methane reforming (SMR), autothermal reforming (ATR), gas heated reforming (GHR) and partial oxidation (POX) fit with integrated carbon capture. The optimum solution for on-purpose blue hydrogen and ammonia production is different to the optimum solutions that have been implemented in the past for grey hydrogen production. Value stacking to profitably utilise all the available process streams is also key to competitive success in the international energy market. Up to date project case studies will be used to provide real life examples.

Using the right technologies can mean the difference between a good and an excellent project –profit margins, energy efficiency and return on capital are at stake. If you are investing in the hydrogen economy or considering technologies to implement, thinking through the options will be fundamental to your decision making. This course will provide some insights support that process.



Agenda

- Integration of SMR/ATR/GHR/POX plus CCS
- Hydrogen vs syngas product requirements and their implication on technology selection
- Hydrogen and CO2 pipeline pressure implications for technology selection
- Value stacking with Ammonia production
- Integration of low-carbon power generation and energy storage

16. Shipping Hydrogen & Derivatives
Combines well with Technologies for Power to Liquids or Technologies for Green ammonia

sbh4 consulting

Green ammonia is emerging as the preferred international distribution mode for green hydrogen from GW-scale renewable power and electrolysis projects. Methanol is another hydrogen derivative that will enable sustainable energy exports. Liquid organic hydrogen carriers, liquid hydrogen and compressed gaseous hydrogen shipping are also likely to become mainstream.

This course will provide tangible examples of technologies for green ammonia and methanol generation from electrolysis and renewable power pathways. Shipping infrastructure and terminals will also be covered, as will key demand drivers such as ammonia-fired power generation and the use of hydrogen, ammonia, or methanol as a maritime fuel.

If you are investing in green ammonia, methanol, or hydrogen as clean synthetic fuels, considering the best technologies for your projects, and thinking through the best fit solutions will be fundamental to your analysis. This course will provide insights support that process.

Agenda

- Liquid hydrogen transportation as a shipping cargo on purpose-built tankers
- Compressed hydrogen gas shipping on purpose-built tankers
- Liquid organic hydrogen carriers for transportation of hydrogen
- Conversion of hydrogen to ammonia for transportation as a shipping cargo
- Conversion of hydrogen to methanol for transportation as a shipping cargo
- Simultaneous use of the cargo as the fuel for the tanker doing the shipping

17. Technologies for Power to Liquids
Combines well with Shipping Hydrogen & Derivatives

Green hydrogen can be converted to e-methanol and other liquid e-fuels such as e-kerosene for aviation. These e-fuels are produced using a range of 'Power to Liquids' or PtL technologies. This course will provide tangible examples of the key technologies required for PtL pathways including electrolysis and the downstream conversion of hydrogen, CO2, and syngas to liquid fuels. Technologies for point source CO2 capture and direct air capture (DAC) of CO2 to provide the backbone of the e-fuel hydrocarbon molecules will also be presented.

If you are investing in clean synthetic e-fuels production, considering the best technologies for your projects, and thinking through the best fit solutions will be fundamental to your analysis. This course will provide insights support those processes.

Agenda

- The motivation to convert green hydrogen to e-fuels
- Chemical pathways to synthetic hydrocarbons
- Alkaline electrolysis technology pathways
- Solid oxide electrolysis technology pathways
- Point source CO2 capture and distribution
- Direct air capture of CO2
- Methanol synthesis and methanol to gasoline
- Fischer Tropsch to generate syn-crude

18. Technologies for Green ammonia
Combines well with Shipping Hydrogen & Derivatives

Green hydrogen can be converted to green ammonia to enable long distance transportation. Green ammonia is emerging as the preferred international distribution mode for green hydrogen from GW-scale renewable power and electrolysis projects.

This course will provide tangible examples of technologies for green ammonia production. Shipping infrastructure and terminals will also be covered, as will key demand drivers such as ammonia-fired power generation. The potential to crack ammonia to re-convert it to hydrogen will also be reviewed.

If you are investing in green ammonia, as a clean fuels, considering the best technologies for your projects, and thinking through the best fit solutions will be fundamental to your analysis. This course will provide insights support that process.

Agenda

- The motivation for green ammonia
- The green ammonia value chain
- Air separation from renewable power to generate green nitrogen
- Green ammonia synthesis from green nitrogen and green hydrogen
- Green ammonia shipping in dedicated vessels and flexi-cargo CO2 / ammonia tankers
- Green ammonia terminals and cracking for reconversion to hydrogen
- Applications of green ammonia

19. Hydrogen Transmission in Pipelines
Combines well with Underground Hydrogen Storage

sbh4 consulting

Hydrogen distribution is a challenging aspect of the hydrogen economy. The low volumetric energy density of high pressure gaseous and liquid hydrogen can make distribution of large quantities of hydrogen over long distances expensive. Hydrogen transmission and distribution in pipelines is a cost-effective mode, but questions are often asked about the possibility to re-purpose existing natural gas pipelines for this purpose.

This course will provide examples of major schemes that have been proposed for pipeline hydrogen transmission and distribution and outline the testing work that has taken place to confirm whether hydrogen can indeed be admixed into natural gas and under what conditions existing infrastructure can be adapted for use with hydrogen.

If you are considering hydrogen distribution, understanding the safety considerations and technology will be fundamental. This course will provide some insights to support that process.

Agenda

- Materials compatibility issues with hydrogen and pipeline steel
- Large-scale hydrogen transmission network proposals with integrated energy storage
- The differences between natural gas and hydrogen compression
- Special considerations for admixing hydrogen in natural gas
- Transmission versus distribution, which infrastructure is more adaptable to hydrogen
- The alternative to hydrogen transmission: decentralised hydrogen production

20. Underground Hydrogen Storage
Combines well with Hydrogen Transmission in Pipelines

sbh4 consulting

When hydrogen replaces natural gas for heating, the demand profile will be highly seasonal according to how warm or cold the weather is. Hydrogen production from hydroelectric power can also be highly seasonal according to how much rainfall or snowmelt is entering the river system. High-capacity storage is required to ensure cost-effective hydrogen production or utilisation in seasonal situations. Underground hydrogen storage in man-made salt caverns is one of the most cost-effective solutions, where the underground geography permits. Other high-capacity storage options exist.

This course will cover some of the high-capacity storage options and explain in which situations each may be suitable. The seasonality of some production and use-cases will also be covered to underline the importance of high-capacity hydrogen storage.

If you are investing in hydrogen value chains or considering the most appropriate technologies to implement for your projects, this course will provide insights to support your decision making. Future operators and owners of high-capacity underground hydrogen storage will also gain exposure to the technique.

Agenda

- The need for energy storage as variable renewable energy production scales up
- Time-shifting with seasonal hydrogen storage and seasonal hydrogen demand
- Large-scale hydro-electric power to hydrogen with seasonal energy storage
- Underground storage of hydrogen in salt caverns, depleted gas fields and aquifers
- Underground storage of natural gas and underground methanation

21. Power to X to Power

Combines well with Hydrogen Transmission in Pipelines or Underground Hydrogen Storage

Green hydrogen from electrolysis is the core of power to hydrogen. From these green hydrogen molecules power generation is possible. Alternatively, green hydrogen can be converted to green ammonia, e-methanol, or e-methane. Each of these fuels can be used for power generation. There are losses in the conversions, but the need for power and energy storage can drive the business case for these processes.

If you are investing in the Power to X, X to power or the full cycle of Power to X to Power, then an appreciation of the technologies involved is required. Understanding the market drivers and options for the potential molecules for use in Power to X to Power is essential. This course will provide insights support all these processes.

Agenda

- Power sector decarbonisation
- Long duration energy storage and the potential role of hydrogen / derivatives
- High-capacity underground hydrogen storage in salt caverns
- Hydrogen blending with natural gas for power generation
- Green ammonia, e-methanol and hydrogen fired gas-turbines
- Green ammonia co-firing with methane and coal
- Fuel cells for small-scale X to Power

22. Natural (Gold / White) Hydrogen

Combines well with Underground Hydrogen Storage

White hydrogen is shorthand for natural hydrogen that has been produced underground through geological or biological reactions. Geological exploration has previously centred around finding minerals, oil, and gas. However, this is likely to include looking and drilling for hydrogen in the future. The appeal of white hydrogen as a potential source of abundant, low-cost hydrogen is clear. But many questions remain.

If you are investing in the production or hydrogen, then an appreciation of the alternatives is required. White hydrogen may feature as one of these alternatives in the future. Either as your source, or a competitive option to your mode of production. Understanding the market drivers and the economics of the most competitive sources is essential. This course will provide insights into all these areas.

Agenda

- What is 'white' hydrogen and how does it fit into the rainbow of colours?
- Where can white hydrogen be found?
- Is white hydrogen a finite resource?
- Matching sources and sinks – distribution of white hydrogen to demand centres
- The economics of white hydrogen
- Lessons from mining, oil, and gas
- Hydrogen underground – clear hydrogen, UHS and hydrogen for methanation

23. Hydrogen Safety Essentials
Combines well with Hydrogen Safety Masterclass

sbh4 consulting

Perhaps you are financing an investment in hydrogen or will be processing this gas in the future as an operator. Or you may be curious about how the public at large will react to hydrogen hazards, based on what they have heard about the Hindenburg airship explosion.

This short course will put the risks of hydrogen into context with real facts and clear examples. You will have the chance to ask questions or raise concerns that you might have about hydrogen safety in a friendly environment.

Agenda

- The psychology of safety: perception matters
- Will safety concerns stop the development of the hydrogen economy?
- Essential safety terminology
- Safety issues and precautions taken with hydrogen production
- Safety issues related to high pressure compressed gaseous hydrogen / liquid hydrogen storage and distribution
- Safety issues and precautions taken related to hydrogen mobility

24. Hydrogen Safety Masterclass
Combines well with Hydrogen Safety Essentials

sbh4 consulting

Perhaps you are financing an investment in hydrogen or will be processing this gas in the future as an operator. Or you may be curious about how the public at large will react to hydrogen hazards, based on what they have heard about the Hindenburg airship explosion.

This short course will put the risks of hydrogen into context with real facts and clear examples. You will have the chance to ask questions or raise concerns that you might have about hydrogen safety in a friendly environment.

Agenda

- Risk, hazard and incident frequency: definitions and real-life mitigation to reduce risk
- The must-know safety aspects for production, distribution, storage and use of hydrogen
- The main risks of hydrogen and how these compare to other green fuels and hydrogen-rich energy carriers such as ammonia and methanol
- Second-order environmental implications of 'green' hydrogen

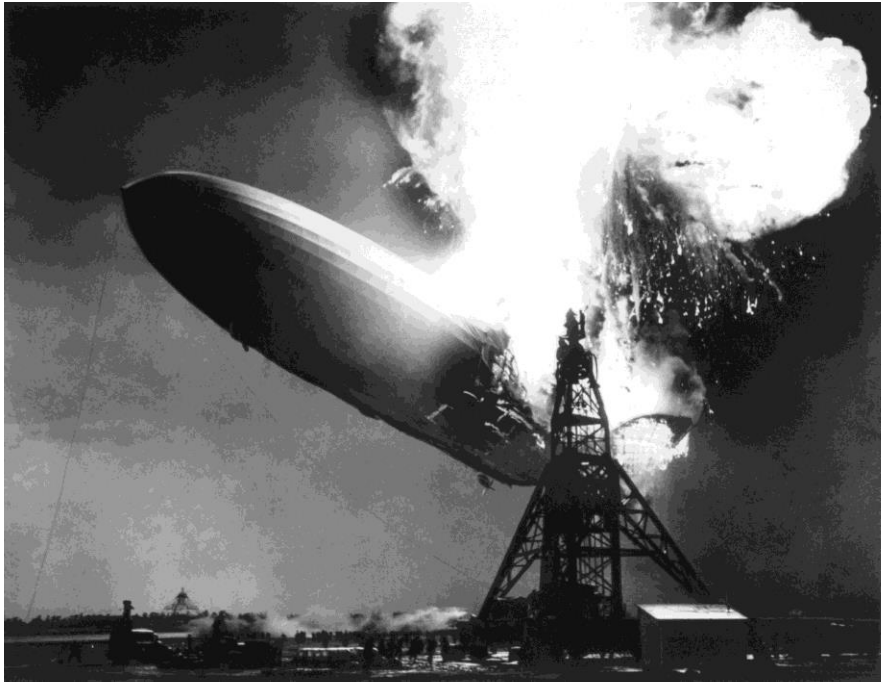
25. Ensuring safe development of the hydrogen economy Combines well with An Introduction to Hydrogen

Perhaps you are financing an investment in hydrogen or will be processing this gas in the future as an operator. Or you may be curious about how the public at large will react to hydrogen hazards, based on what they have heard about the Hindenburg airship explosion.

This short course will put the risks of hydrogen into context with real facts and clear examples. You will have the chance to ask questions or raise concerns that you might have about hydrogen safety in a friendly environment.

Agenda

- The professional language and terminology of safety
- Overview of the main risks of hydrogen and how these compare to other fuels and gases that are in daily use
- The must-know safety aspects of compressed high-pressure hydrogen and liquefied cryogenic hydrogen
- Tools in use and precautions taken to minimise the risks of hydrogen



sbh4
consulting

sbh4
consulting