SQA Advanced Unit Specification

General information for centres

Unit title: Renewable Energy Store: Hydrogen

Unit code: HV5H 48

Unit purpose: This unit has been designed to provide candidates with a knowledge and understanding of the current and future role of hydrogen as an energy carrier to support renewable energy generation. Hydrogen is the simplest element in the Universe with special properties that have an important bearing on storage and distribution, and candidates will learn through practical activities how the gas is produced by electrolysis, and how the stored energy is later recovered using a fuel cell. Candidates will be able to design an electrical or mechanical system powered by hydrogen. The unit includes a practical element to allow the candidate to become familiar with the handling and use of hydrogen while ensuring all appropriate safety precautions are adopted.

On completion of the unit the candidate will be able to:

1 explain the principles of hydrogen production
2 explain the operation of fuel cells
3 explain hydrogen management issues
4 design and build a simple system incorporating the generation, storage and consumption of hydrogen
5 analyse an engineering problem situation and develop a solution that uses hydrogen as an energy source

Credit points and level: 1 SQA Credit at SCQF level 8: (8 SCQF credit points at SCQF level 8*)

**SCQF credit points are used to allocate credit to qualifications in the Scottish Credit and Qualifications Framework (SCQF). Each qualification in the Framework is allocated a number of SCQF credit points at an SCQF level. There are 12 SCQF levels, ranging from National 1 to Doctorates.*

Recommended prior knowledge and skills: Entry to this unit is at the discretion of the centre, however candidates should have a general knowledge and understanding of energy use, the consequences of energy use and renewable versus non-renewable energy sources. This knowledge and understanding may be evidenced by possession of the following SQA Advanced Units HV48 47 *Renewable Energy Systems: Overview of Energy Use*. It would also be helpful if the candidate first completed the double-credit SCQF level 8 unit HV5N 48 *Renewable Energy Systems: Technology* for a basic introduction to hydrogen in the context of renewable energy. A prior understanding of basic thermodynamics would also be helpful.

Core skills: There are opportunities to develop the following core skill and core skill components in this unit, although there is no automatic certification of core skill or core skills components:

- Problem Solving — SCQF level 6
- Communication — SCQF level 6
- Information Technology — SCQF level 6
- Numeracy — SCQF level 6

Context for delivery: This unit has been developed for the SQA Advanced Diploma in Engineering Systems. If this unit is delivered as part of another group award, it is recommended that it should be taught and assessed within the subject area of the group award to which it contributes.

Assessment: The assessment strategy for this unit is as follows:

Outcomes 1, 2 and 3 should be assessed by a single assessment paper taken at a single assessment event. The paper should comprise of 40 multiple-choice questions testing the knowledge and understanding elements of all three outcomes on a sample basis. Assessment should be conducted under controlled, supervised close-book conditions and should last one and one half hours.

Outcome 4 should be assessed through a supervised laboratory assignment where the candidate is presented with basic components such as photovoltaic (PV) cells, fuel cells, connecting pipes and tubes, storage vessels and electrolysers and is expected to design and assemble a complete working system that will guarantee a continuity of electrical output, and must include the appropriate sensors and alarms to ensure safety. The candidates should maintain a lab or log book of activity, though the measure of achievement should be through an observational checklist.

Outcome 5 should be assessed through an assignment where the candidate is presented with a basic engineering or electrical system (or problem scenario) where the system must be powered from a hydrogen source. The solution, including diagrams, drawings and schematics must be presented as a report that justifies the approach adopted and includes consideration of safety, storage, efficiency and how the basic hydrogen fuel is sourced.

SQA Advanced Unit Specification: statement of standards

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The sections of the unit stating the outcomes, knowledge and/or skills, and evidence requirements are mandatory.

Where evidence for outcomes is assessed on a sample basis, the whole of the content listed in the knowledge and/or skills section must be taught and available for assessment. Candidates should not know in advance the items on which they will be assessed and different items should be sampled on each assessment occasion.

Outcome 1

Explain the principles of hydrogen production

Knowledge and/or skills

- Properties of hydrogen
- Hydrogen detection
- Thermodynamics of electrolysis
- Hydrogen produced by commercial electrolysers
- Hydrogen extraction from natural gas

Outcome 2

Explain the operation of fuel cells

Knowledge and/or skills

- Thermodynamics of hydrogen combustion
- Combustion using catalysts
- Types of commercial fuel cell
- Developments in fuel cell technology

Outcome 3

Explain hydrogen management issues

Knowledge and/or skills

- Storage methods
- Transportation
- Health and safety

Evidence requirements

Evidence for the knowledge and/or skills items in Outcomes 1, 2 and 3 should be provided on a sample basis. The evidence may be provided in response to specific questions. Each candidate will need to demonstrate that she/he can answer correctly questions based on a sample of the items shown under the knowledge and/or skills items in all three outcomes. In any assessment of the outcomes **three out of five** knowledge and/or skills items should be sampled from Outcome 1, **three out of four** knowledge and/or skills items should be sampled from Outcome 2 and **two out of three** knowledge and/or skills items should be sampled from Outcome 3. It is anticipated that **five** specific questions are needed to fully and effectively assess any knowledge/skills item being sampled.

Where sampling takes place, a candidate's response can be judged to be satisfactory if the following criteria are met:

Outcome 1

- state the properties of hydrogen
  — mass and density
  — ignition and combustion temperatures
  — colour of flame
  — diffusivity
  — compression properties
  — stored density
- describe detection methods
  — semiconductor
  — thin film
  — catalytic
  — electrochemical
  — optical
  — nanotechnological
- explain the thermodynamics of electrolysis
  — electrical energy input ΔG
  — enthalpy ΔH
  — work to expand gases produced $p\Delta V$
  — entropy $T\Delta S$
- describe how hydrogen is produced by commercial electrolysers
  — alkaline
  — PEM
  — efficiency
  — cost
- describe how hydrogen is extracted by the steam reformation of methane

Outcome 2

- describe the thermodynamics of hydrogen combustion
  — energy output per mole
  — thermodynamic losses
  — comparison with other fuels
- state the advantages of the use of catalysts over direct combustion
  — lower temperature
  — types of catalyst
  — life time

- state efficiency, temperature, anode and cathode gas, and electrolyte and whether reversible for
  - — PEM
  - — alkaline
  - — direct methanol
  - — phosphoric Acid
  - — molten carbonate
  - — solid oxide
- Describe the current developments in fuel cell technology including cost and size trends *

Outcome 3

- state storage methods and the problems
  - — low pressure, high volume
  - — pressurisation
  - — leakage
  - — cryogenic storage
- explain transportation issues
  - — transportation of hydrogen through existing pipe work
  - — building distribution infrastructure
  - — converting vehicles to direct hydrogen combustion or electrical fuel cell
  - — generating methanol and other compounds from hydrogen
- state current health and safety issues *

Note that items marked with an asterisk (*) by their nature will change over time and centres should regularly update these portions of the unit.

The assessment for Outcomes 1, 2 and 3 should be combined into a single assessment paper. The assessment paper, which should comprise of 40 multi-choice questions, should be taken at a single assessment event lasting one and half hours. The assessment should be conducted under controlled, supervised conditions. Assessment should be conducted under closed-book conditions and as such candidates should not be allowed to bring any textbooks, handouts or notes to the assessment.

Outcome 4

Design and build a simple system incorporating the generation, storage, and consumption of hydrogen

Knowledge and/or skills

- Selection of primary power source
- Selection of fuel cell
- Selection of storage means
- Selection of electrolyser
- Construction and testing of complete system

Evidence requirements

All knowledge and/or skills items in Outcome 4 should be assessed. Candidates should be presented with a selection of energy generators such as micro wind turbines and PV arrays, a range of storage vessels and appropriate connection pipes and valves, a number of electrolysers, and sensors and alarms. He/she will be asked to design, assemble and test a complete system that will guarantee a continuity of electrical output for a specified loading condition. The solution must be efficient and conform to safety standards.

Though this is essentially a practical task, candidates should maintain a log of activity that should be available for examination by the lecturer at any time. Candidate evidence should be recorded on an appropriate observational checklist which should be maintained by the lecturer. Performance is judged acceptable if **all** the knowledge/skills items requirements are satisfied in completing the assignment.

Candidates should have access to course notes and other relevant information such as datasheets and a concise specification of the modules available in the laboratory.

Two hours should be allocated for the completion of the assessment with all candidates working individually.

Assessment guidelines

Sufficient equipment should be available so that candidates do not need to compete for resources. The assessment should be well supervised in order that any unsafe practice is quickly identified.

Outcome 5

Analyse an engineering problem situation and develop a solution that uses hydrogen as an energy source.

Knowledge and/or skills

- Power output requirements
- Power generation
- Consideration of hydrogen source
- Storage issues

Evidence requirements

All knowledge and /or skills items in Outcome 5 should be assessed. The evidence should be presented in response to an assignment in which the candidate is presented with a moderately complex engineering problem situation and asked to produce a solution that uses hydrogen as a power source. This may be the design of a new system for a specified application, or the conversion of an existing electrical or mechanical system using a conventional power source.

A candidate’s response can be judged to be satisfactory where the evidence provided is sufficient to meet the requirements for each item by the candidate showing that he/she has:

- ensured power output to ensure satisfactory performance has been determined
  — how far the system must go between refuelling
  — what is the peak hydrogen demand
  — possible incorporation of in-system hydrogen generation
- considered how the power is to be generated from hydrogen
  — hydrogen combustion
  — hydrogen mixed with other fuel
  — use of a fuel cell
- how the hydrogen is sourced
  — purchased
  — in-system generation
  — remote generation
  — refuelling issues

- considered how fuel is stored
  - — storage tanks
  - — pressure and capacity
  - — safety
  - — backup systems

Candidate evidence for this outcome should be presented in the form of a report which should be done in the candidates own time. Centres should make every reasonable effort to ensure the report is the candidate's own work. Where copying or plagiarism is suspected candidates may be interviewed to check their knowledge and understanding of the subject matter. A checklist should be used to record oral evidence of the candidate's knowledge and understanding.

The report should include diagrams, drawings and schematics and must justify the approach adopted. The report should be between 1,000–1,500 words long and referenced as necessary. Candidates should have access to course notes, relevant textbooks, papers, reports and the internet while completing this report.

Assessment guidelines

Candidates should be encouraged to use appropriate software to produce their reports including the preparations of diagrams and drawings. Hand-written submissions should be discouraged. It may be necessary to provide some assistance with formatting the report and the selection of an appropriate style, and the candidate should be encouraged to include a title page and contents list to the document.

The candidate should be introduced to the concept of formal report writing and the necessity of logical development and clarity.

The difference between plagiarism and referencing the work of others should be made clear and a standard method of referencing should be specified. As the assignment may include some research, it is important that candidates have access to the appropriate resources. It should be made clear that only credible internet sites should be referred to (and referenced).

Administrative information

Unit code: HV5H 48

Unit title: Renewable Energy Store: Hydrogen

Superclass category: XK

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Version	Description of change	Date

Source: SQA

SQA acknowledges the valuable contribution that Scotland's colleges have made to the development of SQA Advanced Qualifications.

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SQA Advanced Unit Specification: support notes

Unit title: Renewable Energy Store: Hydrogen

This part of the unit specification is offered as guidance. The support notes are not mandatory.

While the exact time allocated to this unit is at the discretion of the centre, the notional design length is 40 hours.

Guidance on the content and context for this unit

This unit has been written as one of the 10 renewable energy units within the SQA Advanced Diploma in Engineering Systems. The units are:

- Renewable Energy Systems: Overview of Energy Use (2 credits, SCQF level 7)
- Renewable Energy Systems: Technology (2 credits, SCQF level 8)
- Renewable Energy Systems: Biomass (1 credit, SCQF level 8)
- Renewable Energy Systems: Wind Power (1 credit, SCQF level 8)
- Renewable Energy Systems: Wave and Tidal Energy (1 credit, SCQF level 8)
- Renewable Energy Systems: Solar (1 credit, SCQF level 8)
- Renewable Energy Systems: Geothermal Energy (1 credit, SCQF level 8)
- Renewable Energy Systems: Hydroelectricity (1 credit, SCQF level 8)
- Renewable Energy Systems: Microgeneration Systems (1 credit, SCQF level 7)

The double-credit unit, *Renewable Energy Systems: Overview of Energy Use* is a basic generic introduction to the subject and aims to present both a local and global perspective of energy use. *Renewable Energy Systems: Technology* describes the basic technology associated with renewable energy devices. The remaining units take a specialised look at each of the technologies currently believed to be significant, and there is the opportunity to specialise. It is important that all these units are seen as providing an integrated programme of study covering the energy issues with a focus on renewable energy systems. As such every opportunity should be sought to combine the delivery and assessment of these units.

This unit has been written as far as possible in generic terms to allow candidates to specialise in areas of particular interest associated with hydrogen. This may be, for example, hydrogen production, storage, distribution, fuel cell or electrolyser technology, engine conversions or the application to heating. There is considerable research activity in this general field and the candidate may eventually wish to contribute to this. Some individual research is encouraged throughout the unit, particularly new ideas that are being tested but have not yet reached the market such as reversible fuel cells and new types of fuel cell.

In Outcome 1 candidates will consider the physical and chemical properties of hydrogen in comparison to other gases. It is essential to understand how hydrogen differs from common combustion gases such as methane and propane, and petrol or diesel aerosols. Of particular interest is the energy content per unit mass at different densities, the ignition and combustion temperatures, and the nature of the flame.

It is important later when considering storage issues to understand how the density of hydrogen changes with temperature and pressure and the feasibility of liquefying hydrogen.

Once the physical and chemical properties are known, this can be related to the range of techniques used to detect hydrogen, noting always the effectiveness of each technique in relation to the concentration where hydrogen becomes potentially explosive. The thermodynamics of the dissociation of water needs to be fully understood before the potential and actual efficiency of electrolysis is examined. The properties and efficiency of commercial electrolysers is examined with thought given to the factors that make the cost of these devices so high. A demonstration of electrolysis can be helpful. Other methods of obtaining hydrogen may be described though these have less relevance to renewable energy systems.

In Outcome 2 candidates should examine the operation of fuel cells. This will begin with a detailed look at the thermodynamics of hydrogen combustion. Of course this results in the generation of heat, but by the use of a catalyst the recombination of hydrogen and oxygen can be controlled to produce electricity and minimal amount of heat. This process is implemented in fuel cells and is thus potentially highly efficient. It is important to focus on the operation of the membranes used in commercial fuel cells but also to consider new ideas and techniques currently at the research stage. Commercial devices will be described and compared with a particular emphasis on the cost, and issues such as how sensitive the device is to contamination. Controlling the flow of hydrogen to the cell is an important point that will be considered.

In Outcome 3 candidates should be introduced to hydrogen management issues. Particularly important is the problem of how to store a sufficient quantity if used in vehicles. Due to the low density at STP, the gas must be pressurised to reduce the bulk of the storage vessel to a reasonable level. This, plus the difficulty with creating good seals for such small molecules, results in a range of leakage and safety problems.

In Outcome 4, candidates will be able to get hands-on experience in the production, handling, storage and use of hydrogen. The important thing is to be able to choose elements that are appropriate to the problem situation and connect these together to get a working system. As with all hydrogen-based systems, the use of appropriate sensors is essential as well as a strategy for dealing with a leak if detected. It is important to keep a log of all activity (including the prescribed assessment task), as this information may be useful for reference in the future. Generally speaking the greater the variety of components experienced the better (for example, fuel cells in the range < 1 W, 10W, 100W and >1 kW). It is essential that the economics of a particular choice is considered.

Outcome 5 is an opportunity to plan the use of hydrogen technology in a more realistic engineering situation. The task will be moderately complex and may involve the conversion of a building such that the heating system and/or the electrical system are implemented using hydrogen produced by wind turbines or a PV array (or both). Other possibilities are the conversion of a diesel engine to run off hydrogen or a motorised vehicle powered by a fuel cell. This is essentially a planning assignment and a report will be submitted justifying the decisions taken and including diagrams and drawing of the proposed solution. It may be feasible to implement the design later as part of an individual or team project being undertaken as part of a course, and this should be encouraged if the scope is appropriate and the necessary component parts are available.

Guidance on the delivery and assessment of this unit

One of the objectives of the unit is to enable candidates to gain familiarity with the use and handing of hydrogen, and get a realistic understanding of the level of risk. There should be a strong emphasis on practical work and the centre should ideally provide the equipment that will enable the candidate to become familiar with the production, storage, handling, distribution and consumption of hydrogen. A fully commissioned hydrogen laboratory with the necessary safety measures and safeguards in place would be ideal (with a variety of fuel cells featuring a wide range of power output), although the unit requirements could be met using small reversible electrolysers/fuel cells connected to 1W PV cells and driving small DC motors. Safety issues must be emphasised and supported by the use of hydrogen detection devices for the detection of leaks. However, it is important that the dangers associated with the use of hydrogen are not exaggerated.

In delivering Outcomes 1 and 2, candidates should be introduced to a range of fuel cells and electrolysers and encouraged to use them, measure the output, learn how much gas is being used, and so on. It is important to be aware how hydrogen powered systems compete with traditional systems. In describing fuel cells and electrolysers, the issue of current cost and trends over time (eg higher fossil fuel prices, limited supply) should be presented so that the candidate will appreciate that solutions that are not currently cost effective may eventually become so. In this context, describe the difficulty and cost in setting up a distribution system for hydrogen (though this may be compared with the extensive infrastructure already in place to route natural gas) so that the candidate is made fully aware of the issues in competing with established energy production and distribution methods.

When delivering Outcome 4, present the candidate with a variety of configurations of components appropriate to different situations and allow them to assemble these and evaluate system performance.

In Outcome 5, encourage the candidate to choose his/her own problem scenario. This may be related to their work (in the case of a candidate who is employed in the industry) or may form the planning phase of an individual or team project. Since the level of difficulty can vary enormously depending on choice of assignment, it is essential that the marking strategy be tailored to reflect the difficulty of each assignment. If the candidate fails to come up with an appropriate idea, an assignment may be prescribed.

This unit may be delivered by a combination of lecturing, practical and lab work, group discussions, investigation (including the use of the internet) and case studies.

Opportunities for developing core skills

All elements of the core skill of Problem Solving, that is, critical thinking, planning, organising, reviewing and evaluating, will be naturally developed and enhanced as candidates undertake the unit. Identifying and analysing a complex range of factors influencing efficient approaches to powering a system from a hydrogen source is integral to achievement. Candidates seek solutions to a number of theoretical and practical problems and issues. They examine such variables as storage, sources and current safety requirements before identifying and justifying an appropriate approach. Practical work can provide an environment in which to discuss, review and evaluate solutions, and enhance skills in oral communication of technical data using appropriate terminology and techniques.

Access to and evaluation of complex technical information, using text book and internet sources, will support knowledge and develop key skills in communication and information technology. Advice on efficient systems of recording, coding and storing information, using technology to manage the practical aspects of investigation would be beneficial. Candidates should be guided to produce and present written reports and log books using industry accepted conventions, style and structure.

Resources available could include appropriate software packages to support accuracy and the effective presentation of written and graphic information.
Complex calculations and measurements related to systems design, safety and costing underpin the competencies assessed in the unit. Numeracy skills will be naturally enhanced, with a focus the practical interpretation, application and presentation of complex numerical and graphical data. Formative practical activities should be designed to develop essential accuracy, flexibility and confidence in handling concepts in the context of renewable energy.

Open learning

Outcomes 1, 2, 3 and 5 in this unit could be delivered by distance learning, which may incorporate some degree of online delivery and/or support. However, Outcome 4 could not be delivered by open learning because of its highly practical nature. With regard to assessment, planning would be required by the centre concerned to ensure the sufficiency and authenticity of candidate evidence.

Arrangements would be required to be put in place to ensure that the combined assessment paper for Outcomes 1, 2 and 3 is done under controlled, supervised conditions.

Equality and inclusion

This unit specification has been designed to ensure that there are no unnecessary barriers to learning or assessment. The individual needs of learners should be taken into account when planning learning experiences, selecting assessment methods or considering alternative evidence.

Further advice can be found on our website www.sqa.org.uk/assessmentarrangements.

General information for candidates

Unit title: Renewable Energy Store: Hydrogen

Traditionally, power has been largely generated using fossil fuels and distributed with power lines. There are losses associated with this through unavoidable heating of the power lines and the difficulty in matching supply with demand. As electricity demand varies, power stations are switched on and off to match the demand, but switching takes time so there is energy waste. As we move into an era where the quantity of fuel underground is diminishing, and we recognise the effect of burning fossil fuel on the environment, waste can no longer be tolerated.

However, as we move to renewable (alternative) sources of energy such as solar, wind, waves, tidal and hydropower, it becomes virtually impossible to control the power source, therefore attempting to satisfy demand in an efficient way is much more difficult. One proposed solution is to use hydrogen as an energy store or carrier, in effect as an enormous battery. All the electricity produced in excess of demand is converted to hydrogen by electrolysing water; ie breaking water up into hydrogen and oxygen gas by passing current through it. The process is virtually 100% efficient (in theory) and the gas can be retained indefinitely until additional power is needed, whereupon the electrical power is recovered using fuel cells (again, it is possible to aspire to virtually 100% efficiency). One huge benefit is that hydrogen can also be used to power electric cars with many advantages over the use of batteries. It may also be converted into many useful organic compounds.

Of course there are problems to overcome. There is no infrastructure for the distribution of hydrogen and the fuelling of cars, and electrolysers and fuel cells currently have relatively low efficiencies and are extremely costly. But with better devices emerging from a huge worldwide research effort, the economies of scale, and the rising price of fossil fuel, the margin is steadily narrowing.

In this unit you will learn the properties of hydrogen, and see how it is produced by electrolysis. You will consider how it may be stored and the electricity eventually recovered using a fuel cell. You will become competent in the handling of hydrogen and understand the need for appropriate safety precautions (as with all combustible gases), but recognise that some of the commonly held views about the dangers of hydrogen are groundless.

It is important to have a good knowledge and understanding of commercial devices available (both specification and cost) so that reasoned and balanced choices can be made in applying hydrogen technology to an engineering situation. You will have the opportunity to put this knowledge into practice by applying hydrogen technology to a design application of your choice.

There are three assessments, a multiple-choice assessment to test your knowledge, a practical assignment where you have to assemble and test a complete system, and the design of a system powered by hydrogen.