UKRI Co-ordinator for Research Challenges in Hydrogen and Alternative Liquid Fuels

Report on Workshop findings: Alternative Liquid Fuels

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1. Background and Objectives

The Co-ordinator for Research Challenges in Hydrogen and Alternative Liquid Fuels project (UK-HyRES, https://ukhyres.co.uk/) is funded by the UKRI for six months from 1 April 2022. UK-HyRES is engaging nationally with academic, industrial and policy stakeholders to discuss and identify research challenges the solutions to which will accelerate the deployment of sustainable H&ALF technologies to help the country achieve its legally binding net zero carbon emissions target by 2050 and hence contribute to mitigating disastrous global heating. One of the main engagement routes is via facilitated workshops which are promoted widely in H&LF and associated communities in the UK. The outcomes from these workshops will inform and shape the development of a UKRI Centre of Research Excellence in HA&LFs to start in 2023.

On the **20th July 2022** UK-HyRES held a fourth themed workshop, which was conducted online via Zoom at 09:30-12:30 with **64 attendees** (~ 60% >2hrs). Building on the success of the UK-HyRES launch event, this Workshop focused on the **Alternative Liquid Fuels** (ALFs). This is a summary report of the workshop compiled by UK-HyRES researchers Rajan Jagpal (Bath), Diarmid Roberts (Sheffield) and Mengfei Zhang (Warwick) and reviewed and approved by the project investigator and management teams.

ALFs such as ammonia are increasingly regarded as a key component of the future energy mix towards the net zero imperative. The purpose of the workshop was to bring together key and **diverse stakeholders** to identify research challenges, barriers and opportunities surrounding ammonia and other ALFs. The workshop was strategically framed around the **Theory of Change** (Figure. 1), which allows for a systematic unpacking of the key research challenges, opportunities and outcomes, guided by the strategic drivers and the added value of change. The workshop was facilitated by *The Collective,* and was delivered in three separate breakout sessions. The agenda (Appendix A) was distributed to the attendees prior to the workshop and consisted of three breakout discussions, **Challenges and Unmet Needs, Future Vision and Impact**, and **Opportunities for Research**. The workshop is also summarised in an illustrative output by Scriberia (Appendix B).

Principal investigator Tim Mays (University of Bath) outlined the motivation and vision of the project and provided context to the workshop, both in terms of national Net-Zero strategy, and the UKRI "Become a hydrogen research co-ordinator" call from which this 6-month project is funded. Co-investigator Shanwen Tao (University of Warwick) gave an introduction to the Theory of Change and discussed the scale of the challenge as well as the scope of the workshop, highlighting the need for interdisciplinary collaboration. An introduction to ammonia and some of the other ALFs, such as ethanol, methanol and formic acid was also delivered.

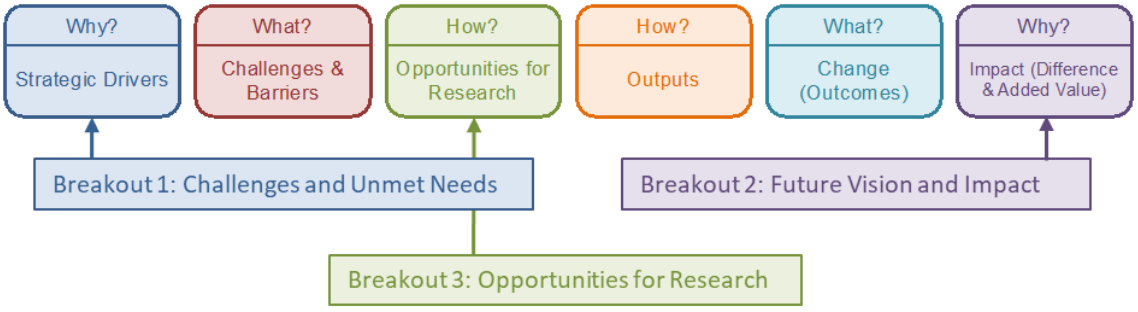


Figure 1: The theory of change framework adopted for the UK-HyRES project, and the location of each breakout session within it.

2. Insight Talks

Engaging insight talks were delivered during the workshop by industry and academic leaders active in the ALF arena. **Dr. Josh Makepeace (*University of Birmingham*)** set out the background of ammonia and why it is so promising, including how the related fuel cell technologies might look. **Dr. Laura Torrente-Murciano (*University of Cambridge*)** explored the reasons why ALFs are needed, remarking "We need novel integrated energy systems taking into consideration energy supply and demand profiles". We also heard from **Dr. Stuart Hawksworth (*Head, Centre for Energy and Major Hazards, Health & Safety Executive & President, International Association for Hydrogen Safety*)** who reminded us that "safety can not be an afterthought" and that we need to think smarter about safety and develop new evidence based standards. **Prof. John Irvine (*University of St Andrews*)** gave the final insight talk, with his perspective on the future vision for alternative liquid fuels and green ammonia, highlighting the particular industrial interest in ammonia for shipping.

Narrated slides for all four insight talks are available to download on the UKHyRES.co.uk website at https://ukhyres.co.uk/alternative-liquid-fuels/

3. Breakout Discussions

For each breakout discussion. delegates were tasked with debating the question posed and producing notes about their discussion on an online collaborative working environment. Following the workshop, the UK-HyRES research team analysed all the comments and grouped the responses accordingly.

3.1 Challenges and Unmet Needs

The first breakout discussion on challenges and unmet needs followed the first two insight talks. Comments were grouped by theme, as shown in Figure. 2.

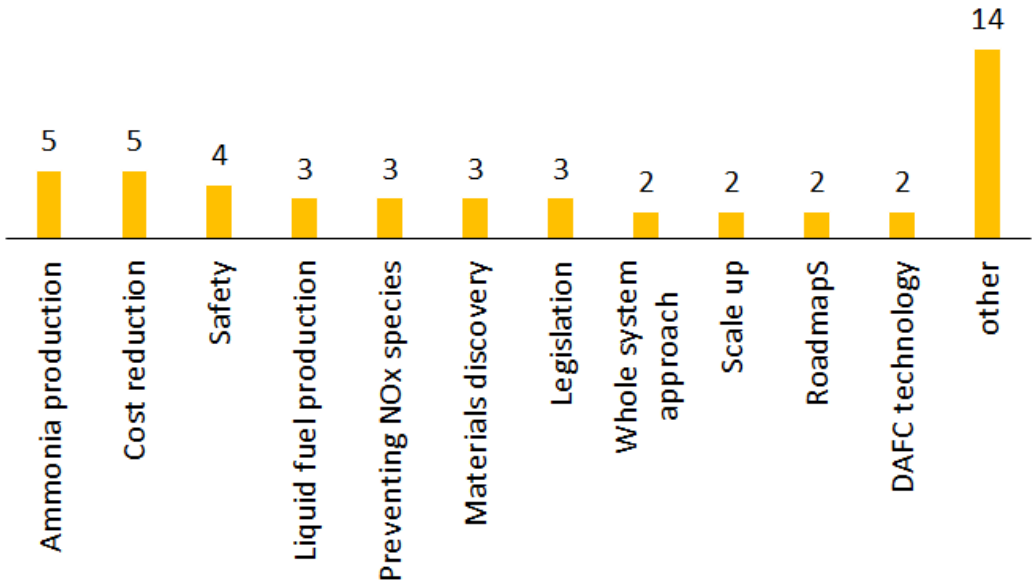


Figure 2: Collated responses to "Thinking of Ammonia & Alternative Liquid Fuels –From your perspective what are the challenges/unmet needs that need to be overcome?", grouped by theme. A larger version is available in Appendix C and the raw data with categorisation tags is in Appendix F.

Summary

- Attendees frequently mentioned that the ammonia production is the major challenge in ALFs. One suggestion was to “adjust Haber-Bosh process to produce large quantities”, another was to use new technology to avoid “ammonia synthesis under high temperature and high-pressure conditions”. This also underlines the importance of ammonia as an ALF.
- Reducing the cost of ALFs was also well discussed. Five people emphasised that reducing fuel production costs and the final power generation cost is vital. Two examples are “Cost of methanol production, cost of hydrogen leading to high ALF cost”, and, “Need to address cost issues associated with lower capacity factors associated with renewable electricity.”
- The safety of ALF use also scored highly, especially for ammonia with participants commenting that there is a “Need for risk assessment for different scenarios” and pointing to the “raised safety issue of NH3”. In the feedback session further discussion highlighted that industry is concerned about leakage and the need to alleviate national security concerns.
- Several people noted that full combustion technology may be needed to consider and prevent NOX species before large-scale application. “Understanding combustion conditions to prevent NOx emissions” and “NOx combustion is quite important” are two examples.
- It was also highlighted the materials discovery is vital. Fundamental research in DAFC with high-performance catalysts and membranes also featured. Participants commented that “Ammonia fuel cells require fundamental research in development of catalysts and membranes” and that “fundamental research in development of catalysts and membranes” was needed.

The “other” category included: C*ombustion of liquid hydrogen, Common fuel, Effective long term storage, Fuel availability, Fuel diversification, Fundamental research, Improve efficiency, Industry/academia collaboration, Plug-and-play solutions, Policy incentives, Public acceptance/perception of ALFs, Skill people, Supply demand, Sustainable resources.*

3.2 Future Vision and Impact

The second breakout discussion focused on the future vision for alternative liquid fuels and followed a similar format to the previous discussion. Figure 3 highlights the responses grouped by theme.

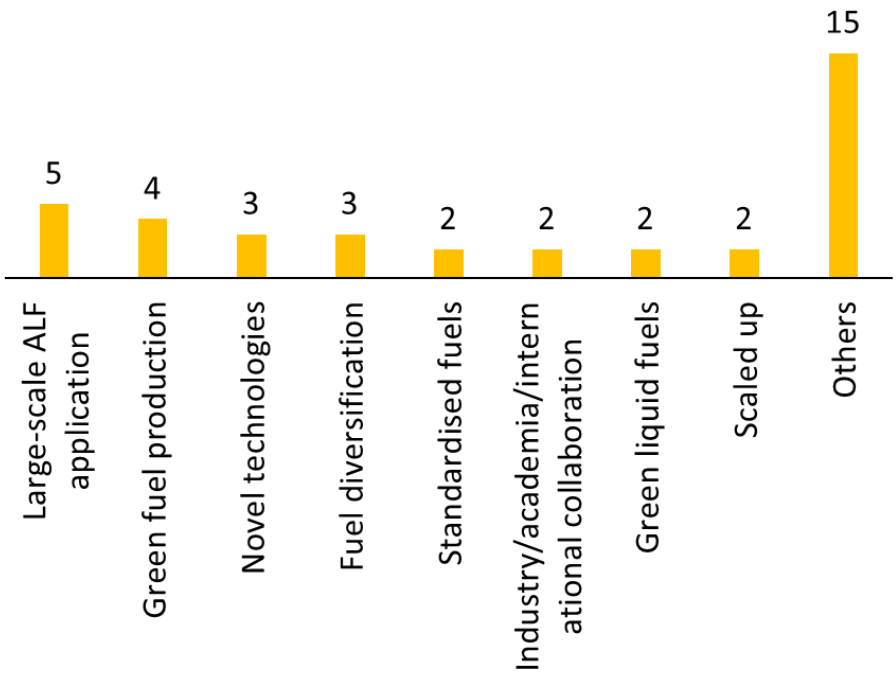


Figure 3: Collated responses to "Thinking ahead – what difference or change would you like to see in Alternative Liquid Fuels by 2050?". A larger version is available in Appendix D and the raw data with categorisation tags is in Appendix G.

Summary

- Attendees frequently discussed the expectation of large-scale ALFs application by 2050, with a desire for "Alternative fuel fuelled trains, planes, HGVs, Marine a reality". Several people also noted there is already a knowledge and operational foundation, commenting "NH3 already has a large supply chain". This was also picked up in the feedback session where people were gaining confidence in ALF deployment.
- Green fuel production was concluded to be a key future need, with efficient storage materials/compressors/purification/use. There was a desire for "More sustainable routes for producing liquid fuels - non-hydrogen based or one step production" and a "Major scale up of production of green hydrogen and ammonia." This was also picked up in the feedback session where it was noted that these fuels must be demonstrated at scale.
- Attendees discussed there will be novel technologies needed in the production/storage of ALFs. This was picked up in comments such as "Further developments in technology ie. carbon capture new membranes etc. but also how to assess what is already available" and "Development of the research/technologies that will set a 'winner' for each job".
- Public perception of ALFs and upskilling of the workforce by 2050 was also mentioned in the feedback session and will be important for the development of the industry. The need for standardised fuels and Industry/academia/international collaboration was also discussed, as well as Fuel diversification.

The "other" category included: *Market impact from ALF, Mature legislation, High volumes of liquid hydrogen production and storage, Novel materials discovered, Mature technology, Methanol favoured, Public knowledgeable about ALFs, Reduced cost, Research funding available, Safe/risk assessed, Upskilled and knowledgeable workforce, Standards developed, Supply collaboration, Timetable for further development, Whole system integration.*

3.3 Opportunities for Research

The final breakout discussion focused on the opportunities for ALFs and followed a similar format to the previous discussion. Figure 4 highlights the responses grouped by theme.

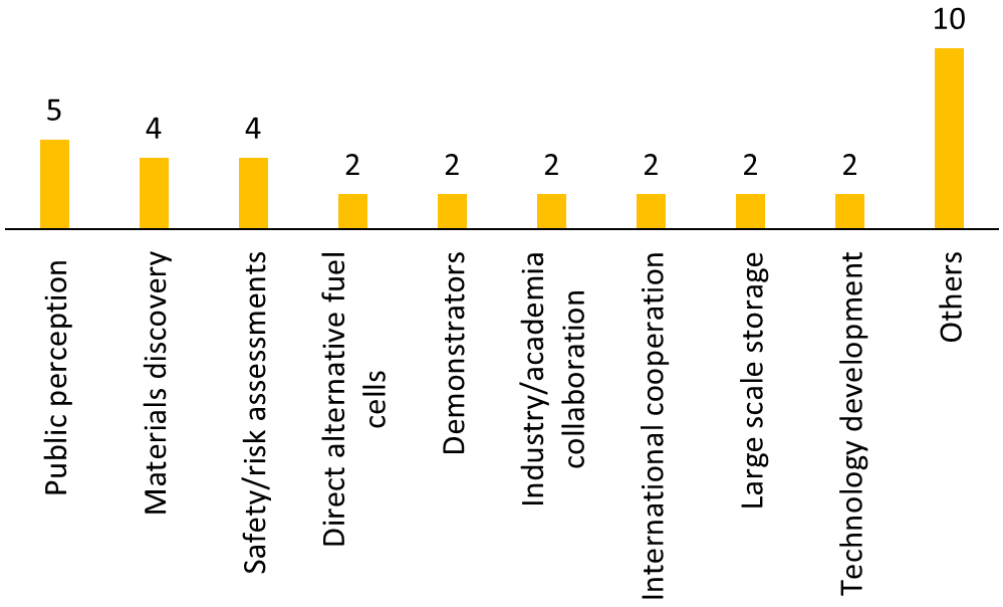


Figure 4: Collated responses to the questions: "Considering the discussions we have had today - What are the opportunities for research that will lead to and make the step change in Alternative Liquid Fuels? - What are the fundamental research that we need to think about? A larger version is available in Appendix E and the raw data with categorisation tags is in Appendix H.

Summary

- Public perception featured heavily in the final breakout discussion. This included comments such as "Social acceptance: coursework in courses CPDs in the modules", "Outreach to people in school is good, but also need to get through to general public" and "General perceptions need to be understood and the explanations need to be done well." It was noted that unlike hydrogen, many members of the public do not understand or have not heard of ALFs. This was picked up in the feedback session where the attendees hope that more people will know about ALFs in the near future.
- Materials discovery was the second most frequent comment, with materials, such as catalysts, still requiring optimisation with one attendee desiring, "Catalyst development for production and reconversion for end use". Machine learning is another tool for discovery of efficient materials and was picked up in the discussion "Using ML for material discovery, more computational research, optimisation etc.".
- The need for research in safety and risk analysis was also highly regarded. High content ammonia can be a harmful fuel if not handled properly, participants commented "Ammonia issues around risk of accidental release".
- Further comments in the feedback session asked for further industry and academia collaboration and large-scale storage solutions.

The "other" category included: *Effective long term use, Emissions control, Fuel diversification, Funding support, Improving whole system efficiency, Infrastructure, Model development, Politics and legislation, Cost reduction, Developing standards*

4. Concluding remarks

There were common themes that emerged throughout the workshop, identified here again as key challenges and opportunities for research.

1. A need for fundamental research on the materials required for ALFs production technologies and applications, particularly DAFCs.
2. Reducing the cost of ALFs was emphasised several times. New liquid fuels need to be cheap and easy to use.
3. Ammonia, regarded as having the most potential for decarbonisation, has attracted widespread attention. But, reducing production costs and developing safety standards should be primary objectives.
4. The public's perception and development of knowledge in ALFs was mentioned frequently. Highly skilled contributors to the ALF workforce will be important for the development of the industry, as well as integration in educational curriculums and wider public engagement.
5. Further important obstacles for ALF deployment were also identified, albeit less frequently. Participants noted that developing standards was crucial and that the research funding landscape and policy incentives were vital. Whole system integration was also requested, although it is noted that this aspect is out of scope for UK-HyRES and will be addressed by the HI-ACT project. Focus groups could be beneficial to engage more social scientists and also to follow-up with specific industrial sectors.

Appendix A: **Attendee Agenda**

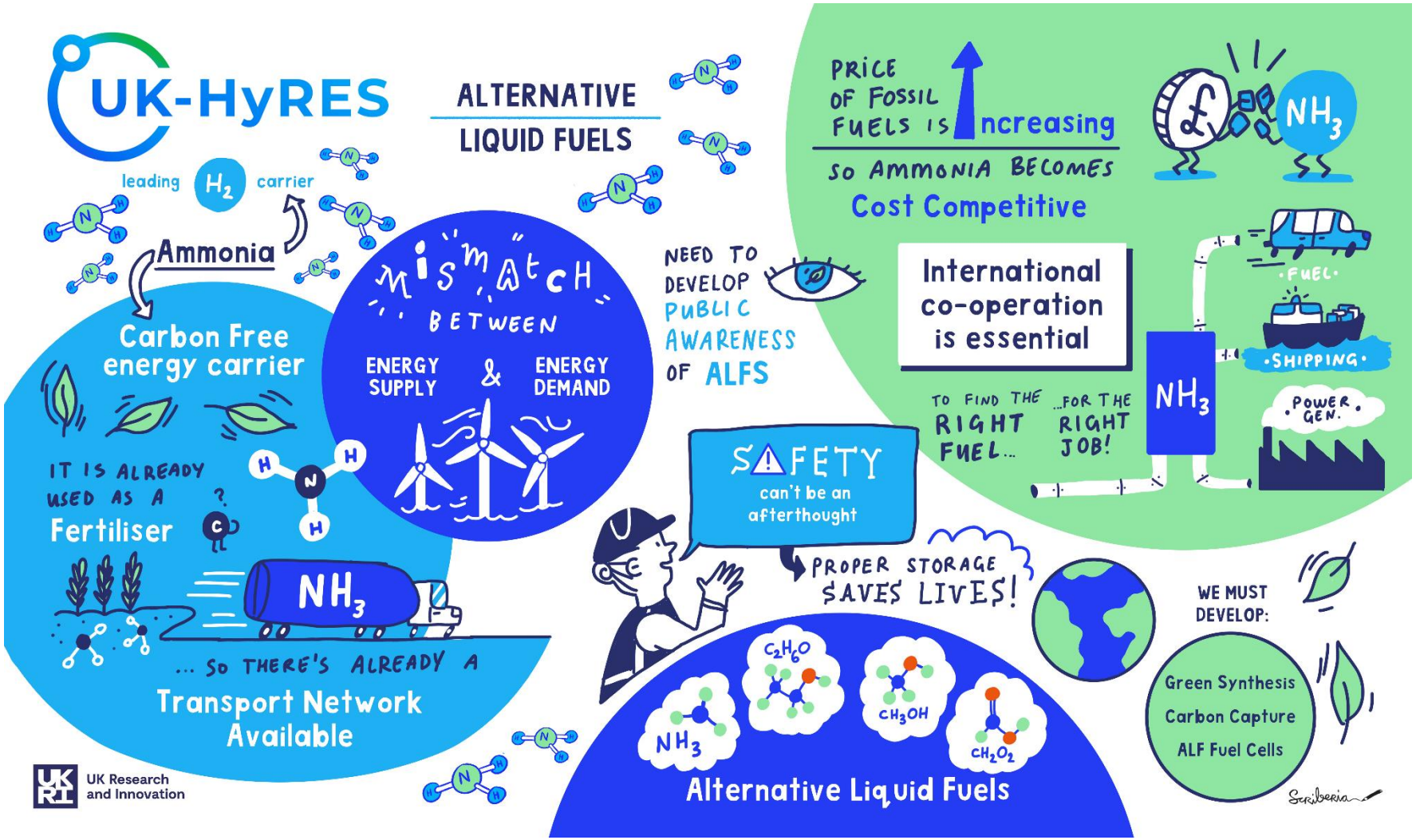
UK-HYRES Project
Theme 5 Workshop : ALTERNATIVE LIQUID FUELS
0930-1230 Thurs 16th June 2022

Zoom link :
https://us06web.zoom.us/j/88979766681?pwd=NEVadllzNzRGK2NyOFJDMG9xblprUT09

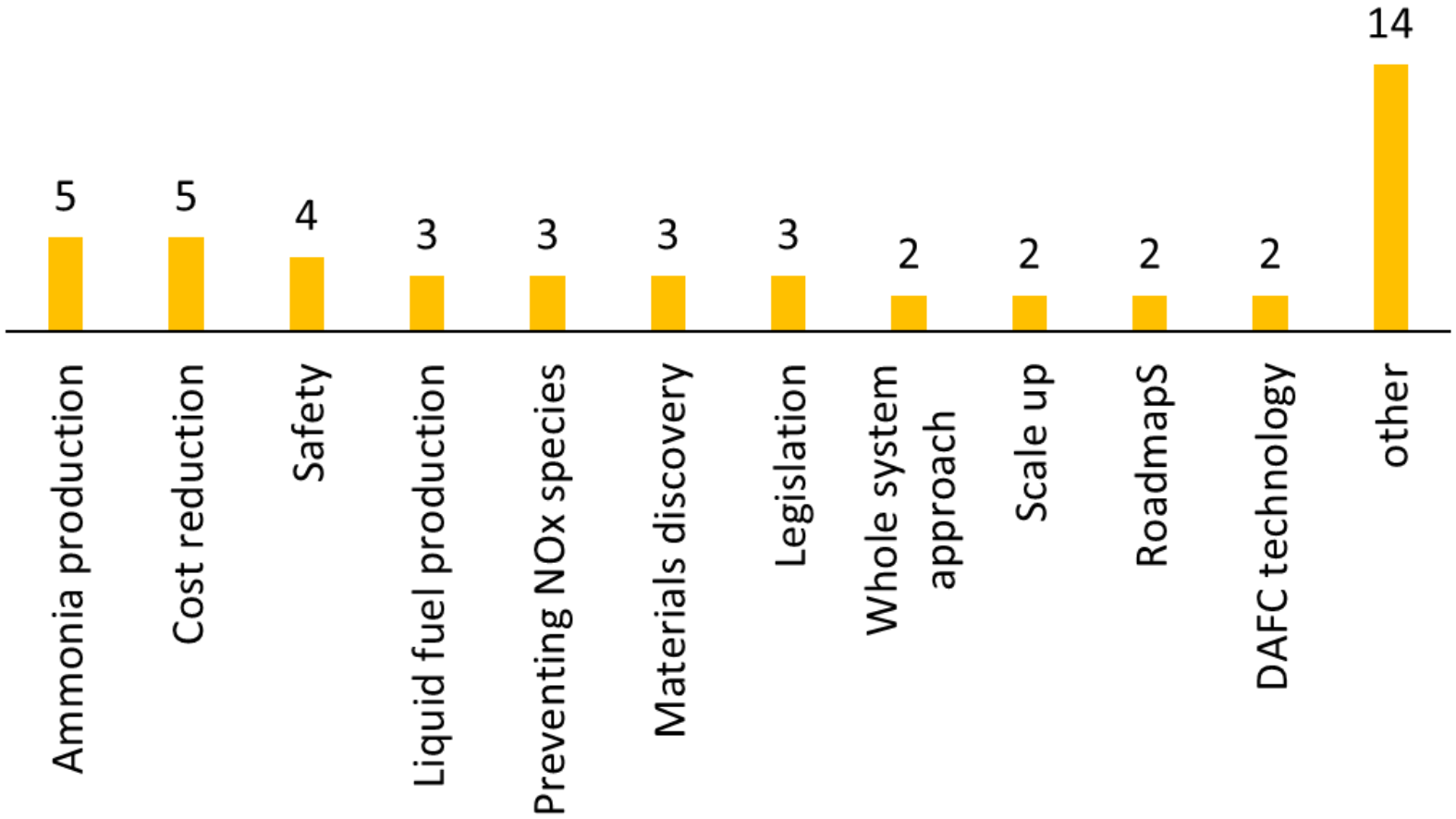
0915	**Waiting Room opens**
0930	**Welcome from the Facilitators**
0935	**How we are going to work together**
0940	**Mingle** **Breakout rooms of 4**
0950	**Welcome and Strategic Context** • **UK-HYRES Tim** • **Alternative Liquid Fuels Shanwen** • **TOC - Rachael**
1000	**Introduction to Theme 1: Alternative Liquid Fuels** **Insight Talks** **ToC Strategic Drivers** • **Dr Josh Makepeace - Lecturer in Materials Chemistry | UKRI Future Leaders Fellow, School of Chemistry, University of Birmingham** • **Dr Laura Torrente-Murciano - Reader in Reaction Engineering & Catalysis | EPSRC Early Career Fellow, Department of Chemical Engineering & Biotechnology, University of Cambridge**
1010	**Breakout Discussion 1** **Thinking of Ammonia and Alternative liquid Fuels From your perspective what are the challenges/unmet needs that need to be overcome?**
1035	**Feedback from each room - main room**
1050	**BREAK**
1100	**Primer for Breakout 2** **Insight Talks** • **Dr Stuart Hawksworth - Head, Centre for Energy and Major Hazards, Health & Safety Executive & President, International Association for Hydrogen Safety** • **Prof John Irvine - Professor of Chemistry, School of Chemistry, University of St Andrews**
1110	**Breakout Discussion 2** **Thinking ahead, what difference or change would you like to see in Ammonia and**

	Alternative Liquid Fuels by 2050?
1135	**Open Floor**
1145	**Primer for Breakout Discussion 3**
1155	**Breakout Session 3** **Considering the discussions we have had today –** **What are the opportunities for research that will lead to and make the step change in Ammonia and Alternative Liquid Fuels? What are the fundamental research questions that we need to think about?**
1215	**Open Floor**
1225	**Next Steps**
1230	**CLOSE**

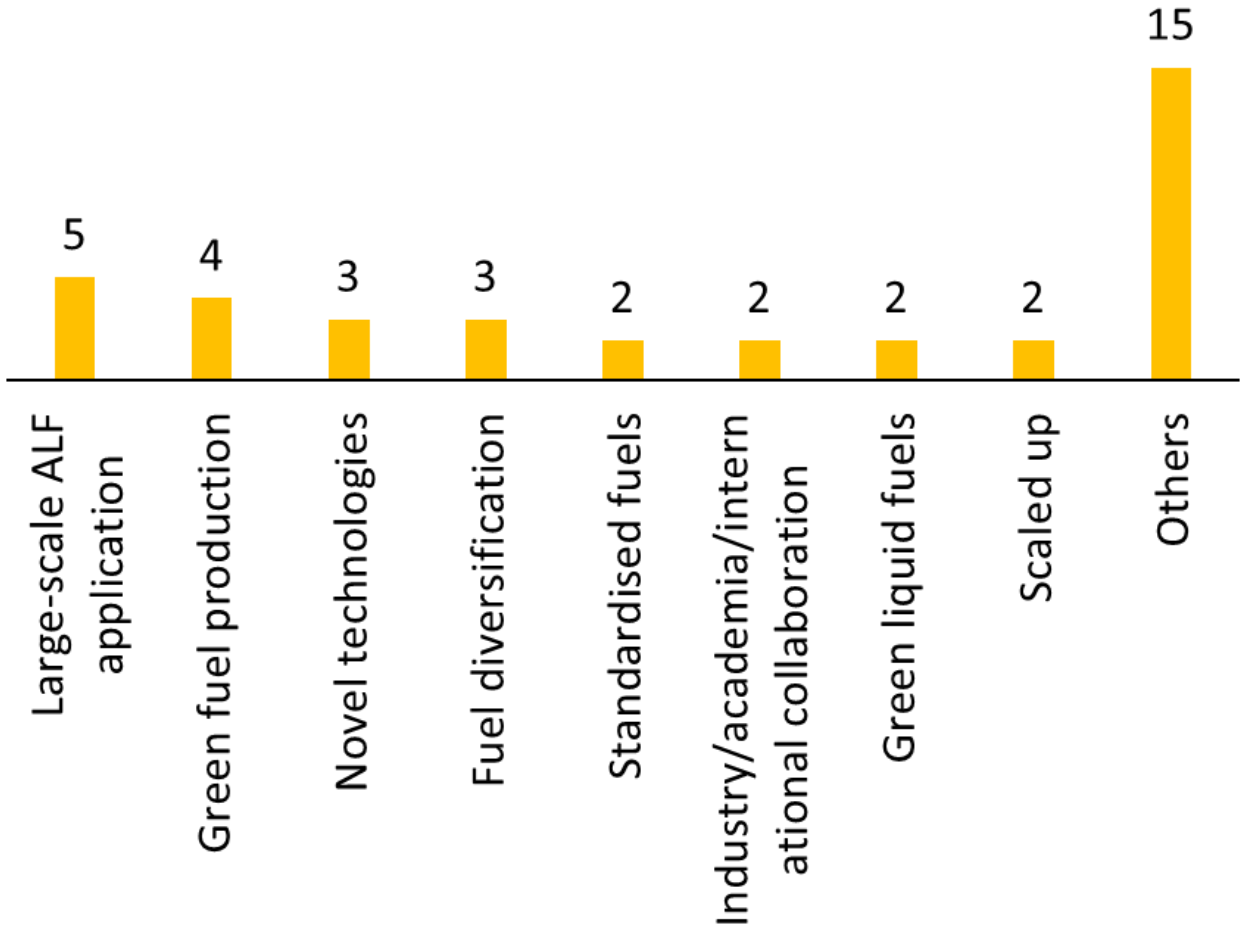
Appendix B: ***An illustrative summary of the workshop produced by Scriberia.***



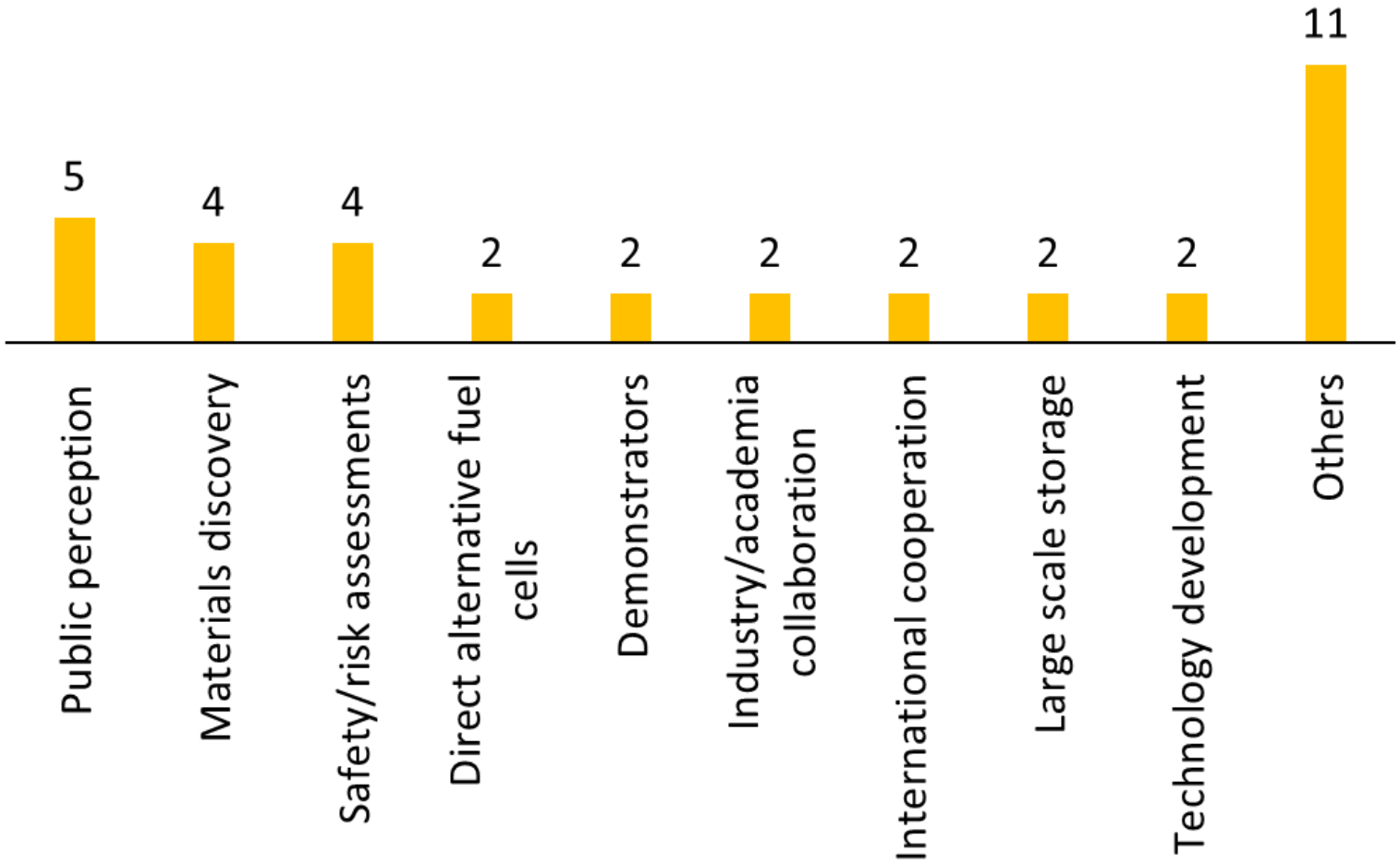
Appendix C: ***Responses to "Thinking of Ammonia & Alternative Liquid Fuels –From your perspective what are the challenges/unmet needs that need to be overcome?", grouped by theme.***



Appendix D: ***Responses to "Thinking ahead – what difference or change would you like to see in Alternative Liquid Fuels by 2050?", grouped by theme.***



Appendix E: **Responses to "What are the opportunities for research that will lead to and make the step change in Alternative Liquid Fuels? What are the fundamental research that we need to think about?", grouped by theme.**



Appendix F: **All responses to *"Thinking of Ammonia & Alternative Liquid Fuels –From your perspective what are the challenges/unmet needs that need to be overcome?",* with categorisation and the counts for each category.**

All Comments

THEME:	STORAGE	
BREAKOUT	1	
QUESTION	Thinking of Ammonia & Alternative Liquid Fuels –From your perspective what are the challenges/unmet needs that need to be overcome?	
ROOM #	Comment	Tag
1	need to plug-and-play solutions to keep running the factories	plug-and-play solutions
1	difficult to predict the spray combustion of liquid hydrogen	combustion of liquid hydrogen
1	NOx combustion is quite important.	prevent NOx species
1	Ammonia propulsion - flames are quite low	DAFC technology
1	Optimisation of sustainable resources.	sustainable resources
1	We need credible strategy on when renewables and hydrogen will be deployed and in which geographies.	Roadmap
1	Need to have electrochemical technology deployed for green ammonia to bypass the hydrogen production process.	DAFC technology
2	Legislation - barrier to development	Legislation
2	certification, security, delivery of fuels	Safe/risk assessment
2	Training and upskilling of people - added into curriculum	Upskilling
2	Cost comparison	Reduced cost
2	Engagement between stakeholders	Industry/academia collaboration
2	green hydrogen helps us get to green ammonia	ammonia production
2	Adjust haber bosh process to produce large quantities	ammonia production
2	Capacity for ammonia production vs hydrogen production	ammonia production
2	Health and safety / risk	Safe/risk assessment
2	how you make them - quantities required	liquid fuel production
3	Ammonia: Energy required to separate air to N2 then synthesis	ammonia production
3	Legislative, government and media focus currently does not well consider alternative fuel	Legislation
3	Ammonia fuel cells require fundamental research in development of catalysts and membranes.	Materials discovery
3	fundamental research in development of catalysts and membranes	Materials discovery
3	Alkaline membranes can suffer from CO2 contamination	Materials discovery
3	Interfaces in the devices	fundamental research
3	Availability of renewable carbon to use in green fuels,	fuel availability
3	Compatibility with existing systems for more rapid decarbonisation.	Whole system approach
3	Challenges of upscaling existing processes.	scale up

4	balancing the cost of production and distribution	Reduced cost
4	Partial combustion of ammonia releases NOx species	prevent NOx species
4	Ammonia process is high temperature and pressure	ammonia production
4	Need a small scale flexible operation to make electricity cost effective	Improve efficiency
4	separating products and then scaling up	scale up
4	gain flexible, longer term storage	Effective long term storage
5	Really require a common fuel for certain industries	common fuel
5	Understanding combustion conditions to prevent NOx emissions	prevent NOx species
5	without a whole system consideration - is not appropriate	Whole system approach
5	think on production, transport and end use holistically to work on the correct answer for what we need.	Roadmap
5	Policy - control on quality of fuel and production process, emissions and leaks for replacement liquid fuels	Legislation
5	No one liquid fuel will necessarily fit all of our fuel requirements.	fuel diversification
5	Supply of H2 as feedstock to these liquid fuels is key - how does this lock with other needs?	supply demand
6	Outstanding technical challenges for sustainable synthesis of ALFs	liquid fuel production
6	Cost of methanol production, cost of hydrogen leading to high ALF cost	Reduced cost
6	Need to address cost issues	Reduced cost
6	Need for risk assessment for different scenarios	Safe/risk assessment
6	Policy settings to incentivise ALF production/use	Policy incentives
6	Adapting traditional chemical engineering approaches to decarbonised/electrified/intermittent ALF production.	liquid fuel production
6	public acceptance/perception of ALFs (particularly ammonia)	public acceptance/perception of ALFs
7	raised safety issue of NH3	Safe/risk assessment
7	Economics	Reduced cost

Category Counts

CATEGORY	COUNT
AMMONIA PRODUCTION	5
COST REDUCTION	5
SAFETY	4
LIQUID FUEL PRODUCTION	3
PREVENTING NOX SPECIES	3
MATERIALS DISCOVERY	3
LEGISLATION	3
WHOLE SYSTEM APPROACH	2
SCALE UP	2
ROADMAPS	2
DAFC TECHNOLOGY	2
COMBUSTION OF LIQUID HYDROGEN	1

COMMON FUEL	1
EFFECTIVE LONG TERM STORAGE	1
FUEL AVAILABILITY	1
FUEL DIVERSIFICATION	1
FUNDAMENTAL RESEARCH	1
IMPROVE EFFICIENCY	1
INDUSTRY/ACADEMIA COLLABORATION	1
PLUG-AND-PLAY SOLUTIONS	1
POLICY INCENTIVES	1
PUBLIC ACCEPTANCE/PERCEPTION OF ALFS	1
SKILL PEOPLE	1
SUPPLY DEMAND	1
SUSTAINABLE RESOURCES	1

Appendix G: **All responses to *"Thinking ahead – what difference or change would you like to see in Alternative Liquid Fuels by 2050?", grouped by theme.",* with categorisation and the counts for each category.**

All Comments

THEME:	STORAGE	
BREAKOUT	2	
QUESTION	Thinking ahead – what difference or change would you like to see in Alternative Liquid Fuels by 2050?	
ROOM #	Comment	Primary
1	would like to see fuel cells that can handle liquid NH3	Large-scale application of ammonia
1	to have a large impact	a large impact of ALF
1	Methanol favoured as requiring less changes to system to make the transition	Methanol favoured
1	should make sure we aren't focusing on one particular fuel.	fuel diversification
1	NH3 already has a large supply chain	Large-scale application of ammonia
1	airlines think of SAF as a short term solution, moving to Liq.H2 eventually due to higher efficiency.	Large-scale application of liquid H2
1	we need to progress all of the tech innovations in the sector to maturity.	mature technology
2		
3	Entirely green liquid fuel	green liquid fuel
3	Flexible and dynamic production with green energy	green fuel production
3	Full system integration and system	Whole system integration
3	overcoming disconnect between blue skies research and impact in industry	Industry/academia collaboration
3	scalable	scale up
3	UK research funding ecosystem in place for 2050, mature r&d	research funding
3	Further developments in technology ie. carbon capture new membranes etc. but also how do assess what is already available	Novel technologies
3	For liquid fuels - potential for more diverse options in the future,	fuel diversification
3	To get to large scale - we need security of supply but also global supply chain by 2050 supported by well trained people	scale up
3	Eduction public engagement - explain and have the public onboard	public acceptance/perception of ALFs
3	Novel technologies by 2050	Novel technologies
4	having a common fuel we can use between countries and facilities	Standardised fuels

4	Development of the research/technologies that will set a "winner" for each job	Novel technologies
4	Governmental Policy needed, in conjunction with delivery, storage, guidance, etc.	Legislation
4	Bring industries together to really address the issues of supply/requirements	supply collaboration/requirements
4	A time-table that is realistic is also needed	time-table
4	Reduction in price to make the solution affordable	Reduced cost
4	Energy security is also critical	Safe/risk assessment
5	Availability liquid hydrogen production and storage	liquid hydrogen production and storage
5	Single alternative liquid fuel for HGVs - acceptance and availability	Standardised fuels
5	Biological systems - marine or land based generation of liquid fuels	Biological fuel
5	More sustainable routes for producing liquid fuels - non-hydrogen based or one step production	green fuel production
5	Scale up electrochemical production	green fuel production
5	Alternative fuel fueled trains, planes, HGVs, Marine as a reality	Large-scale application
5	Education to drive understanding, create skilled people needed	skill people
5	Global standards for green credentials (rigorous LCAs) and for use	Standards developed
5	International R&D co-ordination	international collaboration
6	Efficient catalysts for making alfs	Materials discovery
7	Transition fuels - Viable, safe and handleable energy dense transition fuels that can be used within existing infrastructure and systems	fuel diversification
7	Major scale up of production of green hydrogen and ammonia	green fuel production
7	Wider deployment of fuel cell for transport	Large-scale application

Category Counts

CATEGORY	COUNT
LARGE-SCALE ALF APPLICATION	5
GREEN FUEL PRODUCTION	4
NOVEL TECHNOLOGIES	3
FUEL DIVERSIFICATION	3
STANDARDISED FUELS	2
INDUSTRY/ACADEMIA/INTERNATIONAL COLLABORATION	2
GREEN LIQUID FUELS	2
SCALED UP	2
MARKET IMPACT FROM ALF	1
MATURE LEGISLATION	1
HIGH VOLUMES OF LIQUID HYDROGEN PRODUCTION AND STORAGE	1
NOVEL MATERIALS DISCOVERED	1
MATURE TECHNOLOGY	1

METHANOL FAVOURED	1
PUBLIC KNOWLEDGABLE ABOUT ALFS	1
REDUCED COST	1
RESEARCH FUNDING AVAILABLE	1
SAFE/RISK ASSESSED	1
UPSKILLED AND KNOWLEDGEABLE WORKFORCE	1
STANDARDS DEVELOPED	1
SUPPLY COLLABORATION	1
TIMETABLE FOR FURTHER DEVELOPMENT	1
WHOLE SYSTEM INTEGRATION	1

Appendix H: **All responses to *"What are the opportunities for research that will lead to and make the step change in Alternative Liquid Fuels? What are the fundamental research that we need to think about?",* with categorisation and the counts for each category.**

All Comments

THEME:	STORAGE	
BREAKOUT	3	
QUESTION	"What are the opportunities for research that will lead to and make the step change in Alternative Liquid Fuels? What are the fundamental research that we need to think about?	
ROOM #	Comment	Tag
1	safety issues	Safe/risk assessment
1	Biggest thing is overall efficiency of the full lifecycle of hydrogen production to use (production, storage, conversion and use).	Improve whole system efficiency
1	Large scale storage and efficiency.	Large scale storage
2	Availability of renewable carbon for alternative fuels	fuel diversification
2	Development of ammonia fuels cells - improve catalyst performance	DAFC
2	reduce cost	Reduced cost
2	Catalyst development for production and reconversion for end use e,g, crack to hydrogen or fuel cell	Materials discovery
2	Emissions control at end use	Emissions control
2	Design for sustainability and second life and end of life usage	Effective long term use
3	Material compatibility cryo H2.	Materials discovery
3	Ammonia issues around risk of accidental release	Safe/risk assessment
3	How do we ensure that there is clear policy/quality/HSE procedures to manage this risk globally?	Standards developed
3	How do we keep the public informed without causing negativity or loss of trust?	public perception
4	Technology development from low TRL to commercial and large-scale impact.	Technology development
4	Catalysis, process intensification	Technology development
4	Social acceptance: coursework in courses CPDs in the modules for H2 material	public perception
4	Large scale pilot plants to complement the more fundamental work already being done	Large scale

4	Outreach to people is school is good, but need to also need to get through to general public	public perception
4	Large demonstrators are needed but they need to be complemented with understanding how people will interact with these technologies	demonstrator
4	Need to understand public perception	public perception
4	Replacing infrastructure will be accepted much more readily than a new plant.	infrastructure
4	General perception need to be understood and the explanations need to be done well.	public perception
4	Real demonstration sites are needed.	demonstrator
5	Safety knowledge gaps	Safe/risk assessment
5	More coordinated international approach to research	international cooperation
5	Links with industry	Industry/academia collaboration
5	Politics getting in the way	Politics
5	safe international hydrogen but not sure on ammonia equivalent	ammonia safety
5	Needs large government investment for international cooperation, the better the funding landscape the easier it is for industry to be involved	funding support
5	Close collaboration between research domains	international cooperation
5	Using ML for material discovery, more computational research, optimisation etc.	Materials discovery
5	Catalyst materials etc, we need develop fundamental research into catalysts/membranes/	Materials discovery
6	Safety issue	Safe/risk assessment
7	should be a good choice if DEFC can be well developed	DAFC
7	create links between academia and industry.	Industry/academia collaboration
7	Benchmark flow and combustion behaviour and safety models	Model developed

Category Counts

CATEGORY	COUNT
PUBLIC PERCEPTION	5
MATERIALS DISCOVERY	4
SAFETY/RISK ASSESSMENTS	4
DIRECT ALTERNATIVE FUEL CELLS	2
DEMONSTRATORS	2
INDUSTRY/ACADEMIA COLLABORATION	2
INTERNATIONAL COOPERATION	2
LARGE SCALE STORAGE	2
TECHNOLOGY DEVELOPMENT	2

EFFECTIVE LONG TERM USE	1
EMISSIONS CONTROL	1
FUEL DIVERSIFICATION	1
FUNDING SUPPORT	1
IMPROVING WHOLE SYSTEM EFFICIENCY	1
INFRASTRUCTURE	1
MODEL DEVELOPMENT	1
POLITICS AND LEGISLATION	1
COST REDUCTION	1
DEVELOPING STANDARDS	1