WAVE ENERGY AND CHEMICAL ENERGY CARRIERS

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1. **INTRODUCTION**

The utilisation of wave energy to produce energy intensive chemicals, based upon the electrolysis of water to yield hydrogen, is generally considered to be a viable alternative to the preferred electrical generation and transmission system \(^{(1)}\). This memorandum draws upon the work previously carried out as part of the Wave Energy Programme \(^{(2,3,4)}\) and by means of simple economic arguments shows the relative costs between the two conversion and transmission schemes viz: electrical power at 50 Hz delivered to the grid and hydrogen delivered over the same distance to a chemical plant.

Because of the uncertainty regarding the cost of the wave energy device and the fact that this cost would be borne by both schemes only those elements of cost relating to the production and transmission of the two energy vectors are used in the comparison.

Since all of the chemicals generally regarded as energy carriers are derived from hydrogen it is considered valid to use hydrogen production costs as the comparison with the electrical transmission route to shore.

2. **ENERGY ROUTES**

The two energy routes considered for comparison are therefore:

2.1 **Electrical Transmission**

The preferred energy route in this case \(^{(1)}\) starts with the device on board of which is a conversion train that results in variable frequency (or nominally fixed frequency) a.c. power which is borne, via a flexible a.c. cable, to a platform structure where it is transformed to high voltage for d.c. transmission to a shore inverter.

2.2 **Hydrogen Route**

The preferred energy route for hydrogen synthesis starts with variable frequency a.c. power transferred via a flexible a.c. cable from the device to a platform structure. On board the platform the water for electrolysis will be produced by a flash evaporation sea-water desalination plant followed by ion exchange, if necessary, to produce water of the required quality. Advanced design filter press electrolyser cells mounted on the
platform would be used since they can produce hydrogen gas at a pressure of 30 bar. Thereafter the pressurised hydrogen gas is carried to shore via a sea bed pipe line. A land pipe line would be used with a pumping station, if necessary, to convey the gaseous hydrogen to a chemical plant. Liquefaction for high density storage could also be employed.

3. REFERENCE SYSTEM

For comparison purposes an electrical generation and transmission scheme based on that given in the RPT Report (1) will be used as a reference system.

The principle elements of the reference system are:-

(1) The device (typified by the OWC) including valves, air turbine, generator and exciter with a primary conversion efficiency of 0.68 ignoring factors for wave directionality and unreliability which will be common to both energy transport routes.

(2) Collection and transmission by cable to Perth with an efficiency of 0.8, including a.c. cables, platform mounted h.v. transformer, rectifier and d.c. cable to a shore inverter station at Perth. The as installed capital cost per MW for this system, excluding the device costs, but including the offshore platform structure will be £400/MW approximately. It is assumed, following the comments in the RPT Report (1) that this figure does not include for trenching and burying of the cable on the sea bed.

(3) As a result of the transmission line efficiency of 0.8, approximately 2.5 GW will be available from the devices to the platforms. This essentially is the power input to the hydrogen route.

4. HYDROGEN PRODUCTION SYSTEM

The hydrogen production system under consideration is that based on the advanced electrolysis plant which produces gaseous hydrogen at 30 bar (3,4). The chemical thermodynamics of this system are such that at best efficiency 119 MW (electrical) are required to produce 100 MW (thermal) in terms of the enthalpy of combustion of gaseous hydrogen. This ratio includes the losses in the rectifiers and control gear that would be mounted on an off-shore platform. Thus 2.5 GW (electrical) should yield 2.1 GW (thermal).
4.1 Offshore Platforms

An offshore platform for each 250 kW (electrical) is allowed for in the electrical reference scheme; similarly it is assumed on this basis that eight platforms will be required for the hydrogen production route.

4.2 Gas Pipeline

It is assumed that the pipelines from platform to shore (on Skye) are disposed as shown in Figure 11.2 of the RPT Report\(^1\). This implies a total length of pipeline of 270 miles. The costing of this pipeline is based on the assumption that it is concrete jacketed steel pipe of the type currently used in the North Sea for bringing oil ashore. A further 175 miles of pipeline will then be required to bring the hydrogen from Skye to Perth. Hence a total pipeline length of 445 miles will be required.

4.3 Pumping Stations

Since the hydrogen is produced at 30 bar the requirement for pumping is assumed to be slight and allowance is made for a single boost station sited at Skye.

5. HYDROGEN ROUTE COSTINGS

5.1 Electrolyser and Ancillary Plant Costs

At best efficiency using the advanced electrolyser production equipment the hydrogen gas as it leaves the electrolyser should cost between £100/kW\(^4\) (thermal) and £160/kW\(^3\) (thermal). A mean value of £140/kW (thermal) will be assumed for present purposes, this includes water treatment plant and power conditioning equipment.

5.2 Offshore Platforms

The cost of the offshore platforms has been estimated using a tentative cost of £15,000/m\(^2\) platform area\(^5\) and the plan dimensions of the platform given as Fig. 11.6 of the RPT Report\(^4\) i.e. 40 x 50 m\(^2\). Hence the cost of eight platforms will be £240 x i.e. £114/kW (thermal).

5.3 Subsea and Overland Pipelines

The major cost associated with pipelines of this type is that of laying the pipe which for present purposes is taken as £1 million per mile\(^3\) overall, i.e. £445 million which is £212/kW (thermal).
6. **CAPITAL COST COMPARISON**

Table 1 gives basic cost details in terms of £/KW (electrical) for the Reference System and £/KW (thermal) for the Hydrogen Production System assuming both are delivering energy to Perth.

<table>
<thead>
<tr>
<th>Description</th>
<th>£/KW (th)</th>
<th>£/KW (e)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrolysis, water treatment</td>
<td>140</td>
<td>600</td>
</tr>
<tr>
<td>and power conditioning</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Offshore Platform</td>
<td>114</td>
<td></td>
</tr>
<tr>
<td>Pipelines</td>
<td>1212</td>
<td>400</td>
</tr>
<tr>
<td>Pressure Boosting</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Airturbine, valves</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Generator, exciter</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A.C. cables</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Platform, HV a.c./d.c. conversion d.c. transmission</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**N.B.** Both of these costs exclude the capital cost of the wave energy device.

7. **UNIT ENERGY COST**

A unit cost for the Reference System and the Hydrogen Production System can be calculated assuming a 100% load factor, a ten year plant life and a DCF of 10%.

Under these conditions the unit energy cost for the production and transmission of gaseous hydrogen is 1.39p/KW hr. (thermal) and that of electricity from the Reference System is 1.18p/KW hr. (electrical), excluding any costs arising from the capital cost and maintenance of the device.

8. **COMPARISON WITH DIRECTION HYDROGEN PRODUCTION INTO A CHEMICAL PLANT**

Under these circumstances grid electricity sold directly to a chemical plant user would cost 0.6p/KW hr. (electrical) to this must be added £140/KW (thermal)
converted to a unit energy cost basis (as in Section 7) i.e. 0.41p/KW (thermal). Hence the total unit energy cost would be 1.01p/KW hr. (thermal).

9. COMPARISON OF COSTS TAKING INTO ACCOUNT THERMAL CYCLE INEFFECTIVENESS

In Section 6 it is shown that the difference in cost between the generation and transmission of electricity from wave energy is £400/KW (electrical) whereas the production of gaseous hydrogen is costed at £469/KW (thermal). To put these on a rational basis the cost of hydrogen must be increased in the inverse ratio of the efficiency of electrical power generation from a thermal (steam) cycle power plant (efficiency 35%) whence the cost of electrical energy from hydrogen (if hydrogen was used as an energy store) would be £1340/KW (electrical), i.e. 3.97p/KW hr. (electrical). These costs also do not include the costs arising from the wave energy device itself.

10. LIQUEFACTION AND TANKERING THE HYDROGEN ASHORE

For comparison purposes the cost of producing hydrogen, liquefying it and then bringing it ashore in refrigerated bulk carriers is included using the S. Uist location as a basis. The system as with the Reference System will comprise arrays of devices with an electrical output of 2.5 GW(e) which will be supplied to eight off-shore platforms on which are mounted the liquefaction plants. Power will be required on the platforms to run the hydrogen liquefaction plants. Liquid hydrogen will then be transferred to a bulk carrier and brought ashore, possibly to Clydeside or Merseyside.

For large scale hydrogen liquefaction plant a power input of 0.6 MW(e) per tonne per day of liquid hydrogen output is required\(^3\). Hence 1 MW(e) will liquefy 1.67 tonne per day of hydrogen with a calorific value of \(2 \times 10^5\) MJ, i.e. 1 MW(e) power input will be required to produce 2.34 MW(th).

As stated previously 119 MW(e) will be required to produce 100 MW(th) by electrolysis. Thus 71 tonnes/day of gaseous hydrogen will be produced per 119 MW(e) i.e. 1.7 MW(e)/tonne per day.

Hence a total of 2.3 MW(e) will be required to produce 1 tonne/day of liquid hydrogen, i.e. 1.4 MW(th); for 2.5 GW(e) from the devices 1.52 GW(th) will be produced as liquid hydrogen.
10.1 Capital Costings

The costings are the same as those discussed plus the cost of liquefaction plant which will be £110 M for a 50 Tonne (day plant) \(^{(3)}\), i.e. £143/KW(th), and the cost of shipping. Present costs for LNG tankers are of the order of £60 M for 130,000 m\(^3\) of liquid transported. Assuming that a similar vessel would be used for liquid hydrogen then a £60 M tanker could transport \(\approx\) 1000 tonnes of liquid hydrogen. To serve eight platform mounted liquefaction plants probably 15 such vessels would be required, as a minimum. On this basis the capital cost will be £85/KW(th).

Hence the capital cost of this system can be summarised as shown in Table 2.

### TABLE 2

<table>
<thead>
<tr>
<th>Component</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrolysis, water treatment</td>
<td>£140/KW(th)</td>
</tr>
<tr>
<td>and power conditioning</td>
<td></td>
</tr>
<tr>
<td>Off shore platform</td>
<td>£114/KW(th)</td>
</tr>
<tr>
<td>Liquefaction plant</td>
<td>£143/KW(th)</td>
</tr>
<tr>
<td>Liquid hydrogen tanker</td>
<td>£85/KW(th)</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>£482/KW(th)</td>
</tr>
</tbody>
</table>

N.B. This cost excludes the capital cost of the wave energy device.

10.2 Unit Energy Cost

This has been calculated on the same basis as that given in Section 7 plus an allowance of 10% of the capital cost of the tankers and liquefaction plant for the necessary fuel and manpower costs.

Hence the unit energy cost is 1.5p/KW hr. (th), excluding any contribution relating to the cost of the device.
11. DISCUSSION AND CONCLUSIONS

11.1 The use of hydrogen as a means of storing the random energy input from wave energy devices is both feasible and attractive technically. However in terms of economics (excluding the cost of the wave energy devices) the generation and transmission of electrical energy is 3.35 times cheaper per KW (electrical) than the production of hydrogen by electrolysis and its transmission to Perth by pipe line (using advanced technology electrolysis plant). Whereafter it could be used as a fuel for a thermal power station.

11.2 An alternate scheme of liquefying the hydrogen on offshore platforms and bringing the hydrogen ashore in tankers has also been considered. In this situation the costs are not as favourable as those relating to the use of pipe line to bring pressurised hydrogen gas ashore. However if the devices were situated well out into the Atlantic then the tanker route would be preferred. With 'at sea' liquefaction considerable electrical power will be required on the platforms, some 650 MW, to run the liquefaction plants. This probably represents the major objection to this scheme in so far that in an emergency provision would have to be made for a significant proportion of this power to be supplied to the platforms from the shore. An alternative would be to use hydrogen fueled gas turbine generators but because of the thermal efficiency factor then the cost of the hydrogen actually landed would increase, perhaps two fold.

11.3 Some consideration has been given to the mounting of electrolyser, desalination equipment and power conditioning equipment on the devices and thus eliminating the platform. Of the devices it is considered that only the one would provide sufficient space. This should be feasible but it raises the problem of making numerous flexible connections between devices and the sea bed gas main. Whilst the price of the platforms would be saved additional costs would arise from the extra length of sea bed piping and the gas-tight riser systems that would be required. In principle there is a maximum of £114/ KW(th) to be saved but this must be offset by the extra pipe lines. By assuming the additional pipework would be of the order of the overall length of the arrays of devices then a cost of £60 M would be incurred, i.e. £50/KW(th). A sophisticated system of gas-tight risers is likely to increase this still further. Hence the maximum saving is likely
to be about £80/KW (th) on £469/KW (th) which excludes the device costs; the total saving would be very marginal. The technological difficulties with the scheme and the low potential savings suggested that it should not be preferred.

11.4 The production of hydrogen using electricity from the grid is cheaper in terms of pence per KW hr. (th) than the production and transmission of hydrogen by pipeline (or tanker); 1.01 p/KW hr. (th) total cost compared with 1.39p/KW hr. (th) which excludes the device costs.

11.5 Whilst the production of hydrogen is feasible and attractive the economics are such that even at zero device cost it is not competitive with hydrogen produced on land; also irrespective of device costs the electrical transmission scheme would be preferred on economic grounds.

REFERENCES
1. RPT Report, 1978
2. GT 4.77 Economics of the Hydrogen Route.